Workshop phenotyping, genotyping, breeding, reproduction techniques and evaluating alternative crop species for adaptation to climate change

State-of-art and opportunities for further cooperation

Final report

Wageningen, October 27th & 28th lunch-to-lunch

Agriculture Food Security and Climate Change

0. Summary

The workshop highlighted opportunities, gaps, needs and priorities for novel breeding techniques like phenotyping for resilience under climate change. Starting with four key presentations, the scene was set from the perspectives of policy, end-users and science, accompanied by an overview of phenotyping initiatives. In five presentations several other initiatives were introduced, after which dedicated discussion sessions identified priorities in opportunies, needs and gaps. This resulted in the following ten priorities:

Phenotyping needs multi- and transdisciplinary research, but fundamental research with regard to gene-environment-management interactions is also essential;
High quality open data speeds up research, but policy also needs to deal with the associated risks and legal issues (big data questions);
Regulation of funding needs to be adapted: linkages are needed between (more structural) project funding and infrastructure funding;
Phenotyping needs long-term research;
More focus is needed on breeding for climate change: widening up genetic traits;
More focus is needed on breeding for climate change: crops - also 'multi-valorization' and perennial crops;
Climate change research and phenotyping research needs te be connected; this also includes phenotyping research on different management systems;
Phenotyping for whole value chain approach, including aspects related to quality, is needed;
Public-private cooperation could strengthen research and accelerate impact;
Management of expectations and views of the public at large.

These priorities resulted in four **major recommendations** for FACCE-JPI:

1. There are **several research gaps** that need to be addressed. FACCE-JPI could play a role in addressing these gaps through new or existing ERA-NETs.

2. Where possible, a better alignment of priorities at both EU and national levels should be sought with regard to **funding mechanisms**. There is a special need to align infrastructural and project-based fundings. FACCE-JPI could play a role in mediating between its members on the one hand, and between National levels and the EC on the other hand. The JPI may be a primary partner to moderate between the policy level, user demands and infrastructure access.

3. FACCE-JPI could play a role in investigating **opportunities for public-private research (funding)** that can help furthering research on novel techniques for plant breeding and subsequently disseminating results through its stakeholder community.

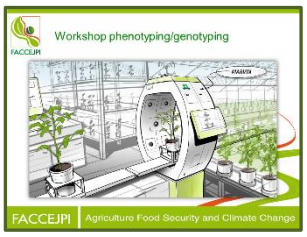
4. FACCE-JPI may help **connect different networks** that are currently not (sufficiently) connected.

1. Introduction

The workshop was opened by Huub Löffler, director of Wageningen International and FACCE-JPI Governing Board member. After a brief introduction to Wageningen University and Research, he introduced the Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI). Huub explained the joint programming concept, the role of FACCE-JPI, its scope and strategy, along with the five Core Themes and the types of activities developed by the JPI. This exploratory workshop is aiming to identify emerging priorities and links to Core Theme 4: *Adaptation to Climate Change* and also - to a lesser extent to Core Theme 2: *Environmentally sustainable intensification of agricultural systems*.

2. Setting the scene *- in four key presentations*

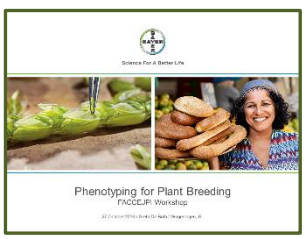
I. Policy perspective - *Huub Löffler (FACCE-JPI NL Governing Board member; Wageningen University and Research)*



Breeding is an essential technology for sustainable food production with high potential for climate smart agriculture. Novel techniques in the field of phenotyping and genotyping (PG) can speed up the breeding process for plant species that can adapt to changing or more unpredictable / extreme climatological circumstances. Breeding plants that are able to deliver high yields with less input (e.g.: water, fertiliser, pesticides) and are more resilient to pest attacks and diseases will be necessary to the need of feeding the world. Policy has high expectations from these new developments. At the same time there are risks that policy needs to deal with. GMO discussions made it clear that public opinion on novel breeding techniques may differ from scientific possibilities. It will be important to be clear about what such phenotyping techniques are, and what the risks and benefits may be.

Breeding has a long tradition of co-existence between public and private funded research and matters concerning patenting versus breeders' rights, legislation and the different seed sectors (formal and informal) will also play a role in phenotyping research (results). Associated questions are related to big data, and its use, ownership and IP. Policy needs to have a view on how it can create enabling environments to speed up developments that contribute to realising the promise due to novel techniques.

II. End-user perspective *- Greta de Both (Crop efficiency breeding & trait development' global manager; Bayer Crop Science SA-NV)*



Plant breeding is essential for tackling the challenge of increased food production and the use of phenotyping is becoming more important. Phenotyping offers the promise of being able to deliver varieties faster to the market (shorter breeding cycles), counteract the effects of climate change on crop performance and limit environmental costs by increasing input use efficiency. Before a variety is commercially released, a large number of selection steps have been taken: the 'funnel of plant

breeding'. Selecting a new variety always starts with a large number of new recombinants (genotypes) which are subsequently tested and selected narrowing down the number of candidates.

Trait phenotyping is the process of researching the relation between genotype, environment and management (agronomic practices). For (commercial) breeders, gain lies in improving trait phenotyping and increasing throughput. Improved phenotyping leads to improved precision in quantification of traits and to earlier discovery of traits previously only visually scored. A more robust identification of correlated traits has several advantages and may speed up phenotypic predictions. Challenges include aligning phenotyping in controlled environments with field phenotyping targets, reduction of costs and increasing throughput. To be able to handle the bulk of (real-time) data, improvements in data information management and technology need to be made.

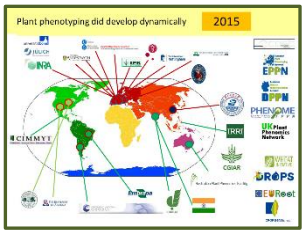
III. Scientific context *- Rick van de Zedde (Senior researcher and business developer Computer Vision; Wageningen University and Research)*

Phenotyping is the measurement of phenotypes – the physical and biochemical characteristics of organisms – as it develops from the genetic setting and the environmental (including management) influences. Its goals is to contribute significant progress in improving the quality and productivity of crops. To be able to do so, there is a need to understand and exploit the genotype and the phenotype of plants in a changing environment. One key issue in phenotyping research is the impossibility to analyse and grow all genotypes of all crops in sufficient numbers in a range of environmental scenarios. Therefore a major challenge is to be able to understand, model and predict how phenotypes emerge based on the genotype and environmental conditions. Phenotyping research is in its essence a multi- and transdisciplinary science as there are many different scientific research areas involved and most researchers cannot have a complete overview of all the different disciplines. On the level of phenotyping equipment a bottleneck remains the high costs of research and development.

Europe harbours several high-tech research infrastructures for plant phenotyping. These are a distributed collection but at different scales and not identical to each other. There is a need for good calibration procedures and standardization, especially when linking phenotyping research to climate change research. Access to high-tech facilities is offered, but most are fully booked. The difference between facilities in combination with long waiting times make it very difficult for researchers to duplicate experiments. Low-tech solutions are available and popular, but results need to be aligned with the requested accuracy.

Phenotyping of species that have a long growth season is extra costly. The extent of the experimental phase is longer and thus requires more funding for a longer period. On a more overarching level, long-term experiments cause funding challenges. Public-private funding in the European Union (EU) becomes more common, but while it is suited for applied research, it is to a lesser extent suitable for more fundamental research, which is essential in understanding gene- environment interactions. Even with different funding schemes, it remains a challenge to attract and link to SMEs to adopt technology from academic institutes with a high technology readiness level (TRL). Comparisons of results obtained in multi-site research require a well-functioning E-infrastructure and the use of big data. Associated with this, there are many issues that need to be dealt with including protocols, standardisation, big data tools, metadata use and storage.

IV. Existing initiatives: EPPN 2020 / IPPN, EMPHASIS *- Ulrich Schurr (EPPN and EMPHASIS coordinator, IPPN; Forschungszentrum Jülich, IBG-2: Plant Sciences)*



In order to meet the diverse breeding objective that support enhancing yield and biomass through optimization of plant phenomics, there are many phenotypic processes and methods required. Phenotyping has developed rapidly in the last decade and Europe has a global leadership Today, competition is globally increasing with demand. Given its specialistic, high-tech, high-costs character, specific networks have been established to exchange information and to gather together knowledge and funding.

Networks operate either at the national, European or global level. The German Plant Phenotyping Network (DPPN) focussing on phenotyping competence and excellence is an example of a national network. The European Plant Phenotyping Network (EPPN) brought (this I3-project ended end of 2015) together seven institutions across Europe, providing transnational access to twenty-three installations. This EU-funded network offered basic (travel and sustenance) funding for users and funds the operating costs of the infrastructures. The COST action *The quest for tolerant varieties: phenotyping at plant and cellular level*, is an example of network support for European researchers. TheWheat Initiative is an example of a one-crop specific network that has a dedicated Expert Working Group on phenotyping. The International Plant Phenotyping Network (IPPN) is a global association of twenty-eight phenotyping centres. The next step is opening up for industry to join the network. Its goals are to integrate regionally and globally fragmented activities, enable exchange of expertise, networking and providing policy advice.

The top three challenges for plant phenotyping are data management, field phenotyping and technological limitations. In light of these challenges, a new network is presently established: the European Infrastructure for Multi-site Plant Phenotyping and Simulation for Food Security in a Changing Climate (EMPHASIS). This ESFRI Roadmap project aims are to generate synergies on equipment, data management, capacity building and the interactions between science and industry. It fits the niche between other infrastructural ESFRI projects (ICOS, ANaEE and Elixir) on the field-to-tissue scale.

3. Field visit

The workshop participants visited several *on site* examples of novel technologies in plant breeding and harvest that are developed in Wageningen. Amongst those were demontrations of equipment used to measure plant features from the air with drones, phenotyping equipment, improved harvesting robots and videos of measuring equipment on farmlands.

4. Networks and initiatives presentations – *in five presentations across day 1 and 2*

Wheat Initiative *– Jose-Luis Araus (Vice-chair Expert Working Group on phenotyping; Wheat Initiative)*

The Wheat Initiative was created in 2011 following endorsement by the G20 Agriculture Ministries to improve food security. It acts as an international framework to establish strategic priorities, identify synergies and facilitate collaborations for wheat improvement. It currently brings together sixteen countries, nine private companies and two CGIAR Centres, thus improving coordination of wheat research by sharing efforts and resources.

Wheat is the world's most widely grown staple crop and provides twenty percent of all calories and protein in developing and developed countries. The demand is expected to grow rapidly, but investments in research and development lag behind. In order to achieve the needed production increase, increased coordination is necessary on the level of policy, agronomy and breeding. To this end a global Strategic Research Agenda (SRA) is developed. The implementation of the SRA started, but it will take a long-term commitment of the partners involved. For each priority that was defined in the SRA, Implementation Plans were developed. These priorities translate into Expert Working Groups. At present there are ten Expert Working Groups (EWG) with 569 members from 52 countries. The EWG on Wheat phenotyping to support wheat improvement has started in 2014. EWGs are a platform for discussion, information sharing and interaction. They offer recommendations to funders and policy makers thus contributing to the SRA implementation. The SRA identifies the following needs for phenotyping: standardisation of protocols, low cost field phenotyping and a network of field phenotyping platforms to test core germplasms.

European cooperative Programme for Plant Genetic Resources (ECPGR) *- Lorenzo Maggioni (ECPGR Secretariat)*

The ECPGR is a collaborative programme in which most European countries participate. It aims at ensuring long-term conservation and facilitates the utilization of plant genetic resources in Europe. Its four core objectives are: *ex situ* conservation (A European Genebank Integrated System – AEGIS), documentation (EURISCO catalogue with passport and phenotypic data) , *in situ* and on farm conservation and management and use of Plant Genetic Resources for Food and Agriculture (PGRFA). The ECPGR operates through several Working Groups that either focus on groups of crops or on a thematic area. Its activities include exchange of information, planning of collaboration, getting agreements on standards and guidelines, setting up databases and exchange data, prepare joint project proposals and capacity building.
AEGIS is a gene bank integrated system for PGRFA to conserve the genetically unique and important accessions for Europe and making these available for breeding and research.
EURISCO is a catalogue that provides information about *ex situ* plant collections in Europe. Its current content includes 1.8 million samples' data from over 350 collections. It contributes to the global gateway to genetic resources, *GENESYS*.

The European genebanks act as a source and sink of germplasm with about two million European accessions conserved. This is a vast reservoir of variation to face climate change scenarios. It is accessible and the gene banks are suitable repositories for reference material. EURISCO is also a storage for non-standardized phenotypic data. At this time there is no ambition to include x-omic information, but it may be possible to link to other databases through Digital Object Identifiers. An important - so far unanswered - question here is how to make x-omics data digestible for users and what the role of genebanks should be. ECPGR can act in a policy brokering role with regard to the

regulations of access to material. They can facilitate provision of access for large genotyping and phenotyping data collections and play an important networking role between crop experts and public-private initiatives with regard to multi-site evaluation across Europe and definition of standards and protocols. There is a need for a strategic alliance between gene banks, documentation centres, consortia that work on phenotyping and genotyping research and users of the knowledge. An issue is that many gene banks are not able to effectively manage germplasm due to lack of support. The recognition of the role of GR Networks by the European Commission (EC)/ EU and the definition of a specific EU Strategy for Agricultural biodiversity could help in strengthening the position of the gene banks across Europe. The ECPGR is interested to act as intermediary between its members and the -omics community.

A European infrastructure for analysis and experimentation on ecosystems (AnaEE) *- Jaques Roy (Deputy director AnaEE)*

AnaEE is a specific ecosystem infrastructure that addresses the grand challenges. Its focus is on food security and bio economy under climate change. Ecosystem experiments form the backbone of AnaEE. With 145 crop experimental platforms all over Europe, AnaEE covers almost all European climate zones. There is a wish to better balance countries that participate. The majority of the actual platforms are field experimentations complemented by analytical and modelling facilities. When looking at agricultural systems, AnaEE focuses on infrastructure that relates to *cropping systems* x environment type experiments, where EMPHASIS brings together infrastructure that relate to *genotype* x environment. AnaEE also brings together four supra-national entities: a Central Hub (coordination and management), a Technology Centre (harmonisation, data quality improvement), a Data & Modelling Centre (access to data, metadata and standards) and an Interface & Synthesis Centre (for interactions with scientists and stakeholders). There are useful overlaps and possible synergies between AnaEE and the EMPHASIS phenotyping infrastructure network. Linking up could bring new advantages for both, like for example the possibility for AnaEE to bring metadata and data into the EMPHASIS network.

ETP Plants for the future (Plant ETP) *- Alexandra Malyska (Executive Manager Plant ETP)*

The Plant ETP is an EU platform for developing strategy, mobilizing industry and other stakeholders sharing information and enabling knowledge transfer to a wide range of stakeholders across the EU. Its members consist of industry partners, farmers and academia. Its vision is that plants are central to global challenges. Plant ETP has an integrated strategy with action plans at the level of innovation, education and research. The latter action plan focuses on three priorities: *sustainable plant production and yield*, *quality of food, feed and non-food products,* and *a vibrant research environment*. These priorities link with improved resource use efficiency, yield enhancement and improving plant health for resilience (e.g. phenotyping for insect resistance traits). The research action plan aims to improve competitiveness and critical scale of EU plant research. This is done by developing and implementing horizontal actions (improving methods and management of farming and production systems, optimization and standardization of data handling processes) and by strengthening basic and applied research, and research infrastructures. The Innovation Action Plan aims at keeping the EU competitive while the Education Action Plan is organised around ensuring a skilled future workforce. The Action Plans strengthen each other and try to integrate the entire collaborative research and innovation cycle. The way forward to address the major challenges for plant phenotyping requires a systemic approach that includes making the best use of existing infrastructure. Development of bi-directional public-private interfaces for enterprises (that could be included as virtual centre for translational research) could further support development in the field of phenotyping. It is also crucial to provide access to data and knowledge across the entire value

chain (e.g. by supporting Public-Private Partnerships). One of the strengths of the Plant ETP is its capability of bringing together stakeholders from different sectors.

ERA-NET for Coordinating Action in Plant Sciences (ERA-CAPS) *- Paul Wiley (coordinator ERA-CAPS)*

ERA-CAPS started in 2012 as an Framework Programme 7 (FP7) ERA-NET. It consisted of nineteen partners and seven observers. Between 2012 and 2015, two transnational calls were launched. After EU funding stopped in 2015, the network decided to continue as a self-sustainable network. The eleven partners and nine observers now include USA and New Zealand and a third call was launched in June 2016. ERA-CAPS funded twenty-five collaborations with an amount of 40 million Euro. The third call raised 16 million Euro.

ERA-CAPS is a follow-up of the Plant Genomics ERA-NET in which a broad scientific scope is maintained. Calls are bottom-up, so there is no direct targeting of proposals. Highlighted themes include food (and nutrition) security, non-food crops, adaptation to a changing climate, biotic and abiotic stresses. The remit of the phenotyping workshop is all within the scope of ERA-CAPS. This refers to the research itself, but also includes data issues and links to infrastructure. ERA-CAPS has taken a particular interest in data sharing policy and has raised an Expert Working Group on data standards and data management. This has led to specific advice for the ERA-NET to include a special topic in its third call that deals specifically with data challenges facing plant sciences. ERA-CAPS is structurally engaged with the EMPHASIS project and it specifically encourages phenotyping applicants in the third call to link with EMPHASIS.

5. Discussions – *across day 1 and 2*

Participants of the workshop were divided in three groups that discussed in a World Café setting on opportunities, needs / gaps and priorities from the policy, science and end-user perspective. This led to a longlist after which each group had to prioritise two entries in potential and in needs / gaps (See Table 1 in Annex I). On the second day of the workshop, the priority topics formed the basis for further group discussion.

Phenotyping needs multi- and transdisciplinary research

Phenotyping does not only offers an opportunity for multidisciplinarity but *requires* it. This can partly be supported by bringing together (monodisciplinary) researchers, like in the COST network. However, this may not be enough. The peer-review system on which careers in science still work, in combination with funding rules, are a hindrance for multidisciplinary researchers. There is a need for more trained researchers that are able to work multi- and transdisciplinary, not only across different scientific areas but also with different kinds of stakeholders. There is a perceived risk that focussing too much on multidisciplinary researchers will lead to loss of experts. Thus, a balanced approach of generalist and specialists and cooperation between them is essential.

> **Specific research questions** that need to be addressed include, but are not restricted to the following areas: integration of the -omics with phenotyping and genotyping, big data questions, standardization issues, phenotyping under different climate conditions, large-scale field experiments; marginal land phenotyping, and disruptive target phenotyping.

High quality open data speeds up research

ERA-CAPS highlights as example the data sharing policy that they are working with now. In general access to data is an item that is becoming more important. Policy needs to be (further) developed to stimulate open data. On the other hand, policy needs to be aware of the risks of sharing data openly, which brings questions to the table regarding patenting, copyright, innovation, exclusivity of data and illegal use of data amongst others. It may also have consequences for the innovation position of countries in the EU if data is open. In public-private cooperation, sharing open data is possible but requires relevant agreements being in place that establish how, when and which data can be disclosed openly. Having open data is one thing, having data that is of high quality and fits standards is another issue. While standardization of data is now often mandatory in H2020 projects, the issue of data quality is not yet addressed properly. Data quality also raises issues regarding the proper processes to track data back to its source. Even with standardization of data in place, issues may still arise when for example using environmental data in combination with genotyping and phenotyping data. Datasets and standards may not be harmonized across different disciplines.

It is a general belief among the workshop participants that sharing data speeds up research and is an important driver. This does not only apply for knowledge shared between public funded institutes, but also for companies. Sharing data does not necessarily have to mean sharing all the raw data. It may also be about meta data or descriptions. Apart from this, it is not unusual in open data settings to negotiate exceptions (for IP) or embargos (data is made open after a certain amount of time).

Regulation of funding: linkages needed between project funding and infrastructure funding

There is an urgent need for long-term funding programmes and for combining project funds with funds for infrastructure. The EMPHASIS example shows this: the network is funded to write the business plan but does not have actual project funding for research in itself. Even more: project funding cannot be transferred to infrastructures. It would be extremely helpful if national policy and funders, as well as EU funding, would connect project funding and its beneficiaries to infrastructure funds that might even encourage synergistic use of infrastructures across borders. The example of ERA-CAPS is a very good one: call applicants of phenotyping projects are strongly advised to link up with EMPHASIS.

Financing of infrastructures comprises different cost categories and different funding needs. Funding is required for 'hardware': investments in buildings and equipment. Other funding is needed for implementation costs of the infrastructure (e.g.: maintenance costs and personnel costs for running the equipment). A third category of costs relates directly to the actual projects that are done using the infrastructure. The policy level could support infrastructures and the researchers using them by aligning the different funding options to support funding the different needs.

Phenotyping needs long-term research

Phenotyping is a research area that needs long-term research, and this includes long-term funding. One example was brought up where long-term applied science driven research (15 years in potato breeding) was mentioned as a success project that did receive long-term funding. It was strongly advocated that such long-term dedicated research is needed. Small-scale projects may be generally more efficient but long-term (fundamental) research is also necessary!

Breeding for climate change – widening up genetic traits

There is a need to not only focus on yield as the most important (complex) trait. Yield is a complex polygenic trait influenced strongly by environment and management, and industry is looking for proxys. Usually breeding does aim at higher yield but this is achieved by improving traits that determine or influence yield. Especially in view of climate change, such other traits may be increased

resilience (drought-tolerance, pest-tolerance) or decreased resource needs (less water). This is what novel approaches in phenotyping can offer if they deliver on potential. In order to be able to live up to this expectation, the range of crops that are currently being phenotyped in research needs to broaden. There is a need to consider more disruptive targets and to look at annual crops; to go for more 'adventurous breeding' (e.g. high-risk breeding targets). Enlarging the gene pool used can also help maintaining biodiversity. The ECPGR seed banks in Europe contain a wealth of genetic material that may be beneficial for plant breeding. However, these collections often are not suffiently characterized (phenotypically and phenotypically). Promoting the use of these collections requires a concerted effort to enrich them with information.

Breeding for climate change – crops - also 'multi-valorization' and perennial crops

Since breeding new varieties takes a long time and is quite risky, again there is need for long-term funding mechanisms. In this, public-private partnerships may provide opportunities for cooperation, but the business model of a company does not fit well with such long-term research. The private sector breeds a lot of varieties that are more resilient under climate change, but only in those crops that can generate return on investment relatively quickly. Also in the public sector there is interest in breeding other varieties than just staple crops, but this is often too high-risk research. Another reason for focusing on staple crop is that here maximum impact is reached in terms of population numbers concerned, as staple crops are the most consumed ones. For future uses, phenotyping for stacking traits is foreseen (the 'multi-valorization crops').

The effects of climate change are feared to be much worse for perennial crops as it is argued that for these crops their microbiome is more important. There are two different needs: One is for research on crop-related microbiome and phytomicrobiome in perennial as well as annual crops, the other need is for more targeted research on perennial crops as research on these crops is not favored by both public nor private funding.

The questions is raised whether there are currently long-term initiatives in developing new crops at the EU level ongoing. Where public funding should focus more on high-risk disruptive breeding research, public-private funding could be used in pre-breeding research settings and low-risk commercial research remains the domain mostly of private (company) funding.

Climate change research and phenotyping research needs te be connected

What is needed is a multi-disciplinary research approach with climate change modelling for phenotyping and genotyping research. MACSUR does some research on ideotyping which provides data for testing traits under foreseen climate scenario's. However, what the climate may look like in the future is an uncertainty that is hard to deal with. Links between climate change data and genotyping and phenotyping data could be strengthened to address this issue better.

Another gap is identified in the discussion: the need for phenotyping research related to different management systems and for marginal lands. In some cases, extreme whether may lead to the disappearance of some management systems altogether.

Phenotyping for whole value chain approach, including aspects related to quality

There is a quite clear gap between looking at traits and looking at the bioeconomy as a whole (chain). Phenotyping can be used at different levels to increase understanding of the whole composition of the plant and how it will affect the end product. One example is the use of phenotyping to function as a high-throughput detection systems of (micro-)concentrations of (toxic) components in plants. Other uses do not need to be restricted to food but can relate to also non-food and feed products.

Public-private cooperation
There remains a gap between technology in research institutes and industry. Improved collaboration may be beneficial to both. Especially universities often work with more high-tech equipment than companies as many SME's have trouble with the high costs of technological developments.

Management of expectations and views of the public at large
Open communication and information on usage of techniques, benefits, expectations and limitations is essential for the acceptance of new inventions by the general public. Policy makers have an important role in the public debate on novel techniques and its usage.

6. Conclusions and possibilities for FACCE-JPI

Priority needs and gaps

- **Phenotyping needs multi- and transdisciplinary research**, but fundamental research with regard to gene-environment-management interactions is also essential;
- **High quality open data speeds up research**, but policy also needs to deal with the associated risks and legal issues (big data questions);
- **Regulation of funding** needs to be adapted: linkages are needed between (more structural) project funding and infrastructure funding;
- **Phenotyping needs long-term research**;
- **More focus is needed on breeding for climate change: widening up genetic traits;**
- **More focus is needed on breeding for climate change: crops - also 'multi-valorization' and perennial crops**;
- **Climate change research and phenotyping research needs te be connected**; this also includes phenotyping research on different management systems;
- **Phenotyping for whole value chain approach, including aspects related to quality,** is needed;
- **Public-private cooperation** could strengthen research and accelerate impact;
- **Management of expectations and views of the public at large** is necessary.

Reccomendations to the FACCE-JPI Governing Board

Research of novel techniques for plant breeding should remain a part of the Strategic Research Agenda (SRA) of FACCE-JPI. There are links with other priorities in the SRA that could strengthen implementation actions. The workshop raised several **research gaps** that need to be addressed. FACCE-JPI might investigate possibilities to do so through new or existing ERA-NETs. ERA-CAPS already takes some of these issues aboard with regard to data and data management. The upcoming ERA-NET SusCrop may be able to address one of these gaps in either a (sub-) call topic or additional activity.

A better alignment of priorities at both EU and national levels should also be sought with regard to **funding mechanisms** There is a special need to align infrastructural and project-based funding. FACCE-JPI could play a role in mediating between the different countries affiliated with FACCE-JPI on the one hand, and between National levels and the EC on the other hand. There are three main recommendations: *1)* a quite pragmatic one for FACCE-JPI to stimulate its members to align project-funds with infrastructure funds (and researchers) and strive for eligibility of infrastructure costs in project-based funding; *2)* FACCE-JPI could seek together with the Commission for modalities of integrating infrastructure funding with project-based Framework Programme funding and funds managed at (sub-)national levels such as Structural Funds (European Fund for Regional Development), and *3)* to seek for opportunities within the Framework Programmes to allocate long-term funding for the topic phenotyping. Given the member state driven nature of FACCE-JPI, it may be a primary partner to moderate between the policy level, user demands and infrastructure access.

In line with the Innovation Union policy of the EC and the need to create impact for end-users, it is important to investigate **opportunities for public-private research (funding)** that can help furthering research on novel techniques for plant breeding like phenotyping from climate chamber to practical farm use. As some FACCE-JPI Member States have experience on this type of research, the JPI could look for opportunities to strengthen this type of cooperation and disseminate results through its stakeholder community .

Given its position in Europe and its international affiliations, FACCE-JPI may be able to help **connect different networks** that are currently not connected (very well). Especially in linking climate change research networks and phenotyping networks FACCE-JPI could play a role. The JPI may also support connecting infrastructure networks in these areas of research.

2016.12.20/ WG PhenGen_DtB

Annex I: Summary of World Café discussions Thursday October 27th

Table 1: *Longlist with priorities (in green) from the policy, the science and the end-user perspective.*

	POTENTIAL	NEED / GAP
POLICY	• Topic is suitable and requires to engage a wide range of different users (multidisciplinary) • Availability of open data will speed up research (BUT: also a risk for setting up PPP)[1] • Alignment of research priorities	• Standardisation of data and data management systems, data and protocols (BUT: who should take the lead?) • Alignment of research activities • Design of funding scheme : link between project funding and infrastructure funding • Communication needed between science and public at large • Public-private partnerships • Policy should encourage agriculture in education • How to implement multidisciplinary approaches • Real common pot for funding
SCIENCE	• Robust varieties in view of climate change • (better) Understanding of Genotype x Environment x Management • Predictive phenotyping[2] • Discover other traits beyond yield • Deliver new varieties more rapidly • Affordable costs and increased user-friendliness for new technologies • Put genotyping to practical use by phenotyping • Co-alignment with other disciplines and other innovations and networks • Apply new breeding technologies	• Big data processing (from big data to knowledge) • Solutions for modelling big data • Integrating phenotyping + -omics • Infrastructure to stimulate future climate and climate weather components • Standardisations of phenotyping (field) • Phenotyping for different environments (tailor-made) • How to bring new technologies to use (greenhouse to field) • Closing the genotype - phenotype gap • Non-destructive field measurements beyond yields • Reproducing objective results across different scales • Multi-stress response and interactions • Regional climate research alliances • Training in new techniques
END-USER	• Tailor-made solutions (see also science) • Discovery of new traits (see also science) • Speed up selection of new varieties and underutilised crops • Potential to secure quality and quantity (consumer gets better products) • Phenotyping can support in creating an improved early detection system that supports more sustainable pest and crop management. • Awareness of the benefits of novel techniques (for example increased food quality) • Potential to satisfy food demand and security • (positive) outreach from industry to consumer	• Data sharing / access / ownership (Science & Industry) • Balance between cost and revenue of geno- and phenotyping (Industry) • Knowledge exchange between researchers and industry • Consumer knowledge and consumer trust
OTHER	• Phenotyping can capture the imagination of a wide audience: e.g.; exiting techniques, pretty pictures. It may increase "sexy-ness" of Plant Sciences	• There is a risk that people being opposed to technology in breeding and agriculture might see modern phenotyping technologies negatively as well.

Please note that the bullet points in this table are collected as were written down in the workshop. In Chapter 5. Discussion (p7) there are more detailed explanations of many of the listed items. [1]See paragraph *'High quality open data speeds up research'; page 7.* [2]How do phenotypes emerge based on genotypes? If predictions (through use of modelling) become accurate, the pre-breeding process speeds up hugely, and ultimately the need for phenotyping at large volmes decreases significantly.

Annex II: Workshop Programme

DAY 1		
12:00 – 13:00	**Registration - Lunch**	
13:00 – 13:15	**Introduction**	
15'	**Welcome, introduction to FACCE-JPI and aims of the workshop** *Dr. Huub Löffler (FACCE GB NL Member, Wageningen University and Research)*	
13:15 – 14:15	**Setting the scene**	
60'	**I) Policy perspective** – Expectations in light of the societal challenges, major questions Dr. Huub Löffler *(FACCE GB vice chair – NL, Wageningen University and Research)* **II) Expectations, needs and challenges from a users' perspective** Greta De Both *(Crop Efficiency Breeding & Trait Dev. Global Manager, Bayer CropScience SA-NV)* **III) Scientific context** – current state of art, gaps in R&I and specific challenges Rick van de Zedde *(Senior researcher and business developer Computer Vision, Wageningen UR)* **IV) Existing initiatives: EPPN 2020 / IPPN, EMPHASIS** Prof. dr. Ulrich Schurr *(EPPN & EMPHASIS coordinator, IPPN; Forschungszentrum Jülich, IBG-2: Plant Sciences)*	
14:15 – 16:00	**Field visit followed by coffee break**	
16:00 – 16:15	**Networks & initiatives presentations[#]**	
	• Wheat Initiative – *dr. Antonella Di Trapani (Programme Manager)*	
16:15 - 17:15	**Discussion I: needs, gaps, priorities, potential**	
60'	*What do you see as major needs / priorities that need to be tackled within the coming 5 years?*	**Outcome:** first overview of needs, gaps, priorities and potential from different perspectives
17:15 – 17:45	**Wrap up day 1**	

DAY 2		
08:30 – 09:00	**Welcome coffee**	
09:00 – 09:15	**Key issues from day 1**	
09:15 – 10:15	**Networks & initiatives presentations[#]**	
60'	• European Cooperative Programme for Plant Genetic Resources (ECPGR) – *Lorenzo Maggioni (ECPGR Secretariat)* • Infrastructure for Analysis and Experimentation on Ecosystems (AnaEE) - *Dr. Jacques Roy (Dept. director AnaEE)* • European Technology Platform Plants for the Future (Plant ETP)– *dr. Alexandra Malyska (Executive Manager)* • ERA-CAPS – *dr. Paul Wiley (Coordinator)*	
10:15 – 11:00	**Common discussion II**	
45'	*Identification of overlaps or gaps with initiatives*	**Outcome:** overview of networks and their activities, possible gaps or overlap
11:00 – 11:15	**COFFEE BREAK**	
11:15 – 12:30	**Common discussion III / resumé**	
75'	*Resumé from discussions I & II* *Discuss on priorities and if and how FACCE-JPI could play a role*	**Outcome:** A distinct view on the needs, gaps, priorities and potential and on existing initiatives addressing these already. Are there opportunities for FACCE-JPI to get involved?
12:30 – 13:00	**Closure**	

Annex III: Participants

Name		Organisation	
ANKER-NILSSEN	Kirsti	Research Council of Norway	representative Norway
ARAUS	José Luis	University of Barcelona	representative Spain
BIEMOND[1]	Christiaan	Keygene	
BOONEKAMP[2]	Piet	Wageningen University and Research	ERA-NET C-IPM
CARPENTIER	Sebastien	KU Leuven, Faculty of Bioscience engineering, division of Crop Biotechnics	COST FA1306 PhenomenAll
CHATOT	Catherine	Germicopa	European Association for Potato Research
COGLIANDRO	Alessi	European Seed Association	
CRNOJEVIC	Vladimir	BioSense Institute	
DE BOTH	Greta	Bayer Crop Science SA-NV	
DOONAN	John	National Plant Phenomics Center, Aberystwyth University	
EWERT	Frank	Institute of Crop Science and Resource Conservation, University of Bonn	MACSUR, Crop M coordinator
JALINK	Henk	PhenoVation B.V.	
KAARE	Külli	Ministry of Rural Affairs, Estonia	FACCE-JPI Governing Board EE, representative Estonia
LÖFFLER[1]	Huub	Wageningen University and Research	FACCE-JPI Governing Board NL
LOIT	Evelin	Estonian university of life sciences	representative Estonia
MAGGIONI	Lorenzo	European Cooperative Programme for Plant Genetic Resources	
MALYSKA	Aleksandra	European Technology Platform Plants for the Future	
MARGRAF	Stefanie	Forschungszentrum Jülich	FACCE Secretariat
MARTIN[1]	Michel	Arvalis – Institute du Vegetal	European Association for Potato Research
OPREL[1]	Leo	Ministry of Economic Affairs, The Netherlands	representative NL
PIERUSKA	Ronald	Forschungszentrum Jülich	International Plant Phenotyping Network
REIJERS[2]	Linda	Ministry of Economic Affairs, The Netherlands	representative NL
REYNS	Piet	Limagrain	
ROGNLI	Odd-Arne	Dean of the faculty of Biosciences, Norwegian University of Life Sciences	Nordic association for agricultural sciences

ROLDAN	Isabel	Instituut voor Landbouw en Visserij Onderzoek	representative Belgium
ROY	Jacques	Centre National de Recherche Scientifique	Infrastructure for Analysis and Experimentation on Ecosystems
RUDOLF	Barbara Maria	Bioland	
SCHURR	Ulrich	Forschungszentrum Jülich, IBG-2: Plant Sciences	EPPN & EMPHASIS
SIMONS[2]	Thijs	Plantum / European Association for research on plant breeding (representing)	
TE BOEKHORST	Dorri	Wageningen University and Research	FACCE Secretariat
TINOIS	Nikolas	Forschungszentrum Jülich	FACCE Secretariat, representative Germany
TRONSMO	Anne Marte	Norwegian University of Life Sciences - Plant & Animal	FACCE-JPI Scientific Advisory Board
VAN DE ZEDDE	Rick	Wageningen University and Research	Senior Researcher & business developer
VAN DIJK[1]	Amanda	Netherlands Inspection Service for Horticulture	
VOGELEZANG	Jose	Wageningen University and Research	Topsector Horticulture & Starting Materials
WILEY	Paul	Biotechnology and Biological Sciences Research Council	ERA-NET ERA-CAPS

[1]Thursday only, [2]Friday only