Promoting Nordic Plant Breeding for the Future

PPP Public Private Partnership for Pre-breeding

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PPP Pre-breeding in the Nordic Collaboration

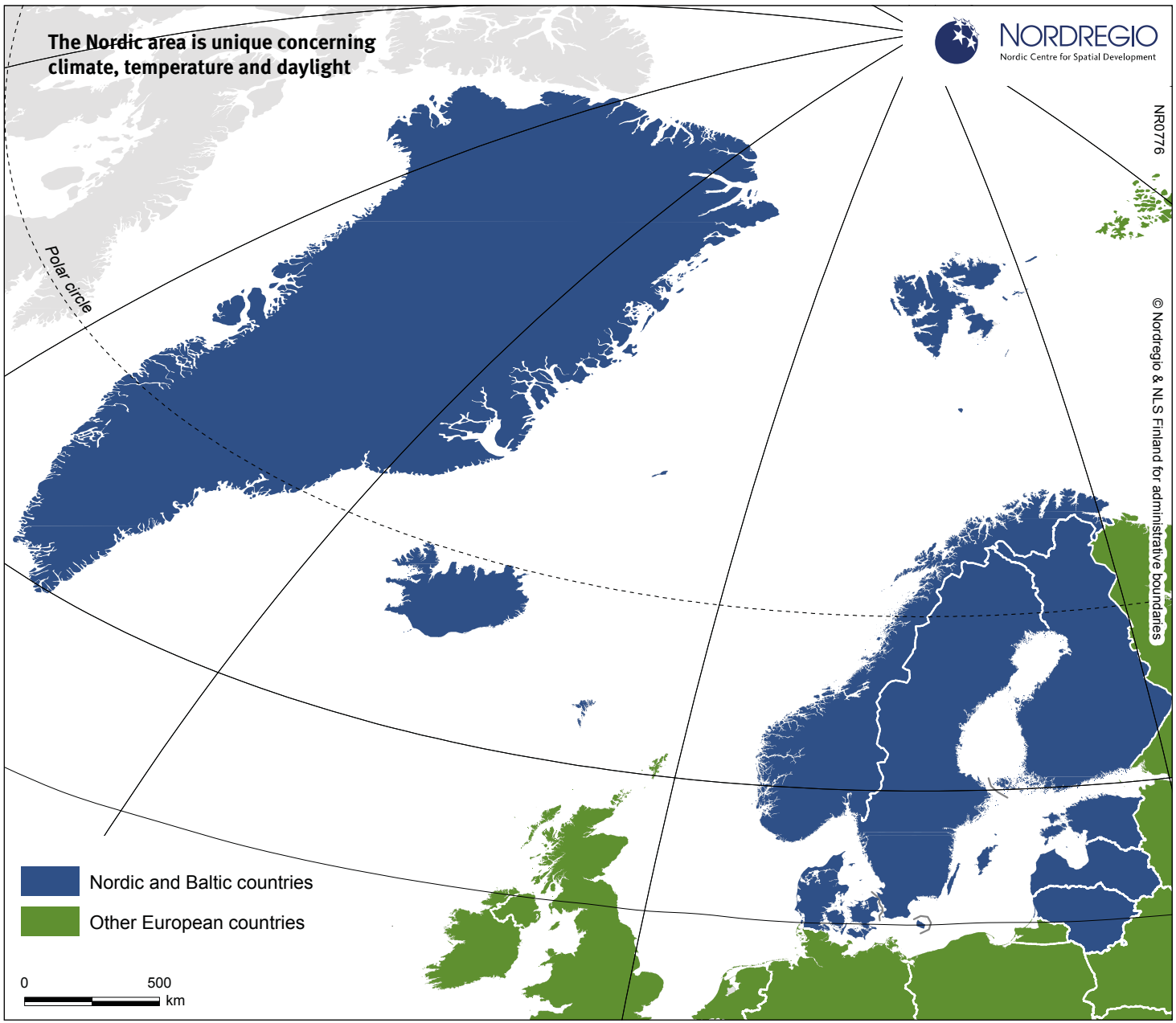
The Nordic countries represent some of the most northern agricultural areas on Earth. Farming contributes to sustainable rural societies, food security and valuable export industries. The key to this success is our long tradition of plant breeding, which has delivered new varieties and characteristics of crops, specially adapted to the unique environmental conditions of the high north. For centuries, plant breeding was a private enterprise, but with the rise of higher education and organized research in agriculture in the late 19th and most of the 20th century, the governmental institutions played an important role in many countries and plant breeding became one of the main foundations of agricultural sciences. Plant breeding is still an important science, but most of the development of new cultivars has moved out of the sphere of public institutes to the private market. Now, much of the global plant breeding is carried out by large multinational companies and a small, unique market, like the Nordic countries, can easily be overlooked and neglected.

It was in this situation, ten years ago, that the first initiatives were taken to strengthen the Nordic collaboration in plant breeding as a *Public-Private Partnership (PPP) for Pre-breeding*. The goal was to secure the development of Nordic agricultural plants to meet the demands, brought about by climate change and consumer expectations for healthy and tasty products, and to contribute to sustainable development of the agricultural sector.

The establishment of *PPP for Pre-breeding*, development, present status and the way forward are all described in this booklet. The success of the PPP is based on four principles:

- Pooled public funding while allowing some countries to move faster
- Project based participation from plant breeding companies
- Engagement of the best research environments for the respective projects
- 50/50-funding between public sources and industry.

The history of PPP for Pre-breeding has been a success and this booklet demonstrates some of the most encouraging cases from the last 10 years of fruitful collaboration. The Nordic Council of Ministers is proud to have initiated the PPP for Pre-breeding, but we are also grateful to all the other partners, who have contributed to the process: the plant breeding companies, the universities, and the governments of the Nordic countries, which have decided to continue funding the project. It is vitally important to continue this work because plant breeding is a long term process, which must never stop. There is no finishing line – only the way forward.



Map layout: Linus Rispling, Nordregio

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Establishment of a PPP

Plant breeding in the Nordic countries has a long tradition. It is based on the need to supply Nordic growers with suitable, well adapted varieties in a large number of agricultural and horticultural crops. Over time this gave rise to international marketing of seeds and varieties for some of these companies from their Nordic basis, while other entities were restricted to development for regional markets. With structural changes in the seed industry only two Nordic plant breeding operations were left with a large international presence as 2010 approached – DLF Trifolium in Denmark, international market leader in forage and turf grasses, and Syngenta Seeds with breeding of sugar beets in Landskrona, Sweden. There was a growing awareness in society of the consequences of increased dependency on seeds from large multinational breeding companies, more or less well adapted to the specific Nordic growing conditions.

In 2008, under the Swedish chairmanship for the Nordic Council of Ministers (NCM), a mission on defining possible ways of strengthening Nordic plant breeding was initiated. In contacts with the leading Nordic breeding companies it was concluded that there was a joint understanding of the need to collaborate in the pre-commercial part of the breeding chain and a willingness to contribute to the funding of such activities. The companies were all strong competitors in different regional Nordic markets, linked to how their owners or partners were organized.

The plan was anchored with the concerned ministries and the set-up of a Public-Private Partnership (PPP) for Pre-Breeding was proposed in 2010. Its principal contents are 50/50-funding from public and private sources. The private and public breeding entities that joined the PPP agreed to participate on a project-for-project basis. The NCM Committee of Senior officials for Agriculture, Food and Fisheries took an active part in the further preparations, leading to the decision to establish the PPP. Twelve out of thirteen Nordic plant breeding entities joined. NordGen was appointed as secretariat and became responsible for the PPP economy and the communication between engaged contacts. Public funding from the responsible ministries in the respective Nordic countries was granted from 2011 and pooled. In 2012 the Steering Committee of the PPP was in place and a first Call for proposals could be opened.

The agreement on the PPP stated that the projects had to be of value for the development of Nordic plant breeding, growers and markets. Three subject areas were identified to be of joint interest:

- Broadening of the genetic basis for plant breeding, for instance to facilitate adaptation to climate change.
- Introduction of specific genes for resistance, qualities, etc., in adapted genetic background.
- Development of new technologies that could speed up the breeding process.

The first three established projects each represent one of these three subject areas. After evaluation and decision on continued and increased funding, a fourth project was started on technology development.

CASE

Project title:

Pre-breeding for Future Challenges in Nordic Apples

Project leader: Prof. Hilde Nybom, SLU, Sweden
Partners:
Plant breeding entities: Luke, Finland; Graminor, Norway; SLU, Sweden
Project grants: 2012-2017; TDKK 12,500 from PPP and Partners

Main goals:

- Improvement of co-operation among Nordic and Baltic fruit breeders
- Analysis of resistance towards apple canker and storage rot in apple cultivars
- Identification of candidate genes and development of DNA markers
- DNA-based analyses of disease resistance in apple
- Information distribution to stakeholders.

Have you met Heta, Siv or Agnes yet? These new apple varieties are attractive, tasty and well-adapted to the challenging climate conditions in our Nordic countries. 'Heta' was bred in Finland, 'Siv' in Norway and 'Agnes' in Sweden.

But nobody is perfect – not even our new apples. 'Heta', 'Siv' and 'Agnes' have many valuable traits but essential parts are still missing in their genetic make-up. This is also true for all the other new – and old – apple cultivars in the Nordic countries.

Demand for superior resistance towards fungal diseases has increased dramatically due to e.g. global warming (rising disease pressure!), consumer awareness (requiring residue-free food products) and environmental-friendly policies (decreased access to plant protection chemicals). Fungal spores are everywhere! Consequently, apple trees suffer in the field and fruits deteriorate during cold storage. Nordic apple growers are forced to chop down large numbers of disease-stricken trees each year, and to chuck out big quantities of inedible fruit.

The only long-term solution is to breed better cultivars. Apple breeding is fortunately fairly straightforward – you select two promising parents with complementary traits, administer pollen from one cultivar to the pistils of the other, sow the

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resulting seed, evaluate seedlings in the field, propagate the best and grow them in test orchards. Unfortunately, apple breeding is also extremely time-consuming (20 years from making a cross to registering a new cultivar), labour-intensive and expensive!

Within this PPP project, we have now set an agenda that will produce the apple cultivars to be grown 20 years from now. We focus on resistance to fruit tree canker caused by *Neonectria ditissima*, and storage rots caused by e.g., *Neofabraea* spp. and *Penicillium expansum*. Degree of resistance is evaluated after inoculation with fungal spores or hyphae.

The first stage of the project has already produced some data that we have used for selecting next-generation parents for the apple breeding carried out by all three partners. In addition, data is also being collected for identification of candidate genes and development of DNA markers for future breeding. By co-operation, we make use of the large collections of different apple cultivars maintained by each of the three partners. Labour division as well as knowledge transfer allow all partners to work more efficiently at the same time as we learn more and become better at our job!

CASE

Project title:

Combining Knowledge from Field and from Laboratory for Pre-breeding in Barley II

Project leader: Research Leader Ahmed Jahoor, Nordic Seed, Denmark
Partners:
Plant breeding entities: Boreal Plant Breeding, Finland; Graminor, Norway; Nordic Seed, Denmark; Sejet Planteforædling, Denmark
Academic institutions: LBHI, Iceland; Luke, Finland; PLEN, Denmark; SLU, Sweden
Project Grants: 2012–2017; TDKK 29,000 from PPP and Partners

Main goals:

- To find a larger variability of genes for abiotic and biotic stresses
- To introduce these genes in relevant breeding material by using multi-parent advanced generation inter-cross (MAGIC) populations
- To develop "easy-to-use" DNA markers to be used in the breeding of new cultivars
- To educate the next generation of breeders by assigning PhD Students and Post Docs to the project.

The long-term goal with the project is to lay the foundation for effective cereal breeding for disease resistance and yield stability in barley in changing climatic conditions, capable to meet current and future challenges in the Nordic region. The objectives of the first phase of the project were 1) to screen current breeding material as well as new material to find a larger variability of genes for abiotic and biotic stresses with emphasis on various climatic conditions; 2) to transfer these genes into relevant breeding material by using pre-competitive multi-parental populations; and 3) to develop DNA markers for the different traits to be used in the breeding of new cultivars.

In the first period we characterized resistance traits present within the Nordic breeding programs. This has made the development of DNA markers for detection of nematode resistance in barley possible, which previously has been very difficult to screen for in practice. In addition, this project has led to the identification and characterization of new resistance sources towards scald and the development of DNA markers to be used for detection of scald resistance.

This project has also led to the identification of previously unknown mutations causing up to three weeks earlier flowering and maturing in

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spring barley, which will enable breeding of spring barley better adapted for Northern Scandinavia.

Highly important gains from the PPP project has been the strengthening of the network of Scandinavian breeders and plant breeding researchers of spring barley, and the increased exchange of material and access to new genetic resources for the breeders, which are crucial for a successful breeding program.

Currently we work in two directions: 1) to gain increased knowledge about current known resistance and to incorporate this resistance into a genetic background of relevance; and 2) to collect and test new genetic resources that could be potential sources of resistance for incorporation in modern varieties. If crosses are made with adapted material it takes around 10 years to develop a new variety. However, new sources of resistance are often found in wild relatives of cultivated plants or in landraces. To transfer these new sources of resistance into adapted material in order to develop new varieties will take more than 15 years – a too comprehensive task for a single breeding program, but thanks to the PPP project it is now achievable.

CASE

Project title:

PPP for Pre-breeding in Perennial Ryegrass (*Lolium perenne L.*)

Project leader: Prof. Odd Arne Rognli, NMBU, Norway
Project partners:
Plant breeding entities: Boreal Plant Breeding, Finland; DLF Trifolium, Denmark; Estonian Crop Research Institute, Estonia; Graminor, Norway; Lantmännen, Sweden; LAMMC, Lithuania; LBHI, Iceland; (Research Institute of Agriculture, Latvia) (partner from 2016, pending)
Academic institutions: Aarhus University, Denmark; NMBU, Norway
Project grants: 2012–2017; TDKK 9,500 from PPP and Partners

Main goals:

- Develop improved germplasm with a suitable adaptation to future climates in the Nordic region
- Create an arena for collaboration, capacity building and synergy among plant breeding companies and academic institutions in the Nordic and Baltic regions.

In Northern Europe, the expected climate changes will result in new growth conditions for forage production due to longer (1–3 months) growth season combined with milder and rainier autumns and winters. The basic assumption behind this PPP project is that the available germplasm and active breeding populations of perennial ryegrass are not sufficiently broad to cope with the requirements of the future climate.

Breeding perennial forage grasses is a long-term activity taking 10–20 years until cultivars are released. This pre-breeding project was designed to run from 2012 to 2018, and the project started by obtaining seed samples of 383 accessions from gene banks worldwide. These accessions were seed multiplied, genotyped by high-throughput sequencing (GBS), established as replicated single plant experiments for detailed phenotyping in DK, SE, NO and FI, and established in crossing blocks in DK and NO for generating broad-based breeding populations. Field experiments last for 2–3 years. In addition, a 3-year field trial in five countries (IS, SE, NO, EE, and FI) for testing the potential winter hardiness of 22 perennial ryegrass cultivars have been completed. The results confirm the need for more robust and stable cultivars with wider adaptations. In 2015, field experiments with

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seeds multiplied from the original accessions were established in all seven countries (IS, SE, NO, FI, DK, EE and LT) for testing using regular plot size. A core set of 150 accessions is present at all locations, and yield and other traits will be recorded for 2-3 years (2016–2018). In 2016, the broad-based breeding population will be sown on large plots at two locations in all countries for natural selection to create locally adapted germplasms. In addition, new tetraploid genotypes will be created by chromosome doubling of 1000 plants from the broad-based population. Based on the phenotyping of single plants, 28 populations have been composed for specific traits by digging out and crossing plants from the field. They are together with the 22 cultivars, and leaf samples of about 2000 single plants, in the process of being genotyped by GBS (pending funding). These genomic resources, together with the GBS data of the original accessions and the detailed multi-site-year phenotypic data, are powerful resources for associating molecular markers with important traits and develop genomic selection schemes. This is the focus of the next steps in this pre-breeding project.

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The Public Private Partnership Plant Phenotyping Project (6P)

The foundation of the Public Private Partnership Plant Phenotyping Project (6P) was laid as the urgent need for closer collaboration between phenotyping researchers, technology developers and plant breeding end-users became apparent during an international Phenotyping Workshop at the University of Copenhagen in September of 2014. The PPP funding call from NordGen was announced shortly after and as they say, the rest is history.

With current plant breeding methods, the development of new crop cultivars takes at least 10 years. With the development of non-destructive high-throughput field phenotyping methods, output and efficiency of crop selection will increase dramatically and contribute to solving some of the regional and global challenges brought forth by climate change and a growing population.

The 6P project represents a two-pronged approach to some of the challenges faced by plant breeders. Firstly, by facilitating stronger pre-competitive collaboration between organizations involved in plant breeding and phenotyping via the Nordic Plant Phenotyping Network (NPPN). Secondly, by targeting cutting-edge research and innovation needs through the R&D portion of 6P. Maintaining a focus on the practical implementation of technological advances and involvement of end-users throughout the entire process via the PPP format of the project creates invaluable public-private synergies and opportunities for future collaboration and development.

CASE

Project title:

The Nordic Plant Phenotyping Network (NPPN)

Project leader: Prof. Svend Christensen, Department of Plant and Environmental Sciences, Denmark
Partners:
Plant breeding entities: Boreal Plant Breeding, Finland; DLF Trifolium, Denmark; Findus, Sweden; Graminor, Norway; Jõgeva Plant Breeding Institute, Estonia; LAMMC, Lithuania; Lantmännen, Sweden; LBHI, Iceland; LKF Vandel, Denmark; Secobra, Sweden; Sejet Planteforædling, Denmark; SLU, Sweden; Syngenta Seeds, Sweden; LUKE, Finland
Academic institutions: Department of Plant and Environmental Sciences, Denmark
Project grants: 2015–2017; TDKK 3,100 from PPP and Partners

Main goals:

- To become the hub of Nordic plant phenotyping activities by facilitating stronger pre-competitive collaboration through information exchange and networking between research institutions, technology providers and plant breeding companies.

The Nordic Plant Phenotyping Network

The NPPN has been successfully established, and valuable network activities have already been completed, and more are planned. Industry partners are involved directly in the governing of the NPPN to ensure that the needs of Nordic plant breeders are met, with regards to research and coordinated activities. An annual general assembly is held in conjunction with the official two-day NPPN workshops. The workshops are open for participation also from stakeholders not currently classified as NPPN partners. An NPPN Summer school is scheduled for July 2016 and the 2nd annual NPPN workshop will take place in Sweden in November 2016. More detailed information about the NPPN and its activities can be found at **www.nordicphenotyping.org**.

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The NPPN itself is a novelty in the Nordic plant breeding context. It is the first time an organization has been established with the aim of supporting plant breeding synergies and development opportunities within the region. So far, the response to the NPPN from partners and external stakeholders has been overwhelmingly positive. The 1st annual NPPN workshop in 2015 was in itself a historic event in gathering so many representatives of the Nordic plant breeding organizations and stakeholders under one roof. We are confident that the NPPN will continue to develop and expand its activities, being the central association for Nordic plant breeders and institutions involved in plant phenotyping activities.

CASE

Project title:

Research and Innovation of High-throughput Phenotyping in Field Trials (6P R&D)

Project leader: Prof. Svend Christensen, Department of Plant and Environmental Sciences, Denmark
Partners:
Plant breeding entities: DLF Trifolium, Denmark; LKF Vandel, Denmark; Lantmännen, Sweden; Secobra, France
Academic institutions: Department of Plant and Environmental Sciences, Denmark
Project grants: 2015-2017; TDKK 7,100 from PPP and Partners

Main goals:

- Develop non-destructive high-throughput field phenotyping methods
- Make it possible for breeders to use drones to regularly and objectively follow the breeding plots
- Score characteristics with different wave lengths that is not visible to the human eye.

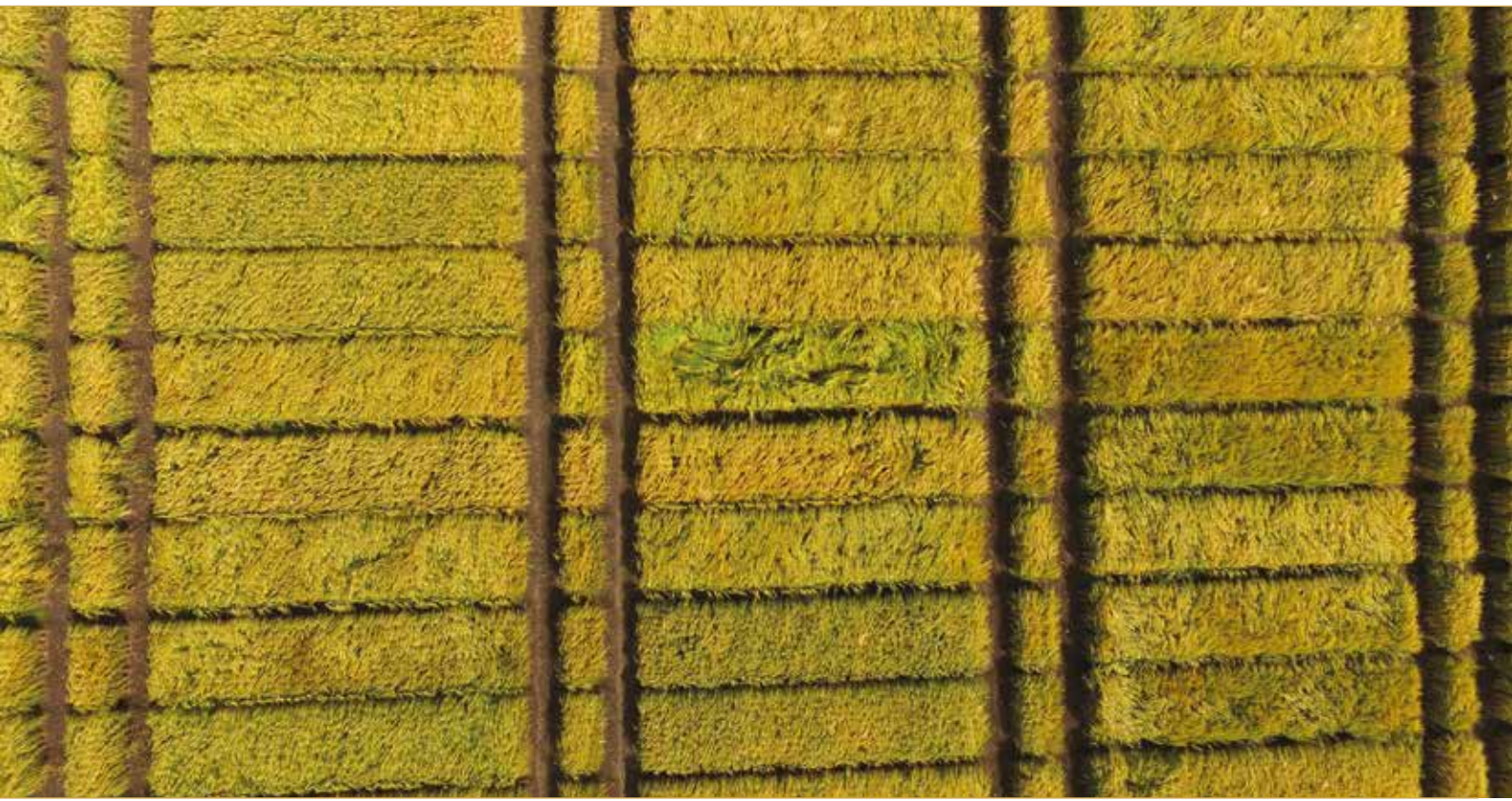
6P Research & Development

The 6P R&D activities focus on the development of new high throughput methods and the implementation of new technology, such as drones, in plant field phenotyping.

In the process of selecting and developing new crop varieties through phenotyping, plant breeders manually evaluate a host of specific plant characteristics (traits), covering a vast number of field plots and plants throughout the growing season and collecting a huge amount of data for processing. Through the implementation of drones and digital images, this process can become more efficient and less labor intensive, eventually shortening the time from first cross to final release of new crop cultivars.

The Dept. of Plant and Environmental Sciences at the University of Copenhagen has established a 6P R&D team that works closely together with the involved companies and consists of drone application and plant phenotyping researchers, an IT developer and a statistician.

The plant phenotypic traits currently targeted for automated phenotyping by the R&D team through the use of drones are: Winter hardiness, germination rates, early growth vigor, heading, and disease resistance (primarily rust and blight). The companies involved in the R&D consortium represent different crops.



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The crops currently included in the 6P R&D trials are cereals, potatoes and ryegrass. It is important to note that the methods and processes being developed within the 6P R&D framework can eventually be applied on a broader scale and will not be limited to the crops included in the current 6P trials.

Until now, the focus within the project has been on developing new software, statistical approaches and standardized methods for drone applications and digital image processing, to ensure that a structured data collection and analyses during the 2016 and 2017 growing seasons can be completed. Most importantly, the R&D team has also worked to ensure that the R&D partner representatives themselves are able to correctly apply the drones and obtain useful digital images of the field plots.

The 2016 6P R&D activities yielded great interest, involvement and investment in time and new equipment from all partners. The implementation of Unmanned Aircraft Systems (UAS) in field phenotyping is well underway, with software, methods and statistical analyses ready to be applied. We expect strong overall results and the ability to potentially include more plant traits in the process as the project progresses.

Development and Recommendations

Public funding of the PPP was initially decided for 2011-2013. Plant breeding in the Baltic countries was invited to participate in the projects. In order to prepare for a prolongation of the PPP, an external evaluation of the collaboration was carried out in 2013 by four experts – two representing the Nordic farming community and two from academia. The evaluation panel fully endorsed the PPP initiative and recommended a substantial increase of its funding

The evaluation was followed by a workshop in Reykjavik in February 2014 with some 40 participants from ministries, the plant breeding community in the Nordic and the Baltic countries, Nordic stakeholders and the Steering Committee. The outcome of the workshop was a strong support for the further development of the PPP

The evaluation panel and the Reykjavik workshop gave the following message:

- Plant breeding is a key element in developing a sustainable Nordic bio-economy. Obtaining a sustainable food production including a reduction of its environmental footprint with healthy, diverse, stable and competitive food products – in a changing climate – is an ambitious but necessary agenda.

- Innovative use of biomass for materials and energy adds to the economic development. All agricultural production – whether it is for food, feed, fuel, or fiber – start with cultivation of the best adapted plant varieties, carrying suitable traits for different purposes. Access to continuously improved, well adapted and competitive plant varieties is a precondition for a sustainable Nordic agriculture. Exploiting the properties of plants by using genetic solutions is a key for tomorrow's Nordic bio-economy.

- More must be produced with, at best, the same input of resources. It has been estimated that half of the increased productivity of plant production over the last 100 years can be attributed to genetic gains from plant breeding.

- With climate change our agricultural production systems will develop changed practices, while at the same time tolerances to weather related stress will have a new understanding. As new races and strains of pests and pathogens evolve or appear in new areas, new varieties carrying corresponding resistance traits must be developed and made available for farmers to maintain and to increase productivity.

- The location of our region far to the north, together with the strong demands for clean, green and sustainable food production, applying less pesticides, provide extra challenges. The Nordic agricultural region has very diverse climatic conditions. Plant breeding in other parts of Europe will give limited contributions to our specific needs. Multinationals will continue to have their focus on the global markets. We have to rely on our own activities to succeed.

In 2014 the Ministers of Agriculture, at their Summer meeting, decided to continue funding of the PPP for 2015-2017, while also envisaging a continuation for 2018-2020. Three countries – Denmark, Iceland, and Sweden – declared that they will increase their support to the PPP from 2015.

Photo explanation, see page 27

The Way Forward for the PPP

Funding of pre-breeding collaboration between the practical plant breeding and plant breeding research is a powerful tool to secure desired development of agriculture and horticulture. It influences other parts of society, relying on deliveries of products based on the growing of plants. It results in improved high-yielding crop varieties with better yield stability and with new traits such as:

- increased efficiency in their use of nutrients, which can secure growth in food production while reducing environmental footprints
- better resistance to pests and pathogens, which can reduce the need for pesticide application and support organic production
- health related characteristics, which can improve the nutritional value of food products
- specific qualities for the use of plants as feed-stock in industrial processes or as raw materials for technical products.

Such development will contribute to sustainable growth of the bio-economy and global food security by adapting our crops to climate change.

Through the established PPP the Nordic and Baltic plant breeding entities have proved that collaboration on a precompetitive level, across borders, between public research and private or public plant breeding provides an efficient way forward to address compelling societal challenges. Nordic collaboration has been strengthened.

The success of the Nordic PPP for Pre-breeding has been noted in an EU context. It is seen as a model on how regional collaboration in pre-breeding between research and breeding communities can be developed.

Plant breeding and especially pre-breeding is a long term engagement. Access to state-of-the-art technologies and specific knowledge is becoming increasingly important in order to keep Nordic crop production competitive in a global context.

Support to pre-breeding efforts requires that there is a clear way forward to market introduction and that the economic, environmental, and societal values are such that support from the Nordic countries through the PPP platform can be justified. Focus on specific breeding goals and traits of importance for adaptation to climate change, targets for environmental policies, sustainable growth of the bio-economy, and competitiveness of Nordic food production will strengthen Nordic collaboration in pre-breeding. As a result, plant breeders will be supported in their efforts to meet the needs for new agricultural and horticultural crop varieties for all Nordic areas. All in all, there are strong motives to further develop the PPP for Pre-breeding with increased funding.

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Contact Information

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Appendix

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Photo Roland von Bothmer.
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Photo Karl Johan Langvad

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Upper picture; Whisky distillery: Photo: Imagesubscribtion.com
Lower picture; From beer brewery: Photo: Imagesubscribtion.com

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Pea flower: Photo Roland von Bothmer

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The establishment of *PPP for Pre-breeding*, development, present status and the way forward are all described in this booklet. The success of the PPP is based on four principles:

- Pooled public funding while allowing some countries to move faster
- Project based participation from plant breeding companies
- Engagement of the best research environments for the respective projects
- 50/50-funding between public sources and industry.

The history of PPP for Pre-breeding has been a success and this booklet demonstrates some of the most encouraging cases from the last 10 years of fruitful collaboration. The Nordic Council of Ministers is proud to have initiated the PPP for Pre-breeding, but we are also grateful to all the other partners, who have contributed to the process: the plant breeding companies, the universities, NordGen and the governments of the Nordic countries, which have decided to continue funding the project. It is vitally important to continue this work because plant breeding is a long term process, which must never stop. There is no finishing line – only the way forward.

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