NORDIC AGRICULTURE AND CLIMATE CHANGE:

MITIGATION AND ADAPTATION

Recommendations from leading researchers and private companies within the Nordic plant breeding.

Nordic Agriculture and Climate Change: Mitigation and Adaptation
Recommendations from leading researchers and private companies within the Nordic plant breeding.

Compiled by NordGen staff.

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NordGen
The Nordic Genetic Resource Centre (NordGen) is the Nordic countries' gene bank and knowledge center for genetic resources. NordGen is an organisation under the Nordic Council of Minister and works with the mission of conserving and facilitating the sustainable use of genetic resources linked to food, agriculture and forestry.

NordForsk
NordForsk is an organisation under the Nordic Council of Ministers that provides funding for and facilitates Nordic cooperation on research and research infrastructure. NordForsk seeks to enhance the quality, impact and efficiency of Nordic research cooperation, thereby helping the Nordic region to become a world leader in research and innovation.

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Contents

Summary

This report summarizes the discussions and presentations at a workshop held in Oslo on January 18, 2019. The aim was to evaluate how future research can facilitate climate change adaptation and mitigation in Nordic agriculture. The workshop gathered leading actors within the field of Nordic plant breeding. Participants included high-level decision-makers and key stakeholders from Nordic plant breeding companies, farmer organisations, universities and other research organizations.

Climate change has already resulted in challenges for Nordic agriculture and the difficulties will continue to increase in the future. It is therefore important to act now to adapt our agriculture to future conditions, especially since the development of new crop varieties takes a long time (8-15 years).

In the following pages, specific recommendations are listed. The recommendations have the main goal to support future food security in the Nordic countries by facilitating the development of new crop varieties adapted to our future needs. Special attention is given to the challenge of adaptation to climate change and high-quality food and feed production.

Recommendations

The recommendations have the main goal to support future food security in the Nordic countries by facilitating the development of new crop varieties adapted to our future needs. Special attention is given to the challenge of adaptation to climate change and high-quality food and feed production.

RECOMMENDATION 1

Establish a Nordic consortium/Nordic centre of excellence with the aim to facilitate research, screening and evaluation of genetic resources, pre-breeding and breeding with the end goal to produce new crop varieties to support future food production in the Nordic countries. The consortium could include a Nordic "big data" platform for phenomic and genomic data analysis, and would also work to adapt new scientific knowledge and tools to application in plant breeding and agriculture (see Appendix 2, for details).

RECOMMENDATION 2

Stimulate efforts to screen genetic resources for agriculturally relevant traits, preferable in Nordic cooperation projects.

RECOMMENDATION 3

Make sure that the genetic resources needed for food security and climate change adaptation are adequately conserved long-term. This would include also gap analysis to identify genetic resources that are today not adequately conserved, and to assure long-term conservation for these.

RECOMMENDATION 4

Continue to develop Nordic public-private pre-breeding projects, in order to channel genetic resources into plant breeding and to support Nordic plant breeding efforts.

RECOMMENDATION 5

Make sure that the Nordic region has an established network of field-testing locations representing the different climates, environments and disease pressures across the region. The number of field-testing sites is today limited.

RECOMMENDATION 6

Support research on topics of relevance for food security and climate change adaptation, such as research on drought and waterlogging, winterhardiness, emerging pests and diseases, plant physiology. Of particular interest is also research that can speed up the plant breeding process and thus increase the speed with which agriculture can be adapted to climate change.

RECOMMENDATION 7

Support research on topics of relevance for climate change mitigation, such as research on cover crops, perennial crops, root systems, no-till agriculture and CO_2 capture.

RECOMMENDATION 8

Encourage research both on the main crops that are important in the Nordic region today, and on new or upcoming crops/crop types. Crops / Crop types / cropping systems mentioned include: Mixtures of species and/or varieties, protein crops, intercropping, cover crops, crops for organic agriculture, cereals, potato, autumn crops, forages, fruits.

RECOMMENDATION 9

Joint Nordic education on plant breeding and related topics. There is a need for well-educated plant breeders in the Nordic region, but the number of plant breeders in each Nordic country is small and good national education is today not available. Cooperation between industry and academia regarding PhD education would be beneficial.

Introduction

The recommendations in this report are based on the views expressed by representatives from Nordic plant breeding companies, farmer organisations, universities and other research organisations. All of them participated in a workshop held in Oslo, 18 January 2019.

The workshop was organised by NordGen and NordForsk with the main aim to identify gaps in current knowledge, and based on this, pinpoint future research needed to facilitate climate change adaptation in the Nordic countries.

The workshop focused on plant genetic research, adaptation, resilience, conservation and breeding needs to meet future challenges in agriculture and horticulture in a changing climate and more extreme weather conditions. We already, and will continously, face challenges for the Nordic agriculture´s ability to produce food and feed under changing climate conditions.

The workshop was opened with a keynote presentation by professor Jørgen E. Olesen from Århus University, describing the future climate changes expected globally and how these changes are expected to affect agriculture.

This was followed by a number of presentations by stakeholders from the Nordic plant breeding companies and also from the research sector and a farmer organisation. The afternoon was dedicated to discussions on topics about how research and innovation can facilitate climate change adaptation and mitigation within Nordic agriculture.

A summary of the talks and the discussions can be found in Appendix 2-3.

The report from the workshop is an important contribution to NordForsk and NordGen and other Nordic actors in planning and prioritizing future research actions and for dissemination to relevant authorities in the Nordic countries.

Background

Humans have already influenced the climate system and a global increase of 0.89 °C has been observed since 1901.

The climate is expected to continue to change due to anthropogenic influences and the temperature is predicted to increase further during coming years (IPCC 2007, 2013).

This is also true for the Nordic area. In the south and west, the temperature is expected to be similar to the global average increase, while the northern and eastern areas are expected to have a higher increase in temperature (Barua et al. 2014).

In addition to the increase in temperature, other changes are expected, for example an increase in extreme weather events, changes in precipitation patterns, reduction in snow cover and rise in sea levels.

The changes in climate will affect agriculture in the Nordic region in several ways. Some can be positive such as increased growing season or increased CO_2 stimulating photosynthesis, while others, such as drought, floods or influx of new pests and diseases will have a negative effect (Barua et al. 2014).

The weather-wise diametrically opposed summers 2017 and 2018 have made the public aware that climate change is here and not

something that only will happen in the future. Last summer's drought demonstrated the risks with shortage of domestic animal feed and farmers were forced to import fodder for their animals. However, the feed shortage occurred all over Europe, which resulted in import of animal fodder of substandard quality and with the risk of carrying plant and animal diseases and new weeds.

The low degree of self-sufficiency of the Nordic region has become obvious and there is a desire among politicians to stimulate domestic food and feed production.

Nordic agriculture will have to adapt to the new climate conditions to be able to produce healthy nutritional food and feed in adequate quantities. In the future, the global importance of Nordic agriculture might in fact increase as the suitability for agriculture decrease in some areas currently important for food production. With this background, it is fortunate that the Nordic region has plenty of good farmland, abundant water resources and climate benefits compared to many other European countries.

We also have a good infrastructure and a well-functioning supply-chain. Furthermore, we have high awareness among farmers: in terms of practical cultivation, in the subsequent processing chain and in respect to the environmentally conscious consumer.

The consumer demands are expected to change as the standard of living improve, especially in poor countries. In addition to these demands for efficient, healthy and varied food production, there is also a need to limit the environmental footprint of agriculture itself and minimize the production of greenhouse gasses, thus mitigating climate change.

Part of this is likely to be an increased demand for plant-based protein, resulting in increased demands of crops like beans, peas and quinoa. Climate change and the diversified market demand is a worldwide trend.

After years of consolidation in the plant breeding and seed industry, there are now only a few large multinational companies left. However, these concentrate their breeding effort on a few crops for the large markets, for example central Europe. The acreage in the Nordic countries is far too small for them and our unique climate with long summer days and need of winter hardiness puts additional demands on the varieties grown here.

Plant breeding for the Nordic market need to be addressed within our own region and to tackle the many challenges associated with climate change. One important undertaking will be to continuously breed new more resilient cultivars.

The question is now how this can be done in an efficient way to meet the rapid changes in climate, demands for climate mitigation and high quantity and quality of food production.

A major challenge is that plant breeding is a lengthy process, and research to further develop and speed up the breeding would be very beneficial. Academia, gene banks and public and private breeding companies need to work together with the aim to solve the challenges for agriculture that climate change poses.

Priorities for research and plant breeding

Presented below are high-lights from the lectures and discussions at the meeting. More detailed summaries of these can be found in Appendix 2 and 3.

Plant genetic resources

Genetic resources are the raw material needed to develop new crop varieties and without genetic resources there will be no plant breeding. The concept "plant genetic resources" include the modern crop varieties, landraces, crop wild relatives and breeding and research material. With the exception of the modern varieties, genetic resources are generally maintained long-term within gene banks.

There is a great need to increase the knowledge of our genetic resources maintained in the Nordic gene banks. The existing genepools need to be screened, especially for agriculturally relevant traits connected to climate change adaptation and food security. Increasing the knowledge of the genetic resources makes it easier for users to select appropriate material suitable for breeding and research.

There is today an increased ambition to build bridges between gene banks, pre-breeding and breeding entities, resulting in improved possibilities to start common projects. There is also an interest in local landraces / old varieties with specific traits suitable for local food production. To facilitate utilization of genetic resources, there is a need to make it easy to access genebank material and its associated information.

There is a need to identify gaps in the current PGR collections to make sure that there is enough variation conserved for our future needs. NordGen has a special responsibility for native Nordic crop wild relative species, such as grasses, forage legumes and berries. It was suggested that joint Nordic projects should be developed to identify such gaps and to collect, or in other ways conserve, the plant genetic resources that is missing and potentially important in the future.

A prerequisite for use of genetic resources in the future, is proper long-term conservation of a wide range of genetic resources and thorough documentation of the characteristics of these resources. Long-term conservation of living material such as seeds or plant, entails constant active maintenance, which in turn requires stable long-term funding. This type of funding is therefore required to conserve the genetic resources for the future. The current Nordic collections contains a wide range of species and diversity, but there are also gaps and therefore a need to supplement and collect material in order to fill these gaps.

Traditional breeding goals

It is important to remember that even under climate change, the traditionally most important breeding goal, high crop yield, will still be one of the most central traits to breed for. It is strongly connected to food security since it determines the amount of food that can be produced per hectare. The human population is also expected to continue to increase in the future, resulting in a rise in the global demand for food.

At the same time agricultural land in many locations that are currently high-yielding, is expected to lose in productivity. For example, modelling of wheat yields under climate change clearly show decreases in yield in many locations across the globe. Potentially, Nordic agriculture could increase in global importance under such a scenario where many southern agricultural areas decrease in productivity. In addition, more land is expected to be used for buildings and road networks resulting in loss of agricultural land.

Crop yield need to be stable in more varied weather conditions and to achieve that, breeders need to search for genetic resources giving more resilient and robust varieties. Other traditional goals to breed for like earliness and straw stiffness will continue to be significant. With increased frequency of extreme events such as heavy rains and storms, straw stiffness is expected to increase in importance. Specific crop quality requirements like starch and protein content, malting quality or more subjective features like appearance and taste will also remain important.

Abiotic stress

The most obvious stresses to address in a changing climate is the abiotic stresses. Increased temperature, changes in precipitation patterns and a higher frequency of extreme weather events such as floods all results in new demands on crops, for example heat and drought tolerance and waterlogging resistance. We have a lack of knowledge in drought and waterlogging in the Nordic countries since this has not been a breeding goal before and the experience from other dry and hot regions is not directly applicable here.

Further, the Nordic countries have many temperature zones, but even with an increased average temperature breeding for winter hardiness will be vital. Generally speaking, it is expected that plant growth will cease later in autumn with climate change, whereas in spring there is a risk of too early dehardening and both may increase the risk of frost damage and mortality. The expected changes and fluctuations with increased rain- and snow-fall may give more prevalence of waterlogging, ice damage and subsequent diseases like snow mould in e.g. forages.

Biotic stress

In the predicted warmer climate scenario, new pests and diseases are expected to migrate into the Nordic area or into new parts of the region. Growers lack experience with these and the currently cultivated varieties may lack resistance towards new diseases. In addition, pathogens continuously evolve new strains that are better adapted to the resistance in the crops and therefore new varieties with new resistance genes needs to be developed again and again. >>

In this context, screening of gene bank material for resistance genes is important and needs to be done over and over again for the newly developed pathogen strains. In parallel, there are fewer approved pesticides on the market. Taken together, this poses a great challenge for growers to be able to produce high quality and healthy food and feed. Therefore, the Nordic countries have an overall need of increased knowledge about plant pathology.

This research area involves modelling and predicting future patterns of pests and diseases as well as improved prognosis systems, both for new and current diseases. Insect damage is expected to increase as southern strains migrate northwards and this will probably be a substantial challenge. Breeding for resistant varieties may be a feasible way to fight this problem.

Plant physiology

A very basic research area is plant physiology. With deepened knowledge in this area, solutions to both abiotic and biotic stress can possibly be found. There is a demand for both Nordic research and education in this area. Plant breeders ask for increased knowledge of the roots' adaptation to different ratios of moisture and drought. Should they be deep, broad and how branched? Thick or thin? Close to the roots exist a rich flora of microbes. Some are beneficial for the plant and others are negative. This complex area of root rhizobia, endophytes etc. is still under-investigated. The green part of the plant above the soil and its architecture is also of interest among breeders. Rapid emergence and coverage of the soil has been an aim in some crops, but is this nutrient efficient? What is the optimum leaf area relative to the harvested product when it comes to nitrogen requirement, which we want to be low, or to carbon dioxide uptake, which we wish to be high?

New and less cultivated crops

The Nordic countries are heavily dependant on imported protein fodder crops, mainly soy. There is now an interest in increasing the local production of protein crops, such as fava beans, peas, soy, clover and other legume crops.

There is also a discussion regarding, a reduced intake of meat in favour of vegetarian diets, as a mean to reduce our climate impact. To achieve this, animal protein has to

be replaced by vegetarian alternatives, both as food and feed. The current acreage in the Nordic countries for these crops is not large enough to cover the need, and neither is the supply of varieties and seed amounts.

The legume crops have both beneficial and negative effects on the soil. A major advantage is that they fix nitrogen, but on the other hand many soil-borne diseases are found in fields where legumes have been grown intensively without long enough crop rotation cycles.

Examples of almost new crops for our latitudes are quinoa, sweet sorghum and soybean. Quinoa is mentioned as a non-grass protein crop alternative and sweet sorghum as a suggestion of a C_4 plant for capturing CO_2, together with maize. These two crops also have a potential for bioenergy production.

Soybean as one of the world's most valuable sources of plant protein and have repeatedly been discussed as a potential crop also in our region. Soybean is mainly a short-day crop although there are cultivars that can grow and set flower in our long-day conditions. Before soybean can become a profitable crop in the Nordic countries, more plant breeding is needed.

In forage and fodder production from different grasses, there would be a benefit to increase the protein content. Researchers mentioned that there will probably be additional forage grass development the coming years. Depending on which species are chosen, there will be an interest in more basic research on the adaptation and appearance of these more or less used species in agriculture.

Alternative cultivation systems

To meet the increased impact of Climate Change on our farmland and soils, alternative cropping systems are tested and discussed. Systems like no-tilling systems, growing perennial crops, cover crops, intercropping, or mixtures of varieties, need further research and evaluation. There is however a concern that profitability will continue to limit large scale trials.

Many participants at the conference expressed their worry about the soil properties on farms and that there is a danger that fertile soils will become infertile due to overuse and bad crop rotation. We need more research regarding this important problem.

Plant breeding for organic production was mentioned, however no deeper discussions were held. Most breeding goals within conventional pre-breeding will be the same as for organic production's need.

New techniques and data management

Plant breeding in all crops take very long time (8-15 years) from the first cross to a new released variety. Breeders constantly look for new processes that can make the breeding cycle faster and shorten the time to market.

Today's plant breeding technology is under constant development and some plant material can be described in detail at the genomic level. The new techniques progress very fast and new methods are replacing each other.

Phenotyping is made in different specialized simulation facilities or outdoor with camera-equipped drones. Many new phenotyping and genotyping methods result in very large datasets, "big data", and there is an increasing need among researchers to develop storage and analyses approaches for these data sets.

One approach to analysing the data is "machine learning" and this is deemed a promising approach for future accurate and efficient analysis.

Nordic added value and long-term financing

Genetic resources is a field where many advantages can be seen with Nordic approaches. As concluded earlier, the Nordic agricultural region is comparably small. Our unique day-length in combination with several shared temperature zones mean that our conditions for cultivation are different than in the rest of Europe and the rest of the world.

Our total cultivation area is small, and therefore also the income that seed production for this region can provide. Thus, we cannot expect non-Nordic breeding companies to prioritize variety production for our needs.

Management of our genetic resources and pre-breeding needed for designing pre-competitive material should therefore preferable be done in cooperation among Nordic academia and plant breeding entities.

Examples of research areas with high interest are: joint screening of NordGen's genetic resources, development of a Nordic big-data platform, set-up of a phenotyping platform for diseases, pest and disease monitoring and distribution, high-throughput phenotyping and data handling.

The different examples of networks can be realised within partnerships like the Nordic PPP for pre-breeding or by building up a Centre of Excellence for pre-breeding. Interdisciplinary collaboration is also advocated and there is a need for cross-border cooperation between the food, feed and health sectors.

Financing of such activities is crucial, and must be long-term.

Conclusions and recommendations

All participants at the conference agreed that climate change has already caused challenges in Nordic agriculture and also that the challenges will continue to increase in the future. Nordic agriculture has some advantages compared to countries further south, but there are still many issues that needs to be addressed if Nordic agriculture is to adapt fully to climate change. In addition, these issues need to be addressed now as plant breeding takes many years from start to end product.

Cooperation within this field can lead to substantial added value for the Nordic countries. Both due to similarities across the borders regarding crops and climate-photoperiod but also due to the small size of the Nordic countries and markets. By pooling financial resources and sharing infrastructures much progress can be made. As the main area of cooperation, the new technologies were suggested, such as phenotyping and genotyping, crop simulation in artificial climate and handling of large amounts of data. Highly important is the need of having access to well-described and evaluated genetic resources.

At the following page, specific recommendations are listed.

Recommendations

ESTABLISH a Nordic consortium/Nordic centre of excellence with the aim to facilitate research, screening and evaluation of genetic resources, pre-breeding and breeding with the end goal to produce new crop varieties to support future food production in the Nordic countries. The consortium could include a Nordic "big data" platform for phenomic and genomic data analysis, and would also work to adapt new scientific knowledge and tools to application in plant breeding and agriculture (see Appendix 2, for details).

STIMULATE efforts to screen genetic resources for agriculturally relevant traits, preferable in Nordic cooperation projects.

MAKE SURE that the genetic resources needed for food security and climate change adaptation are adequately conserved long-term. This would include also gap analysis to identify genetic resources that are today not adequately conserved, and to assure long-term conservation for these.

CONTINUE TO DEVELOP Nordic public-private pre-breeding projects, in order to channel genetic resources into plant breeding and to support Nordic plant breeding efforts.

MAKE SURE that the Nordic region has an established network of field-testing locations representing the different climates, environments and disease pressures across the region. The number of field-testing sites is today limited.

SUPPORT research on topics of relevance for food security and climate change adaptation, such as research on drought and waterlogging, winterhardiness, emerging pests and diseases, plant physiology. Of particular interest is also research that can speed up the plant breeding process and thus increase the speed with which agriculture can be adapted to climate change.

SUPPORT research on topics of relevance for climate change mitigation, such as research on cover crops, perennial crops, root systems, no-till agriculture and CO_2 capture.

ENCOURAGE research both on the main crops that are important in the Nordic region today, and on new or upcoming crops/crop types. Crops / Crop types / cropping systems mentioned include: Mixtures of species and/or varieties, protein crops, intercropping, cover crops, crops for organic agriculture, cereals, potato, autumn crops, forages, fruits.

JOINT NORDIC EDUCATION on plant breeding and related topics. There is a need for well-educated plant breeders in the Nordic region, but the number of plant breeders in each Nordic country is small and good national education is today not available. Cooperation between industry and academia regarding PhD education would be beneficial.

Appendix 1: Participants list

Ahmed Jahoor	Nordic Seed
Anna Palmé	NordGen
Annette Hägnefelt	NordGen
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Elina Kiviharju	Luke
Emma Tcheng	NordForsk
Erik Alexandersson	SLU/NordPlant
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Sara Landqvist	NordGen
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Appendix 2: Summary of the discussions

1. Conservation and utilization of genetic resources

Question: *What are the needs for conservation and utilization of genetic resources stored in gene banks in connection to plant adaptation to climate change? Climate change mitigation? Changes in consumer demands?*

Plant genetic resources (PGR) are needed as raw material for plant breeding, which in turn plays an important role for adaptation of agriculture to climate change, for food security and human health. There is a need to identify gaps in the current PGR collections to make sure that there is enough variation conserved for our future needs.

It was suggested that joint Nordic projects should be developed to identify gaps in the current collections and to collect, or in other ways conserve, the PGR that is missing and potentially important in the future.

There is a need to screen the plant genetic resources conserved in the gene banks in order to increase the knowledge on the accessions, and in this way facilitate efficient use. Such screening should include evaluation of traits/genes believed to be of relevance for adaptation of crops to climate change. The evaluation can be done using traditional field evaluation but should also include genomics, phenomics and predictive characterisation to make screening more efficient.

It was suggested that joint Nordic evaluation projects would be a good way forward and that they should focus on traits related to climate change and food security. It is important that the knowledge and abilities / competencies in NordGen are used in such projects and that funding is made available.

We must create a bridge between gene banks and breeding companies to channel PGR into breeding programs. Using genetic resources in breeding is often time consuming and costly and the resources of individual Nordic plant breeding companies are limited. Pre-breeding projects with external funding, especially Nordic public-private partnerships, play an important role here.

A complication is that breeding and pre-breeding takes much longer time than the average research grant and specific long-term funding is therefore needed. It was suggested that NordGen should be more integrated into research projects such as NordPlant (www.nordplant.org/) and take part in research applications to encourage use of genetic resources within research.

Communication and information were other issues that were mentioned as important. It is central that information on the availability of genetic resources and how to access them is available in a user-friendly format. Also, characterisation and evaluation data on PGR should be easy to find and search. Communication about the benefits of genetic resources is also important. It should be stressed that PGR have a role in climate change adaptation and food production. >>

2. Research needed for climate change adaptation

Question: *What type of research/research infrastructure/innovation is needed to support the Nordic plant breeding industry regarding climate change adaptation? Please indicate what you consider to be the three most important topics and provide a motivation.*

Infrastructure needed

- An established network of field-testing locations representing the different climates, environments and disease pressures across the Nordic region. The locations should be fixed so field evaluation can be done at the same locations year after year.

- A Nordic Platform dedicated to adapting new knowledge and tools to be used in plant breeding and agriculture. There is in particular an interest in analysis of "big data" (for example from high-throughput phenotyping, genomics etc) and machine learning. To establish such a platform long-term stable funding is needed.

Most important research topics:

- Drought and water logging. There is a lack of knowledge on drought and waterlogging in the Nordic countries and therefore know-how development is needed. There is a different type of drought in the Nordic countries than in other regions and knowledge from other regions can therefore not be directly implemented. Variation in drought and waterlogging tolerance should be evaluated with both genotyping and phenotyping approaches and emphasis should be placed on how to easily transfer important traits into adapted material.

- Winterhardiness. A different type of winter tolerance is needed with climate change, for example changes in snow cover is expected.

- Emerging pests and diseases. An increase in temperature in the Nordic region is expected to result in an influx of pests and diseases that are not common today. Adapting our future crops to these threats are therefore crucial. Research topics relevant in this contact would be: modelling to predict future distribution patterns, plant pathology, screening of genetic resources for resistance/tolerance to incoming pests and diseases, incorporation of resistance/tolerance into adapted material.

3. Research needed for climate change mitigation

Question: *What type of research/research infrastructure/innovation is needed to support the Nordic plant breeding industry regarding climate change mitigation? Please indicate what you consider to be the three most important topics and provide a motivation.*

- Plant breeders are generally not working with breeding goals/traits associated with climate change mitigation or with species/crops used specifically for this task. It is difficult for plant breeders to have an impact on mitigation, while working within their current focus crops and major breeding goals associated with efficient food production (e.g. yield, quality and pest and disease resistance).

Most important research topics:

- Cover crops (cover crops can be used to limit soil erosion, improve soil health, decrease effect of flooding/drought and increase the amount of bound carbon). More knowledge is needed on cover crops in the Nordic area.

- Perennial crops like Miscanthus, Salix, Phalaris and perennial wheat.

- Root system research / crops with good root systems

- No-till agriculture (no-till agriculture aims at improving soil structure, including improving retention of water and organic matter)

- CO_2-capture in plants, for example C_4-plants like maize and sweet sorghum (biomass crop)

- Tolerance to drought/heat/flooding

4. Research needed to facilitate the use of plant genetic resources

Question: *What type of research, technologies and tools would facilitate the use of plant genetic resources and cooperation with gene banks? (for example: screening wild genepools, evaluating landraces, molecular tools…)*

Easy access to PGR and associated information facilitates the use of the material. Gene banks should make sure that the IT systems that are used to disseminate information, are user-friendly and similar to those used by plant breeders. Perhaps gene banks and plant breeders/researchers could share the same IT platforms? Good if gene banks have similar platforms to make it easier to find data.

Most important research topics:

- There is a need for hardcore plant physiology research; e.g. what is robustness, can we be able to earlier identify outbreaks of disease, how to earlier visualize and identify risks?

- Research on techniques to speed up the breeding process and make it easier to transfer traits (for example pest and disease resistance) from "primitive" PGR (for example crop wild relatives or landraces) into adapted material

- PGR should be characterised and evaluated for agriculturally relevant traits and this information should also be made easily available (using both molecular tools and field evaluation).

- Analysis of "big data" and machine learning

5. Important crops for research and development

Question: *What crops/type of crops should the crop specific research be focused on? (for example: cereals, forages, vegetables, perennial crops, new crops, mixtures, whole cropping systems …)*

With this kind of research, it is very important to think out of the box, and in addition to the traditional crops and cultivation approaches, alternatives should be explored.

However, there is a long start-up phase from the initiation of a research or pre-breeding project to an actual product/approach/crop that can be used in agriculture (minimum of 10-12 years) and economic incitements are needed to stimulate this type of projects.

Nordic cooperation is a key. We use the same crops, share the same unique climate-environment combination and the Nordic companies are rather small with limited budgets, which means that much can be gained by cooperating. To conduct research and plant breeding benefitting all parts of the Nordic region, a network of testing sites across the Nordic region is needed. This can be utilized both in national and Nordic level projects.

When choosing what research projects to conduct, it is central to consider the sustainable development goals and the long-term sustainability of Nordic agriculture.

Several groups discussed this question and many suggestions were made. The following crops/types of crops were considered important within the context of climate change:

- Mixtures of species and/or varieties: forage mixtures, new mixtures etc.
- Protein crops: grain legumes such as fava bean, peas, beans, soy (does not work now, but maybe in the future), also quinoa was mentioned.
- Protein crops: forage grasses and legumes. Both important for fodder/forage production but there are also alternative uses to consider, such as cover crops and carbon sinks
- Intercropping, for example peas and barley
- Cover crops. Italian rye grass was discussed as one potential cover crop
- Varieties well adapted to organic agriculture
- Cereals, especially oats but also rye should be more investigated. They are good crops for the Nordic area.
- Potato
- Autumn crops also important to consider
- Forages. Timothy is an important forage grass for the Nordic region and more research should be conducted on this species
- Fruits
- Import and test varieties from regions south of the Nordic countries

6. Cooperation

Question: *What are the needs for cooperation between different fields of research? What would be an ideal consortium (name the research fields and institutions) to develop (e.g. biological sciences) and utilize (e.g. policy, economics, social sciences) climate-proven new varieties?*

There is a substantial need for research cooperation on many topics that could facilitate climate change adaptation and mitigation, for example genetics, genomics, plant protection, plant physiology and pre-breeding. The goal should be healthy food in adequate quantities for all people, which would also include healthy fodder production for farm animals.

It was suggested that a Nordic consortium/ Nordic centre of excellence should be established. The aim should be to facilitate research, pre-breeding and breeding with the end goal to produce new crop varieties. The Nordic added value in this project would be substantial.

- The consortium could include cooperation on topics such as phenotypic evaluation, genotypic evaluation and data analysis. Also fund raising could be part of the tasks of the consortium.
- Establish a Nordic "big data" platform by developing existing Nordic genomic and phenomic platforms (NordPlant etc.).
- Partners would include the private industry with all Nordic plant breeders, academia, NordForsk and NordGen.
- It would be beneficial to establish the consortium as a Centre of Excellence or a program under NordForsk.

- The current Nordic PPP program on pre-breeding might be integrated into this Nordic consortium.

- Funds for the consortium could in part be raised via a COST Action

- Funding could be motivated by referring to SDG (sustainable development goal) 13 ("Take urgent action to combat climate change and its impacts"), target 13.2 ("Integrate climate change measures into national policies, strategies and planning"), indicator 13.2.1

- Cooperation discussed included the health sector, food and feed sectors, blue and green sectors (land- and sea-based food and feed production)

7. Nordic added value

Question: *How can a joint initiative create Nordic added value?*

The Nordic region share the same crops and the same climate-photoperiod combination across the national borders, so from a biological/agricultural aspect it makes sense to cooperate. In addition, the Nordic region is a small market, making it more difficult to profit on crops developed for this particular region. The Nordic countries also have similar cultures and experience of cooperation, making it easier to cooperate successfully.

Some research/infrastructure topics that would benefit from Nordic cooperation:

- Jointly screen/evaluate genetic resources in different Nordic countries.

- Develop joint big data platform, including development of machine learning techniques

- Development of efficient experimental setups

- Phenotyping platform for diseases. Should include high-throughput phenotyping and analysis of phenotype data

- Common projects on modelling regarding for example genomic predictions and pest and diseases distribution/migration in response to climate change

- Pre-breeding for the Nordic area, building on the current PPP-cooperation

- Joint Nordic education on plant breeding and related topics. There is a need for well-educated plant breeders in the Nordic region, but the number of plant breeders in each Nordic country is small and good national education is today not available. Cooperation between industry and academia regarding PhD education would be beneficial.

8. Funding policy

Question: *Funding policy in the Nordic countries. How to get public and private funders committed to long-term funding? What are the best funding instruments (Nordic Centres of Excellence, projects, networks, summer schools)?*

Establishing Nordic funding policies (like for example the Swedish Livsmedelsstrategin and the Norwegian Matfondavtale) that involve both the public and private sectors and cover longer funding periods (6-10 years+) is crucial.

A Nordic Centre of Excellence, or a program under NordForsk, for one of the initiatives mentioned under items 6 and 7 could help to commit public and private funders to longer funding periods (6-10 years+) and possibly help raise more money from the national research councils.

The model of the PPP-cooperation was emphasized as a starting point for a future Center of Excellence for pre-breeding that work with ensuring the local food supply in the Nordic countries. A proposal for a Center of Excellence should also include utilization of genetic resources and research in root systems, hybrid systems and address the difficulty with getting Nordic students interested in plant breeding. Funding should not be spread across too many separate projects but rather focused on a few well-defined tasks.

9. Other suggestions

Question: *Other research suggestions and ideas.*

Other important research issues include:

- Variety mixtures and intercropping. Difficult both due to complexity of mixtures, policy issues and profitability.
- Plant physiology. The development of new varieties can be made more efficient by improving our understanding of plant physiology, for example plants response to pests and diseases and the links between physiology and genetic variation.
- Research om symbiosis and symbiotic organisms, endophytes, is needed. Many plants are dependent on endophytes and they perform central functions. One important example is Rhizobia, symbiotic nitrogen-fixing bacteria in legumes.
- How to involve farmers? Participatory approach. Some farmers are willing and enthusiastic working together.
- Insect resistance. Research to better understand adaptation of insects to insecticides and how to deal with new pest invasions.
- Vegetable proteins for food and feed. What are the needs and what are the possibilities? Do we need new protein sources?
- Plant breeding for organic agriculture
- IPM (Integrated Pest Management) approaches to reduce use of conventional pesticides, including plant breeding for IPM.

It was also noted that Nordic cooperation and funding is essential.

Appendix 3: Summary of talks

The effect of climate change on Nordic agriculture – today and in the future

Jørgen E. Olesen, Professor, Århus University

Projections for the future global average surface temperature towards the end of the century show an increase of 3 degrees in mean temperature, but the spatial trends show that temperature over land could increase in the order of 4-5 degrees and that we in the Nordic countries could experience increased total rainfall.

In an agricultural perspective the consequence of a temperature increase will cause spatial ecosystem shifts which leads to shifts in the suitability for crops, and soil moisture during summer will decline. Climate change will also enhance cereal cropping in the Nordic area, since warming extends the growing season in cool climates and enhance crop development rates. This leads to northward expansion of cereal cultivation. Yields such as wheat will decline in warmer parts of the world and this will affect global food production.

In the future we will experience more variability in weather extremes like heat waves, frost, droughts, long and lasting rainfalls, storms, pest and diseases. Inter-annual variability will increase due to shifts in the Jetstream, which is generated by the temperature difference between the Arctic and the mid-area of the continent. Since the temperature in the Arctic has increased more than at mid-latitudes, the effect of the changes in the Jetstream will become more intense in the future.

Climate changes in agriculture will provide opportunities for new production systems and grasslands could benefit. But a higher focus on adaptation to climate changes and genetic diversity is needed to explore these opportunities and we need more knowledge about soils, plant- and animal diseases and management of genetic resources.

The effect on agriculture of the extreme weather 2017 and 2018

Kjell Ivarsson, Senior Policy Advisor, Federation of Swedish Farmers, LRF

Nordic agriculture will become even more important in the future. We have plenty of land and water, a favorable climate and good infrastructure.

But the summers of 2017 and 2018 came with challenges. The wet autumn of 2017 showed the importance of drainage and the dry summer of 2018 meant that the harvest of cereals and oil seeds was around 50 % of normal in Sweden and the bean yield was even worse. Forage import had an extreme variation in quality which raised concerns of new weeds and animal diseases.

Nordic agriculture expects to experience a higher demand of different kinds of crop in the future such as beans, peas and quinoa, and in order to be able to meet these demands we must invest more in plant breeding research to increase the plant variety and the value of products.>>

Research needed to meet climate change challenges – from the perspective of a Nordic breeding company

Muath Alsheikh, Head of Research and Development, Graminor

Plant breeding plays a major role in securing future food and feed production to meet future challenges of predicted climate changes and global population increase.

However, plant breeding operation is time consuming and laborious; and it takes at least 10-15 years, so we need to face these challenges and act fast.

To develop new crop varieties to meet challenges in crop production and ensure breeding for robust varieties, we need to intensify plant and breeding research. It is also important to better integrate industrial and basic research. Future research should focus on multiple issues such as environments and diseases, secure enough variation within plant material, identify important traits that will be valuable for future climate challenges (e.g. pre-harvest sprouting, root mass) and where to find them, new rotation crops, and implementation of high throughput breeding technologies.

There is a need to develop performance prediction models to combine all the data and we need competencies to understand these big data models and utilize them in variety development.

The PPP-cooperation is very important and highly valuable, and a future focus area could be a Nordic platform for big data to predict performance of different crops.

What are breeding companies doing today to adapt their crops to climate change? What is the timeline?

Merja Veteläinen, Director Plant Breeding, Boreal

Climate change adaption in plant production requires various measures. These include development of new climate resilient varieties with different growing time demand. In addition, breeding of new species for crop diversification belongs to plant breeding actions.

However, also precision farming and conservation agriculture are needed along the tools that plant breeding can provide.

In the Nordic area there are number of challenges that plant breeders have to address in the face of climate change such as seasonal changes in temperature and moisture conditions, extreme weather conditions, variation in over-wintering conditions as well as new pests and diseases.

To meet these challenges breeding goals need to include traits like straw stiffness, robust plant architecture, and resistance to pests and diseases. In the future, root traits variation should be studied in order to improve e.g. nutrient use efficiency and water economy of the crop plants.

There are number of other research areas that should be emphasized in order to develop new varieties that can cope with extreme weather conditions.

The PPP-cooperation is very important and highly valuable and a future project could also include sub-regional projects with focus specific needs and crops in these regions.

What needs does the market for plant varieties have in the Nordic countries?

Ahmed Jahoor, Head of Breeding and Research, Nordic Seed

The current global trend, with just a few large multinational companies, is resulting in a concentration of plant breeding to a few crop varieties developed for large markets. This poses a challenge for the development of crops well adapted to the unique climate of Nordic countries. Nordic collaboration is very important to develop varieties for Nordic market.

Market needs for the new plant varieties for Nordic countries are:

- High yield and yield stability
- Fulfillment of requirement for earliness for different part of Nordic countries
- Resistance to existing disease as well as emerging diseases and pests
- Tolerance to high temperature (heat tolerance)
- Tolerance to drought; in particular early drought
- Tolerance to water lodging
- Improved quality for different use

Collaboration in the frame of PPP is important and needed. Also needed is capacity building for applied genetics and plant breeding. The lack of well-trained plant breeders means that breeding companies should collaborate with public institutes (Universities and research centers) to insure the presence of the needed competencies. This could be done through a joint educational program for new breeders between universities and plant breeding companies among Nordic countries.

Broadening of the gene pool to meet climate change in forages

Odd Arne Rognli, Head of Department, Norwegian University of Life Sciences

There is a need for more research on the new challenges in growing and producing forages due to climate changes; such as heat stress and drought. Climate change may lead to an introduction of new forage crop species currently not adapted to the Nordic region.

The main aim of the ongoing PPP-project Perennial Ryegrass is to improve the adaptation of perennial ryegrass in the Nordic-Baltic region so this valuable forage grass can be utilized further north. The major challenges are inferior winter survival due snow mould attack, and non-adapted seasonal growth rhythm, especially growth cessation in the autumn.

In the project, nearly 400 gene bank accessions of perennial ryegrass are being investigated to identify and select new plant materials for the development of future cultivars. Finding gene bank accessions that per se are better (yield and winter survival) than the elite breeding materials of the breeding companies is unlikely, and this has been confirmed in the project.

Therefore, a key element of the project is to generate broad breeding populations by recombining all exotic materials with existing germplasm to create new genetic resources for the breeders. A number of trait-specific and local synthetic populations has been generated by the partners. These populations are being genotyped using genotyping-by-sequencing, which makes it possible to establish genome-wide associations for important traits. This can be used to implement genomic selection schemes by the breeding companies. The results have also shown that >>

there is lack of crown rust resistance among the gene bank accessions. The most promising germplasm seems to be originating in the Baltic region, emphasizing the importance of a Nordic-Baltic collaboration on genetic resources.

Importance of plant genetic resources for climate change adaptation of crops

Annette Olesen, Plant Breeding Director, Lantmännen

Plant breeding has unique possibilities of delivering robust varieties with stable yield and quality, crops that benefit from climate changes and varieties for sustainable agriculture in a changed climate.

Access to genetic resources is a prerequisite for progress, and breeding companies will benefit from integrating gene banks in research projects. More research is needed to identify important traits in relation to climate change, and efforts shall be made to handle the genetic variability in gene banks as well as further improving tools to extract relevant genetic information from the gene pools.

Plant breeding takes time, especially the introduction of traits from unadapted gene banks material, and to allow a fast introduction of new traits for a changed climate, further developments of breeding tools is needed.

It was proposed to establish a Nordic platform that could integrate big data, artificial intelligence and prediction models to support the development of precision designed varieties.

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