CROP INNOVATION DENMARK
- from genes to seeds

Increasing efficiency – reducing footprints

In the field, the stable, the industry and the final product

The challenge

Climate change is the biggest challenge facing the current and future generations and therefore we have an obligation to take action. The Danish agricultural sector has a vision of becoming carbon neutral by 2050, and the EU Green Deal and Farm to Fork strategy are pushing the sector towards a more sustainable production. These are visions and goals we must strive to achieve across the entire value chain – starting at the basis of our value chain – the genetics of our plant production.

When plants grow, they sequestrate CO_2 from the atmosphere to produce organic matter, but plant production also contributes to greenhouse gas (GHG) emissions – both directly and indirectly with N_2O, CH_4 and CO_2. The growing world population is requiring more food and higher quality products, and meanwhile we are witnessing the climatic and environmental degradation and biodiversity losses on our planet.

This more than ever demands that the solutions, we choose, have a holistic approach and take the entire value chain into consideration. The agricultural land needs to be used more effectively by maximizing yield per area while reducing the need for highly energy consuming inputs. This will reduce the CO_2-eq footprint pr kg. biomass or final product produced. We must ensure a stable, increased, and robust plant production in an otherwise increasingly unstable climate. The solutions should integrate how it effects the value chain further down also in the industrial processing steps.

Plant breeding presents several solutions to the challenges above. More research is needed, and the approval and implementation of new genomic techniques (NGTs) can speed up the development and solve current bottlenecks in the process of breeding for new varieties.

Breeding for adaptation and mitigation

In the past decades much work has been put into *adapting* our crops to perform well under the expected climate changes. However, our crops also have the genetic potential to contribute to *mit-igate* the effects of climate change.

Genetic improvements in the crops can give beneficial climate and environmental effects as well as elevate the creation of value both directly in plant production and in the subsequent stages of global food production.

Since the millennium a yield increase of 1.16 % per year in the EU can be ascribed to plant breeding-induced innovations[1]. To keep up with the food and feed demand – while at the same time reducing the footprint from plant production – we must increase the contribution from the plant breeding sector to achieve the needed global yield increase.

Future plant breeding efforts will contribute by making our crops both more robust and well adapted to the current and future conditions but also by increasing the yields and performances even more.

Plant breeding presents solutions at the beginning of the feed and food chain

Genetic improvements in crops hold great potential to create more sustainable cropping systems. The genetic foundation of our crops is essential as it defines the potential performance of the crops, and strong genetic potential will shine through no matter the environment and agricultural practices.

The following goals and underlying research areas are where CID sees the greatest potential from breeding to tackle climate change both in the short term and the long term. We acknowledge that to make plant production sustainable in the long run, plant breeding is a key tool that must be incorporated.

THE TARGET – increase the efficiency

The Danish plant breeding sector will contribute to bring Danish agriculture and food production into the carbon neutral era before 2050. A more efficient production and higher food security will contribute to reducing the CO_2 footprint per area and increasing the CO_2 capture. Breeding efforts will focus on the most valuable traits and targets that can make a significant step forward towards climate neutrality and sustainability. They are comprised within three main areas:

1. Increasing yields

By 2035 the sector will have doubled the contribution from plant breeding induced innovation to the annual yield increase which will lead to a reduced CO_2-eq footprint pr kg output.

- This contributes to achieving the current potential and enhancing the future potential of our crops.
- Breeding will improve the resource use efficiency of water, CO_2, and fertilizers to produce more with less inputs.

2. Improving resistance and robustness

- In 2035 plant breeding induced innovation will secure 10 % higher yield during periods of drought. This will be achieved through breeding for deeper and more efficient roots among other traits that help preserve scarce water resources.
- Genetic improvements in crops will lead to stronger performance and yield security, and crops with enhanced resistance against new emerging pests and diseases. This strengthens our crops and contributes to reduce the need for chemical pesticides.

[1] Noleppa, S. & M. Cartsburg (2021): The socio-economic and environmental values of plant breeding in the EU and selected EU member states. *HFFA Research Paper.*

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3. Increasing quality

- Content and quality of protein will be increased to enlarge regional self-sufficiency.
- Content and quality of sugar and starch will be improved to increase efficiency in the subsequent industrial processes.
- Breeding will focus on optimizing and improving crop quality to achieve (i) better nutritional value for humans and animals, (ii) improved digestibility of feed for ruminant animals to reduce methane emissions and (iii) crops more suitable for industrial utilization.

Plant breeding in Denmark

Plant breeding in Denmark is characterized by strong innovative companies that present world leading research and results. The academic research environments are of the highest standards and are strengthened by a close collaboration with and between universities, industry, and agricultural advisory services. They ensure relevant and applicable research at a high international level.

Prioritized research areas

Yield

To meet the growing demand for food and feed, innovation throughout the whole value chain is necessary. Yield, understood as both biomass and the content of starch, sugar, oil and protein, must be increased in a sustainable way to relieve the pressure on marginal lands and leave more space for biodiversity and protecting the remaining carbon sinks from land-use changes.

Breeding holds the potential to increase the efficiency of the photosynthesis by increasing CO_2 uptake and minimizing respiration. High yielding intensive cropping systems require large amounts of fertilizer – especially artificial nitrogen fertilizer is responsible for large GHG-emissions. Also, the subsequent formation of the very potent greenhouse gas nitrous oxide, NO_2, is harming the climate. In addition, input of nitrogen to our fields comes with a risk of leaching. Breeding for higher resource use efficiency, of especially nitrogen but also phosphorus, can reduce the need for fertilizer and lower the environmental footprint of production. In addition, exploration and utilization of biological nitrification inhibitors (BNI) is another genetic tool to directly reduce N-losses from the field.

Therefore, plant breeding research should focus on:

- Increasing yields to lower the climate footprint per kg biomass or final product produced.
- Exploring the genetic diversity from plant genetic resources.
- Increasing the efficiency of photosynthesis to enhance yield.
- Increasing nutrient, especially nitrogen, and water use efficiency by breeding for better and more efficient varieties.
- Discovery and utilization of microbial interactions with plant genes that have the potential to increase nutrient mobilization and uptake.

- Screening new and existing varieties for abilities as biological nitrification inhibitors.

Robustness and resilience

Pests, diseases, and abiotic stresses such as extreme weather cause great losses in plant production every year. In Europe 23 % of all food loss and waste happens at the production level[2]. In addition, a stressed crop makes less photosynthesis and thus has a lower CO_2 uptake. Robust crops are therefore key to achieve high yields. The climate changes are expected to cause more extreme weather leading to both drought and flooding and a higher risk of lodging incidents due to heavy rainfall. Today it is still possible to uphold yield by suppressing pest and diseases with pesticides and growth regulators. But these options are reduced year by year and at the same time disease resistance in several crops are broken down. Plant breeding is therefore necessary to develop new varieties with improved disease resistance and stress tolerance that will last even during suboptimal conditions.

Therefore, plant breeding research should focus on:

- Increasing the resistance towards important pests and diseases.
- Improving the physical robustness of crops so that they are less prone to lodging.
- Increasing the crop's tolerance to extreme weather events such as drought or waterlogging.

Case: Powdery mildew-resistance (MLO)

Powdery mildew is a common fungus in barley and wheat that usually causes around 10 % in yield losses but may go as high as 25 % in losses. The discovery of the MLO-resistance gene in barley is an example where plant breeding innovation has ensured a yield increase and reduced the use of pesticides. Experts estimate that the MLO-resistance in barley has led to a 25 % reduction in pesticide use for barley production.

It is estimated that the development time of resistant wheat varieties can be reduced to 2-3 years in modern varieties by using NGTs (new genomic techniques), after which it is ready for variety registration. This is a reduction of more than 6 years.

Case: Increasing water uptake efficiency in potatoes

Potatoes are propagated from seed potatoes and not true seeds. Therefore, secondary lateral roots emerge in contrast to primary horizontal roots. Consequently, potato root systems are relatively shallow, and potatoes are drought sensitive and vulnerable to N-loss and subsequent N_2O emission.

However, unexploited genetic variation in root systems size and, not the least, depth exist that should be used to develop varieties with improved water and nutrient uptake as well as, decreased N_2O emission from potato fields.

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[2] World Resources Institute (2019): Creating a sustainable food future. A meny of solutions to feed nearly 10 billion people by 2050. *World Resources Report*.

CROP INNOVATION DENMARK
- from genes to seeds

Quality

While the world's demand for food is increasing so are the demand for higher quality food products, as people's standards of living are increased. Yield and quality are two factors, which are inseparably linked, so while increasing the yields there must be a strong focus on nutritional value, as to protein and digestibility, and quality parameters in the subsequent industrial processes.

Case: Energy saving malting barley varieties

Breeding of new barley varieties with innovative traits (Null-lox, DMS) will optimize the industrial malting and brewing processes leading to a 5 % energy savings, while at the same time the enzyme content has been improved.

(Personal communication Carlsberg)

Protein is an especially important quality parameter. Today 68 % of feed protein is produced in Denmark while the remaining 32 % is imported from EU or third counties[3]. Increasing the share of regionally produced protein has the potential to reduce the GHG-emissions from production in less intensive and less sustainable countries significantly. Optimizing feed digestibility must be a priority as increasing digestibility of feed can reduce the methane emissions from ruminant animals.

Therefore, plant breeding research should focus on:

- Increasing the quality of plant products to lower the climate footprint per calorie produced.
- Developing crops more suitable for industrial utilization ensuring a lower carbon footprint from the subsequent processing.
- Increasing the amount of Danish produced protein by breeding for higher protein content in cereals and grasses and breeding to adapt new protein crops, such as fava beans, lupins, and peas, to future Danish climatic conditions.
- Improving the digestibility of feed and protein for ruminant animals to lower methane emissions from feed digestion.

Case: Reducing methane emissions

Increasing fiber digestibility in forage grasses with 5% results in one extra liter milk per day per cow and a reduction of CH_4 emissions by 7-8%.

(Personal communication DLF Seeds & Science)

Case: Faba bean

Currently, the full potential of faba beans is not realised in Denmark due to the crop's high sensitivity to drought stress.

Plant breeding can contribute to develop more drought tolerant varieties. In addition, breeding can increase the protein content and quality of faba beans. All together this contributes to increasing the security and profitability of fava bean production in Denmark.

[3] DAKOFO estimate

Case: Improving feed digestibility with varieties low in enzyme inhibitors

Livestock feed is supplemented with enzymes such as xylanase, protease and phytase to increase the nutritional value. However, the crops used for feed has a natural content of enzyme inhibitors which may reduce the effect of these feed enzymes.

Studies have shown that the content of such inhibitors varies among wheat varieties. This enables breeders to select for varieties low in inhibitor levels, which will increase the digestibility and nutritional value of the feed, again leading to increased growth rates and an overall lower carbon footprint of production. In a feed experiment with broilers a 7 % difference in weight was observed between treatments high and low in inhibitor levels, respectively.

Besides natural variation, a deregulation of NGT would aid in speeding up the process of producing varieties low in inhibitor levels, and in cases where natural variation is not at hand, NGT will be an invaluable tool for the induction of new genetic variants less inhibitory to the feed enzymes.

[4]

Accelerating the breeding progress

Today it takes 10 years to develop a new variety. This time frame makes it very difficult to stay ahead of the fast-evolving challenges. The generation time of most plant species represent a major bottleneck for crop improvement. New genomic techniques (NGTs) must therefore be used and allowed to realize present and future breeding goals.

In this regard plant breeding research should focus on:

- Accelerating the development and breeding progress by combining speed breeding with other state-of-the-art technologies, such as genomic selection 2.0, CRISPR/CAS, cisgenesis and artificial Intelligence (AI).
- Using mutation populations and existing genetic diversity in e.g., gene banks as a source of biodiversity.
- Exploring the potentials within big data from "DK plant production as large test field".
- Developing simulation tools for optimizing breeding programs.

[4] Madsen, C. K., Pettersson, D., Hjortshøj, R., Katholm, A. & H. Brinch-Pedersen (2018): Superior growth bates in broilers fed wheat with low in vitro feed-xylanase inhibition. *J. Agric. Food Chem.* Vol 66, pp 4044-4050.