# Bedre Afgrøder til Fremtidens Jordbrug (”Better crops for future agriculture”)

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An analysis of the potential for breeding better plant varieties

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## English summary

Roughly 60 % of Denmark’s surface area is used for agricultural purposes, which generate a large production of plant products, mainly grain and grass, that are the foundation of a large production of meat and dairy products and an agro industrial export worth more than 120 billion DKK/ year (approx. 16 billion €). Furthermore, wheat, barley, potatoes, oat and rape are produced for human consumption, and sugar beets and potatoes for the industrial production of sugar and starch. Moreover, the agricultural industry contributes annually around 1.5 million tons of straw for energy purposes.

During the last 20 years, agricultural production in Denmark has been subjected to increasing limitations to the application of fertilizers and pesticides. At the same time an organic production has developed, which completely abstains from the use of these aids.

During the same period of time, global agriculture has seen large investments in development and marketing of genetically engineered crops, and there has been an increasing demand for meat based foods, raw material for bioenergy and plant based raw material for bio based industry.

Globally, we are looking at man-made climate changes which in large parts of the world are expected to complicate the production of food, despite the fact that global food production will have to increase by 70-100 % by 2050 in order to feed a larger world population. At the same time, the transition to a society independent of fossils demands the use of biomass for industrial nonfood products and for energy.

## Increased productivity through plant breeding

The environmentally conditioned limitations as well as the need for increased productivity underline that there is a need for better use of biological systems to increase production value with less input. This report addresses possibilities for increasing production value with less input and less environmental impact through the development of more robust, disease and insect resistant plant varieties.

Plant varieties are botanical units of crop plants which can be distinguished from each other and which do not change during propagation. The supply of plant varieties for agricultural production is done through a "seed chain" which ensures that when farmers invest in seed/plant propagation material, they get quality seeds of the right variety. Through pre-breeding, this seed chain combines plants with different genes (genetic resources) and new knowledge on heredity in order to make plants that can be developed into new varieties. In Denmark, the development of new varieties for the market is done by private breeding companies using cross-fertilization and selection. Subsequently, the variety is approved for marketing, and propagated seeds are certified for correct variety, health and quality. The financing of the private breeding of varieties is ensured through plant variety protection which enables the breeders to claim a license from the growers to the extent the variety is grown.

Despite a strong global concentration of breeding companies, Denmark still has competitive private breeding of some of the most important agricultural crops like barley, wheat, potatoes, grass and clover. In Denmark, these activities are primarily financed through breeding licenses or another form of income from the sale of seed. With respect to the conventional production, it is now well documented that plant breeding in our growing area has generated a constant yield increase over the last 50 years. With respect to cereals, this increase has been around 0.5 % a year, together with a corresponding annual yield increase due to improved growing methods.

During the last 15-20 years, Danish cereal breeders have adapted to the restrictions on the use of nitrogen and pesticides in Denmark by developing varieties of cereals that are easier to grow with less input compared to varieties developed in neighboring countries. The Danish private plant breeding has thus supported Danish agriculture in the transition to a more environmentally friendly production. Varieties that are distinct and stable and thus allow the farmer to know what he is buying and the breeder to have an income, have been an important driving force in the positive development between the breeding companies and the plant producers, which has progressed very far in Denmark, where more than 80 % of all the used seed and propagating material is certified. The high level of organization and trust in the seed chain in Denmark is a strong starting point for developing more robust and resistant varieties for conventional production with less input in the future and for the continued development of the organic production.

## Genetic resources

Genetic resources became a central, global topic when the Convention on Biological Diversity (the Rio Convention) was agreed upon in 1991. The convention gave every nation the responsibility for and the rights to their biological diversity. Most crops originally come from rather small geographical areas, from where they have been spread with agriculture during the last 10,000 years. During cultivation in different parts of the world, substantial genetic differences have been

generated in most crops, which today is the foundation for breeding progress. It is likely, however, that only a minor part of the total amount of genetic diversity within a species has been incorporated in the cultivated plants, while the rest of this diversity, for instance with respect to disease resistance, yield and quality, is still to be found in the crops' wild relatives in their original areas of origin.

Today, the practical conservation of the world's plant genetic resources takes place in a large number of primarily national gene banks, which conserve the material either through seeds or collections of live plants or through the protection of the wild species' habitat. The International Treaty of Plant Genetic Resources for Food and Agriculture (ITPGRFA) exists in order to ensure the exchange and continued use of the plants' diversity. Denmark is party to the treaty, which works to coordinate the entire system of gene banks and ensure a free exchange of plants through a standardized Material Transfer Agreement (sMTA).

Together with the other Nordic countries, Denmark runs the joint gene bank NordGen, where the grown material is conserved in seed stores and clone archives located in different places in the Nordic countries, with a security backup in the global seed vault in Svalbard. Besides its work on conservation, NordGen is gaining increasing importance as an institution that also works to exchange knowledge on the conserved accessions and supply samples for research, development and breeding through the international gene bank system.

**Variety breeding**

Plant varieties have generally become more uniform during the last century, which means that the plants within the varieties are more homogenous. This is necessary for finding the best varieties and checking the trueness to variety when they are traded. With respect to the crops in the field, more diversity can be achieved by growing variety mixtures, while it is not possible, within the current regulation, to market dynamic populations that are propagated mixtures. Although varieties have become more homogenous, it does not seem that genetic differences between different varieties have been reduced due to breeding. Today, research and education relating to plant variety breeding primarily takes place at Copenhagen, Aarhus and Aalborg Universities with focus on i.a. disease resistance, exploitation of nutritious matters, competition with weeds, genetic marker systems and genome research and associated education of candidates. In Denmark, there is not a plant breeding education as such. Research and education related to plant breeding are part of the topic Plant Science.

Pre-breeding is the term used for breeding activities that do not lead directly to varieties and therefore can not be financed through breeder's fees. Pre-breeding, for instance, may transfer new genes for resistance, yield or quality from foreign material to an adapted crop for subsequent development of varieties. Pre-breeding is often of great importance to agriculture, the environment and society because it brings new genes into the variety pool. However, pre-breeding is often a long way from generating new varieties, which is why it traditionally has been practiced by public research and development institutions. With the gradual inclusion of sectorial research in the university sector, pre-breeding activities in Denmark have been severely reduced. This can inhibit future progress in the private development of varieties, among other things because specific, national environmental rules apply to agricultural production in Denmark. Internationally, large

companies try to finance their long term breeding investments in e.g. genetic engineering by taking patent rights on the plants.

The global warming is expected to raise the average temperature with 1-1½ °C over the next 50 years, which will prolong the growing season and at the same time change the rainfall pattern. It is expected to lead to increased stress for the crops in the form of drought, heat and increased pressure from diseases and pests. These problems are best overcome by ensuring diverse breeding and variety material with great adaptability in the production.

In order for new plant varieties to be approved in Denmark and Europe, they have to be distinct from all other varieties as well as homogenous, and they are not allowed to change at propagation, which is checked in a DUS-test ("Distinct, Uniform, Stable"). Furthermore, agricultural varieties have to represent an improvement, and this is tested in the VCU-trials ("Value for Cultivation and Use"). The VCU-testing can be done for conventional or organic growing conditions or for both and its results are published so that they can be used when choosing varieties for the commercial production. If the variety is approved in the tests, it is added to a variety list and can be marketed. Increased diversity in the production can be obtained through the use of variety mixtures, which can also stabilize the yield.

Certified seed/plant propagating material is produced according to special rules and regulations in order to avoid mixing with other varieties or the presence of diseases. The certification of seed also includes tests to ensure that the seeds belong to the right variety, that they are free of diseases, and that they have a high germination capacity.

In Europe, the financing of the continued breeding of new varieties is based on plant variety protection. Varieties that are approved can achieve plant variety protection according to the UPOV Convention, which puts the variety owner in control of the propagation of the variety and allows the breeder to collect a breeding license from the growers of the variety. The protection, however, is only for the variety itself, which means that it can freely be used for further breeding, just as the use of farm saved seeds is generally allowed against payment of a license to the breeder. Varieties can furthermore contain genes that are patented. However, such plants cannot be marketed in Europe without undergoing the normal variety approval. In connection with the future development of the patent area, it should be ensured that the future European patent legislation will allow both the freedom to breed and the use of farm saved seeds in the case of plant varieties that contain patented genes.

Today, most breeding programs consist of crossings of existing varieties or adapted plant lines followed by an advanced procedure for cultivation and selection in order to find the rare offspring that is good enough to become the basis for new varieties. If the breeding program is to result in new good varieties, both parents in the cross must normally be adapted to the area of cultivation. Otherwise it constitutes pre-breeding that cannot be plant variety protected and financed by breeder's fees. Private breeders therefore often have limited financial opportunity to bring decisive new genes into the breeding pool.

Especially breeding for disease and pest resistance is efficient as a means of reducing the use of pesticides. However, most resistance genes stop working when they have been used in cultivation for a shorter or longer period of time, and this is why new resistance genes constantly have to be brought into the breeding programmes through pre-breeding from unadapted or wild material.

Particularly wild relatives of our cultivated species are rich sources of new resistance genes. Introgression of genes through pre-breeding also adds other important genes for yield, quality and robustness to the breeding programs, and this can ensure further improvement of the varieties.

The technology used to produce new and better varieties is still undergoing development. During the last 60 years, especially the development of chromosome-doubled haploids, fingerprinting technology (molecular markers) and genetic engineering have contributed to faster and more efficient breeding. Currently, especially the fingerprinting technology is being developed quickly to use a very large number of markers for genomic selection, which can be of great importance.

**Better economy through breeding**

An actual environmental assessment of the potential of breeding in relation to a greener type of agriculture will be very complicated and uncertain. Instead, the committee has taken a starting point in the expenses that agriculture pays for the most important input factors affecting the environment in the most important plant species (cereals, potatoes and grass field plants), which still have ongoing Danish plant breeding activities. On a national basis, fertilizers for cereals, potatoes and grass cost around 4 billion DKK a year (approx. 533 million €) (including expenses for manure), disease control costs around 600 million DKK (approx. 80 million €) and weed control costs around 550 million DKK a year (approx. 73 million €).

In comparison, the total breeding of new varieties in Denmark costs in the area of 120 million DKK a year (approx. 16 million €). It is obvious that where possible, substitution of parts of the input expenses above with the breeding of varieties that better utilize nutrients or need less weed or disease control while having the same or higher production value, can benefit both the economy of agriculture and society as well as the environment. At the same time, such an effort, at first driven by conventional agriculture, will also be of great importance to the organic production, if the breeding methods used are acceptable to organic farmers. Furthermore, it is important that Danish knowledge environments prioritize research in the breeding of crops that are of importance to Danish agriculture and Danish breeders.

**Fields of action**

When going through the most important crop plants in Danish breeding (cereals, potatoes and forage plants) to see if there is any potential for breeding to improve utilization of nutrients and have better disease resistance or competition against weed, it is evident that breeding for disease and insect resistance is the area where improved efforts have the best chance of success in the short run.

Therefore, it is proposed that a large national initiative is established to reduce the use of fungicides and insecticides in agriculture through pre-breeding in order to bring a large number of new resistance genes into the breeding material, so that they can be quickly used in production through the private development of varieties.

Breeding for better utilization of nutrients has a big financial potential, but knowledge of how this characteristic is transmitted is still fragmentary, and the area should therefore be further developed

through an intensified basic research effort. Breeding varieties that enable better weed control is likewise a complex problem, where genetic diversity in the plants must be combined with new initiatives with respect to cultivation. These opportunities should be explored further through programs where plant breeding researchers work together with agricultural researchers, for instance with in the knowledge that has been generated in previous organic research programs.

**The organic development**

Organic agriculture constitutes 7 % of the total agriculture in Denmark, and the political goal is to double this share. Currently, Denmark imports large amounts of organic cereals and protein products that possibly could be produced by Danish, organic farmers. At the same time, the organic production is facing a challenge with respect to reducing the dependence on input from the conventional production systems, and Danish organic goods have difficulty competing with imported goods on prize.

The organic production of plants is done within the frames set by the EC Regulations on organic agriculture. The EC Regulations on organic agriculture determines which breeding and growing methods that can be accepted in organic production. Previous research programs with the purpose of supporting the development of organic agriculture have been performed within the frames of the"Danish Research Centre for Organic Food and Farming" in Danish FØJO and have included FØJO I (1996-2000), FØJO II (2000-2005) and FØJO III (2006-2012) and the current program Organic RDD.

None of these programs have had specific elements directed at the breeding of plants, although important knowledge on e.g. production of seed and propagation material as well as disease resistance of varieties has been generated. On this basis, an acceptable production of organic seed grain for the major grain crops, grass and clover has now been established, while most minor crops still use conventional, chemically untreated seed/plant propagation material for production. Only in very few areas, has financing of the breeding of plants specifically for organic agriculture been successful.

**Varieties for organic agriculture**

Plant varieties that are used in organic farming today have, for the most part, been bred for the conventional production system, while the last propagation of seed grain is carried out organically if possible. Generally, there is no problem with the methods that are used for breeding of plants for conventional agriculture in relation to the rules for organic agriculture, as long as genetic modification (GMO) is not used in the breeding program. The most important plant species that are bred for conventional agriculture, spring barley, winter wheat, grass, clover and potatoes are also used to a large extent in the organic production, although their relative significance may be different in the two systems.

At the same time, tests have clearly shown that many of the genes that cause increased yield in the conventional production system also increase yield under organic conditions, although their effect may be smaller due to differences with respect to nutrient supply and, among other things, competition from weeds. Besides a high yield, organic and conventional farmers want many of the

same characteristics in their plants, although the relative significance of these characteristics may be quite different in the two production systems. Therefore, it is obvious that organic agriculture benefits from the extensive plant breeding for conventional agriculture, although not all varieties fulfill the needs of the organic farmers.

Over the last years, a number of plant characteristics have gained increasing importance for both the conventional and the organic production. These characteristics are resistance to some of the seed borne diseases that complicate organic seed production, better baking quality in wheat, and increased ability to absorb nutrients from the soil, both in the early and late stages of the growth process, combined with competitiveness against weed. For crops included in a good conventional breeding programme, a subsidy scheme is proposed to finance a targeted testing of new and existing plant varieties for their suitability for cultivation under organic conditions.

A subsidy scheme will, in a short time, be able to identify more varieties that are suited for organic production and will stimulate the organic seed grain market so that the established breeding system starts to produce varieties that are even more suitable for the organic segment. In this connection it is important that public research and development cooperate with plant breeding companies to support this development with efforts aimed at increasing the genetic abilities of cultivars to compete against weed, to absorb and utilize nutrients better to resist diseases and to gain better quality characteristics.

To organic agriculture and to a certain extent also to the conventional production, a local production of plant protein for food and human nourishment is important for reducing the dependence of imported soya. The best protein comes from soya, however, soya is relatively poorly adapted to the Danish climate and currently generates a yield which is too small. Therefore, in order to reduce the dependence on imported soya, focus should be on peas, broad beans and lupines even though protein from these species cannot completely replace protein from soya.

In order to stimulate this development, a public support system is proposed for extended testing of more varieties of peas, broad beans and lupines to determine their ability to grow under Danish organic conditions. Furthermore, with respect to the species in question, the State should prioritize basic and applied research with the aim of gaining increased insight into their resistance to diseases, greenflies, their amount of growth inhibitors, their ability to compete with weed and their protein quality both for animal feed and human nourishment.