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An abstract in English or Swedish not exceeding 160 words is required together with 4 to 6 keywords.

Contributions should not exceed 16 A4-pages with double spacing including figures and tables. Manuscripts exceeding this recommended number of pages must obtain a preapproval from the Editor. Illustrations shall be submitted separately: EPS, TIFF or JPEG formats. Authors are requested to submit a recent photograph (TIFF or JPEG-format) in addition to the manuscript.

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Roland von Bothmer, Agnese Kolodinska Brantestam & Morten Rasmussen

Växtförädling blir alltmer uppmärksammad i ett globalt men även i ett regionalt perspektiv. Klimatförändringar gör sig märkbara med ändrade odlingsbetingelser och andra förutsättningar för t ex patogentryck och stresstolerans på olika platser i världen. Matsäkerhet för en växande världsbefolkning och ökade miljökonsekvenser av människans verksamhet sätter också ett ökande tryck på den globala jordbruksproduktionen. I takt med att dessa ändrade betingelser får genomslag får de genetiska resurserna och deras användning inom växtförädlingen en allt större betydelse.

Fokus på regionalt producerad mat, kvalitetsmedvetenhet hos konsumenterna och en önskan från statsmakterna att öka den ekologiska produktionen är andra parametrar, som inverkar på sortvalet. En intensifiering av förädlingsinsatserna och ett mer optimalt utnyttjande av de genetiska resurserna som bevarats i våra genbanker är en nödvändighet för att klara av den framtida efterfrågan på nya och bättre anpassade sorter med hög kvalitet. Dessa nya förutsättningar för jordbruket ställer också nya krav på forskning, utveckling och praktisk förädling. För att arbeta med dessa långsiktiga frågor måste ett nytt tidsperspektiv få genomslag. En "normal" förädlingsinsats för att framställa en nya sort från den första korsningen tar normalt ca 10 år – om man arbetar med närbesläktat och välanpassat material. Skall man använda mer "exotiska" genkällor av icke anpassat material, men med intressanta egenskaper, som man vill inkorporera är processen mycket längre, ett 20-tal år. Det är inte möjligt för ett enskilt mindre, privat eller publikt, företag eller institut att ha detta långa perspektiv av praktiska eller främst ekonomiska skäl. Då blir enda möjligheten att inleda ett samarbete över företags- och institutionsgränser på ett sådant initialt stadium där konkurrensen på marknaden är av liten betydelse. Samhället har här också en viktig roll att spela – man eftersträvar en mer hållbar jordbruksproduktion och en ökad användning av genetiska resurser som leder till bättre resistensegenskaper hos grödorna eller bättre stresstolerans. Det är då rimligt att också samhället engagerar sig i gemensamma projekt och även skjuter till medel för denna långsiktiga pre-breeding. Därför har ett sådant brett gemensamt samarbete etablerats, ett Public-Private-Partnership (PPP), på nordisk basis där de 7 nordiska växtförädlingsföretagen ingår och med engagemang från de fem nordiska länderna. En gemensam finansiering har anslagits som kanaliseras via Nordiska Ministerrådet (NMR). NordGen (Nordiskt Genresurscentrum) har utsetts som koordinator. Även de baltiska länderna erbjuds att deltaga.

Planerna om PPP-projektet har rapporterades tidigare i Sveriges Utsädesförenings Tidskrift (SUT; 2010:1-2). Två projekt har etablerats: ett som rör sjukdomsresistens i korn, ett angående pre-breeding i rajgräs, *Lolium perenne*.

För att det stora PPP-programmet skulle få en god start anordnades en workshop i Finland 17-18 februari 2011, organiserat av NordGen, och med finansiering från bl a NorFa. Ett 40-tal personer deltog, representerande växtförädlingsföretag och publika förädlingsenheter, universitetsinstitutioner och andra internationella och nationella organisationer. Även om fokus i workshopen var på nordiska förhållanden presenterades och diskuterades såväl globala som andra regionala problemställningar, framför allt från de baltiska länderna, Resultatet av workshopen, föredrag och diskussioner, presenteras i detta nummer av SUT.

En uppföljning av workshopen i Finland kommer att genomföras i slutet av maj 2012 i Stende, Lettland. Förädlingsinstitutet här firar sitt 50 årsjubileum med en konferens och seminarier där det nordiska pre-breeding-programmet ingår. Ett utökat samarbete med de baltiska länderna kommer att diskuteras.

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Plant breeding
is a long term process

Roland von Bothmer, Agnese Kolodinska Brantestam & Morten Rasmussen

Plant breeding gets an increasing attention in a global but also in a regional perspective. Climate changes start to get an effect and gradually leading to changed cultivation practices and changes in, for example, pathogen patterns and abiotic patterns, with drought and flooding in different places in the world. Food security for an increasing human population and increased environmental consequences of human activity also put an increasing pressure on global agricultural production. Utilization of genetic resources, pre-breeding and breeding with conventional or newer technologies will get an increasing importance.

A joint Public-Private-Partnership (PPP) in the Nordic countries have been established where all the 7 plant breeding companies are partners together with the 5 Nordic countries. A joint funding for the programme has been allocated through the Nordic Council of Ministers (NMR). Nordic Genetic Resources Centre (NordGen) has been assigned as the coordinator. Also the Baltic states are invited to take part. The PPP has been presented in an earlier issue of the Journal of the Swedish Seed Association (SUT 2010: 1-2). Three projects have been established, one concerning disease resistance in barley, one in *Lolium* and one in apple.

A workshop was organized in Finland 17-18 February 2011 to inaugurate the start of the PPP. NordGen organized the meeting, which was also sponsored by NorFa. Around 40 persons attended the meeting with representatives from international organizations, private and public plant breeding companies and institutes and other organizations. Even though the focus in the workshop was on Nordic conditions more global and other regional issues were also discussed, particularly for the Baltic area. The outcome of the Finnish prebreeding meeting is presented in this issue of SUT.

A follow up on the Finnish workshop will take place in the end of May 2012 in Stende, Latvia. The Stende Breeding Institute will celebrate its 90th anniversary with a breeding conference where lectures and discussions on the Nordic PPP-programme will be included as well as possibilities and expanded collaboration between the Nordic and the Baltic states.

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Aktuellt från Utsädesföreningen

News from the Seed Association

Anders Nilsson

Den 10 november 2011 arrangerade SUF tillsammans med KSLA ett seminarium som handlade om frågor kring sortprovning. Detta seminarium kan ses som en uppföljning av tre andra aktiviteter som berört växtförädlingskedjan tidigare under året: rundabordssamtalet om ett svenskt perspektiv på NordGens framtid den 10 april, två miniseminarier om sortprovning på Borgeby fältdagar den 29-30 juni och inlägg vid sommarmötet den 1 juli som handlade om bl. a. växtförädling och sortprovning i potatis.

Seminariet om sortprovning den 10 november hade samlat ett 40-tal deltagare. Flera av inläggen kommer att publiceras i kommande nummer av Utsädesföreningens Tidskrift. Presentationer och diskussion utmynnade i följande slutsatser:

- Sortprovningen av stora grödor som stråsäd, foderväxter och oljeväxter behöver fortsatt vara tillräckligt omfattande och utvecklad för att sortera bort de sorter som vi inte vill att de ska komma i odling. Ämneskommittén Sorter, knuten till FältForsk vid SLU, kommer att intensifiera sin diskussion om utformningen av sortförsöken samt resultatens bearbetning och presentation baserat på dagens diskussion.
- Vi behöver en fungerande sortprovning av potatis vilket saknas idag.
- För kommersiellt mer betydande specialgrödor, t. ex. morot, lök, sallat, jordgubbe och äpple, skulle en återupptagen sortprovning vara värdefull, inte minst för rådgivning och medelstora odlare. Ett nordiskt samarbete i provningen av sådana grödor kan vara en nyckel till att få detta på plats.

Föreningen har därefter nåtts av information om att jordbruksverket har en utredning på gång om hur verket framöver ska engagera sig i sortprovningen. Det visar på att de arrangemang som SUF svarar för och de initiativ som tas vid dessa tillfällen också medverkar till att olika frågor förs framåt. Vi hoppas att föreningens medlemmar ska se detta som ytterligare ett argument för fortsatt medlemskap i SUF och ett aktivt deltagande i de olika arrangemangen. SUF har också svarat på en remiss från jordbruksverket om införande av en nationell sortlista för frukt och bär. SUF pekade på behovet av att jordbruksverket ser så pragmatiskt och praktiskt som möjligt på frågan om registrering av sorter av frukt och bär. Alla möjligheter till undantag från krav på registrering måste tas. I den mån som registrering trots det kan bli aktuell bör kostnaderna för detta täckas med offentliga medel.

KSLA kommer att arrangera ett seminarium med rubriken ”Husdjurens och nyttoväxternas mångfald” den 20 april. SUF har aktivt deltagit i utformningen av programmet och kommer att medverka genom inlägg från flera medlemmar, men står den här gången inte som medarrangör. Seminariet är öppet och medlemmar i SUF är självklart välkomna att delta. Uppgifter om programmet och hur man anmäler sig finns på KSLAs hemsida. SUF planerar att följa upp diskussionen vid seminariet den 20 april med att särskilt beröra utvecklingen av växtförädlingsprogrammen vid LTJ fakulteten, SLU vid årets sommarmöte. Detta kommer att äga rum den 29 juni och kallelse kommer att skickas senare.

Den 30 augusti kommer KSLA att arrangera ett större seminarium om genteknik tillsammans med SUF i Stockholm. Syftet är att vända på perspektiven beträffande vår syn på genteknik och uthålliga produktionssystem för jordbruket. Den fråga som seminariet kommer att cirkla kring är att det kanske är det ekologiska jordbruket som skulle ha mest att vinna på att utnyttja gentekniskt framtagna nya sorter. Någon form av uppföljning planeras ske under hösten.

Med detta nummer distribueras också ett inbetalningskort för årets avgifter. Medlemsavgiften för årsbetalande medlemmar är oförändrat 100 kr och avgiften för SUFs Tidskrift oförändrat 200 kr. Det är viktigt att ni anger på inbetalningskortet vem som betalningen avser. I fjol fick vi flera inbetalningar som saknade avsändare, men vi lyckades trots detta dechiffrera alla avsändare förutom tre stycken. Vi har alltså tre betalande medlemmar som vi inte kunnat identifiera och det är så klart mycket otillfredsställande. Inbetalningskort kommer nu också att skickas till tidigare medlemmar och medlemmar som valt att inte teckna sig för distribution av tidskriften. Vi hoppas att den vägen kunna återuppliva några medlemskap och också att de tre som betalat utan att ge sig till känna ska kunna identifieras. Jag vill också passa på att i förväg tacka för de eventuella frivilliga bidrag som kan komma att lämnas till SUF från i första hand ständiga medlemmar!

Summary

SUF has arranged several seminars and other meetings during the last year:

- April 10th, 2011 together with Royal Swedish Academy of Forestry and Agriculture (KSLA) on a Swedish perspective on the future of NordGen
- June 29-30th, 2011 two miniseminars on variety testing at Borgeby Field Show
- July 1st, 2011 the summer meeting of SUF
- November 10th, 2011 together with KSLA on variety testing

And the following activities with engagement from SUF are planned for 2012:

- April 20th, 2012 a seminar at KSLA on "Diversity of domesticated animals and plants"
- June 29th, 2012 the summer meeting of SUF
- August 30th, 2012 a seminar at KSLA on "Sustainable agriculture – does it need modern biotech?"

With this issue of the journal a form for the payment of the annual fees is included. The annual fee for members who pay annually is unchanged at 100 SEK. The additional fee for the distribution of the Journal of the Swedish Seed Association is also unchanged at 200 SEK. We kindly ask you to observe that the distribution is not included any longer in the perpetual membership in SUF, now that all the costs of the association have to be covered by fees from members and contributions from foundations etc. We are, of course, most grateful for any supplementary contributions from perpetual members!

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Pre-breeding: an alternative to add value to the plant genetic resources

Pre-breeding: ett alternativ för att öka värdet på växtgenetiska resurser

Elcio Perpetuo Guimaraes, Daniel Debouck, Stephen Beebe, Cesar Pompilio Martinez, Clair Hershey and Hernan Ceballos

Abstract
The world continuously needs more food for its growing population. Plant breeders have responded by developing new and more efficient varieties. Despite significant success in these endeavours critics suggest that this strategy has contributed to a decrease in genetic diversity in farmers' fields. Therefore, more attention has to be placed on pre-breeding to enhance the utilization of plant genetic resources to minimize this problem. International instruments are calling attention to the need to look at plant genetic resources in a more holistic way, linking collections in the genebanks with breeding activities, and these with seed delivery systems. The focus of this paper is on pre-breeding and the related topics of characterization and evaluation, knowledge of the genetic diversity, inter-species relationships, and pre-breeding experiences. It ends by laying out challenges to pre-breeding.

Keywords: plant genetic resources, pre-breeding, plant breeding and genetic diversity

Introduction
Food prices in the second half of 2010 reached their highest values since the 2008 food crisis (CEPAL/FAO/IICA 2011). There are no clear signs on the horizon that prices will drop significantly or that hunger will no longer be an issue. Therefore, any actions we take now to help deal with long term world hunger are welcome.

Crop genetic improvement has been contributing to increased productivity and production since its beginning, when our ancestors started selecting the best seeds for the next season's planting. The Green Revolution, through the development of new and more productive varieties, was a major set of events in this history of success (Evans, 1998). Today the world needs another revolution to respond to the current and future demands of 9 billion people projected for 2050.

Considering that new techniques and tools are available for breeding today, we are left with the challenge of using them more effectively to generate the needed increases in yield and yield stability. The plant genetic resources required for breeders to work may still be hidden inside wild and traditional materials, but today they are better conserved and managed than in the past. There is more information on their genetic content, and breeders are more interested in looking beyond their usual sources of diversity to solve problems. Therefore, more and more often we have been asking how could we easily access and utilize these hidden or difficult-to-access genetic resources. The response to this question relies on pre-breeding.

Breeders are increasingly considering pre-breeding as a way to provide better base materials for their improvement programs. This paper brings attention to the importance and the role of pre-breeding in enhancing utilization of plant genetic resources by plant breeding programs. The document is organized by: an introduction where the basic concepts are provided and the need for pre-breeding emphasized; followed by a discussion of important aspects to be considered when carrying out pre-breeding activities. It concludes by laying out challenges to enhance pre-breeding.

Need for Pre-breeding
The International Treaty on Plant Genetic Resources for Food and Agriculture defines plant genetic resources for food and agriculture as "any genetic material of plant origin of actual and potential value for food and agriculture" (FAO 2009).

Although there are different concepts of pre-breeding the definition used here includes all activities designed to identify desirable characteristics/genes from unadapted plant genetic resources and their transfer to an intermediate product that breeders can use to develop improved varieties for farmers (Nass and Paterniani, 2000).

The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture states that pre-breeding activities are a unique and most frequently a fundamental step between the plant genetic resources conserved in collections in genebanks and their utilization by plant breeders (FAO 2010). In the same document, Chapter 4 deals with the state of use of plant genetic resources; the section on gaps and needs highlights that national programs should give more attention to pre-breeding in order to enhance use of plant genetic resources.

Plant breeders worldwide rightly consider their responsibility to produce the best variety possible for the target environment with the most efficient breeding strategy. This approach was responsible for the development of the best varieties for a diverse range of crops the world cultivates today. However, more and more frequently plant breeders have been accused of converting farmers' fields from a genetically diverse set of varieties to a more genetically uniform situation, reducing genetic diversity and thereby creating conditions for catastrophes similar to the potato blight in the 19th century (Gray, 1995). There is evidence that this might not be true for all species (Casler, 1995).

Different international instruments, such as the International Treaty on Plant Genetic Resources for Food and Agriculture and its Article 14 "The Global Plan of Action for Conservation and Sustainable Use of Plant Genetic Resources for Food and Agriculture", emphasize the importance of considering a more holistic approach to plant breeding, one that goes from the pre-breeding work that better exploits the plant genetic resources available in genebanks, passing through the plant breeding activities and ending by ensuring the existence of a process for seed production and dissemination to farmers. This pipeline (i.e. pre-breeding/breeding/seed system) is fundamental, not only to broaden the genetic base of today's crops in farmers' fields but also to ensure adoption of the new varieties.

One of the main reasons to strengthen pre-breeding activities worldwide is to contribute to broadening the genetic base by exploiting a wider range of genetic diversity. The limited genetic diversity of the world's most important crops is alarming. Currently fewer than 150 species are being cultivated and out of them fewer than 12 are the bases for human sustenance (FAO, 1997).

The importance of characterization and evaluation

Knowledge about the potential of a given genebank accession to solve a problem is key to its use. Therefore, the first step after collecting a material is to characterize and evaluate it. Characterization identifies and describes the main characteristics or the quality of an accession. Thus, characterization makes reference to the description by which materials are differentiated or identified (Plucknett *et al.*, 1987). In general, this description is linked to highly heritable traits. Complementary to characterization, evaluation refers to the description of the behaviour of a given accession in a specific environment where the interaction between genotype and environment determines the expression of the trait (Frankel, 1989). Typically, breeders will subject accessions to different biotic/abiotic stresses under controlled conditions to identify sources of resistance/tolerance to factors affecting production in farmers' fields. By integrating phenotyping with genotyping breeders can identify specific segments in the genome of an accession associated with a trait of agronomic importance and then transfer this specific trait to elite material via molecular markers (Gutierrez *et al.*, 2010).

Characterization and evaluation are essential to promoting use and to start pre-breeding activities, since they allow genebank managers and breeders to have a clear idea about the potential of a given entry to contribute to the solution of a problem to be solved. The availability and regular use of biotechnology tools have contributed tremendously to the production of knowledge about genebank accessions (Tanksley and McCouch, 1997).

Usually, breeders will not turn to wild species unless a trait of interest can be found only in this material. To use genes from wild species requires repeated backcrossing to the female cultivated parent to eliminate undesirable traits from the wild parent. A carefully planned pre-breeding program is necessary to transfer useful genes from many wild species to cultivated parents. In rice, the development of several monosomic alien addition lines is one pre-breeding approach followed by IRRI (Jena and Kush, 1990). Since 1994 the CIAT Rice Program has followed a strategy known as chromosome segment substitution lines (CSSL), whereby BC2F1 lines from interspecific crosses are run through anther culture to produce double haploid lines (Gutierrez *et al.* 2010). Different CSSL populations have been developed and characterized molecularly at CIAT using wild species such as O. *rufipogon*, O. *glaberrima*, O. *barthii*, O. *glumaepatula*, and O. *meridionalis*.

For more than three decades the CIAT genebank has served as the source of parental material for the breeding program of common bean (*Phaseolus vulgaris* L.). However, both characterization and evaluation were carried out more systematically when a formal core collection was created. The core collection was characterized extensively for morphological traits, for its genetic structure using molecular markers (Beebe *et al.* 2000), as well as for reaction to key diseases. While previously three genetic groups or races had been described within the Mesoamerican gene pool (Singh *et al.*, 1991), a fourth group was discriminated through the study of the core collection. This group was designated race Guatemala, and this proved to be the source of important resistance genes for angular leaf spot (Mahuku *et al.*, 2004). At least one line with this resistance gene is now being considered for formal release in Honduras.

Encouraged by the success with the common bean core collection, CIAT created a similar collection for the sister species of the secondary gene pool of common bean, *P. coccineus* and *P. dumosus*. One hundred forty five accessions of these two species were systematically chosen to represent the agroecological variability of their sites of origin. Several accessions of *P. coccineus* were identified as tolerant to aluminum toxic soil in a field screening and in subsequent greenhouse evaluations (Beebe *et al.*, 2009) and one in particular, *G35346-3Q*, has been singled out for use in interspecific crosses with *P. vulgaris* to improve common bean for aluminum tolerance (Butare *et al.*, in press). The secondary gene pool originated in very moist environments, and it may prove to be useful as a source of traits for regions that are expected to receive more rainfall under climate change, such as East Africa or the northern Andes (Beebe *et al.*, in press).

In the case of cassava the collection held at CIAT has evolved from being just a repository of genetic variability to a dynamic source of high-value traits (Ceballos *et al.* 2006). Vast studies were conducted not only to complete the morphological characterization of the cassava germplasm collection but also to screen it for traits of economic importance such as starch functional properties and biochemical traits (Sanchez *et al.*, 2009) and nutritional value (Chavez *et al.*, 2005), and reduction of chronic problems such as the short shelf life of cassava roots (Morante *et al.* 2010).

The systematic screening of the germplasm collection evolved to the need of inbreeding (one generation of self-pollinations) to allow the expression of useful recessive traits. This approach allowed the identification of two useful starch mutations (Ceballos *et al.*, 2007; 2008) which became key examples and justifications to invest on pre-breeding activities not only at CIAT but also in other institutions involved in the genetic improvement of cassava. Pre-breeding work went beyond *M. esculenta* and included also wild relatives (Fregene *et al.*, 2006).

Knowledge of genetic diversity

In this section we choose to talk about the genetic diversity in the different gene pools. The selection of a few variants of wild plant species better fitting human needs has been the beginning of a long process called crop domestication (Heiser, 1990). The outcome is a lack of survival capacity of the domesticated in the wild, and dependence on humans for growth and reproduction (an extreme example of it being maize; Pickersgill, 2007). Allard (1966) mentioned that: "when a plant breeder transfers one or a few desirable genes from a wild relative to a cultivated type, he is, in a sense domesticating the wild species". Because of the variety of human selection pressures and man-made habitats, an increasing number of variants appears and through traditional seed systems will result in hundreds of landraces (Debouck *et al.*, 2004). Wild plant species often display anti-nutritional characteristics (Johns, 1990) and there was thus little incentive for farmers to resume the domestication process, but rather to exchange the products of their own selections. Particularly in the case of pre-Columbian agricultures in tropical America, the number of domestication events per crop has been low (1-2) (Pickersgill, 2007), leaving most of the diversity existing in the species untouched in the wild (founder effect). As human selections have rarely changed completely the reproductive system of the original plant (Andersson and de Vicente, 2010), the landraces and the wild ancestor make up the primary gene pool of a crop, with full genetic compatibility between them. The secondary gene pool will be made of all populations of a plant species sister to the one affected by the domestication process, while the tertiary gene pool will be made of populations of a more distant species of the same plant genus (Harlan, 1992).

The breeder can thus access different kinds of genetic diversity, depending on the age of the crop and the plant species, also on the ecological range of its wild ancestor and early landraces (Hawkes, 1983). An early domestication and adoption, crosses with the wild ancestor over a wide range, and extensive seed distribution systems will favour high genetic diversity in the crop in the form of numerous landraces. In contrast, a single domestication event in a wild plant with a very restricted range will result in a crop with narrow evolutionary potential (for example, in the Andes, compare the potato with maca, *Lepidium meyenii* Walpers). If the species affected by the domestication process has several related (wild) species, then the secondary gene pool will be wide, with many opportunities for the breeder, although one can anticipate that he/she will have to work hard to eliminate some of the wild unwanted traits (Harlan, 1976).

Pre-breeding needs to operate in an environment of a strong breeding program

Pre-breeding operates at the interface of genebank management and of breeding. It cannot succeed if either of these activities is deficient. Plant breeding has been transformed in several significant ways in the past two decades, impacting in both positive and negative ways the potential for pre-breeding to contribute to crop improvement.

In most developed countries and in several larger developing ones, plant breeding has moved from the public sector, and from public-private partnerships, to almost an exclusively private sector enterprise. While this has allowed large and rapid gains for the small number of crops where there is a viable commercial seed sector, many minor crops have been left behind, without adequate attention. Even in the major crops, the private sector typically does not provide major support to germplasm collection or utilization.

On the positive side, new tools – especially molecular tools – are contributing immensely to the ability of pre-breeders to identify and move traits from exotic materials (as shown in the previous section) and wild species into materials that can be used as parents by breeders. Strong genebanks and strong breeding programs with access and experience in molecular techniques are in a good position to effectively use pre-breeding to advantage.

Funding for pre-breeding within breeding programs has been the major constraint to its successful application. The private sector typically sees pre-breeding as too long-term and risky to invest. Only the public sector is usually able to take on these challenges, but the public sector is broadly underfunded in all aspects of plant breeding. Creative public-private partnerships are often the best option for crops and for regions where there is private sector investment. But for most minor crops and in many developing countries, the public sector will continue to have the main responsibility for breeding and pre-breeding well into the future. Therefore it is important that policy initiatives support this key research through capacity building and other investments (GIPB/FAO, 2011 a, b, c, d).

There are experiences with the major crops that are useful to minor ones

The case of maize and cassava can be used to illustrate the concepts for this section. Although cassava is not a minor crop, it is much less understood than maize. In addition, cassava and maize compete for many of their industrial applications (mostly for the starch, animal feed, and bio-ethanol industries), as well as in their role as food security staple crops. There has been a mutual influence among these two crops. The Second World War prevented the shipments of cassava starch (known also as tapioca) from Java and Thailand into the U.S.A. This prompted the American starch industry to look for alternative starches. This situation lead to the development of the waxy (amylose-free) maize starch industry in the U.S.A. (Fergason, 2001).

Most of the knowledge on starch applications, biosynthesis and breeding is based on cereals (maize, wheat and rice) or potato (Hannah, 2000). The information generated from these crops has been very helpful in defining pre-breeding and breeding approaches adapted to cassava. The knowledge and experiences in cereal crops and potato in relation to starch technologies have helped cassava in aspects beyond those related to starch biosynthesis and its application issues. The amylose-free (waxy) gene was one of the first genes fully characterized (Hannah, 2000) in plants and that knowledge is immediately applicable for cassava. Genetic transformation for the production of novel starch phenotypes has also been used in cassava (Raemakers *et al.*, 2005).

Challenges

Extinction is forever. Although progress has been made, there is still substantial work to be done to advance knowledge about the composition of gene pools of our crops. For instance, we do not know the number, distribution and attributes of the wild species of *Oryza* in the Neotropics (in contrast to a common belief, there are wild species of rice in tropical America; Vaughan *et al.*, 2003). With few exceptions (maize: Fukunaga *et al.*, 2005, potato: Spooner and van den Berg, 1992, tomato: Warnock, 1988), the gene pools of the American crops are botanically not yet fully inventoried, while destruction of native habitats goes on at a rapid pace (Rands *et al.*, 2010).

A second challenge is the full evaluation of entire germplasm collections. Often very useful traits are displayed by only a few individuals or a few accessions out of collections of thousands of accessions. For instance, resistance to whiteflies in cassava is found in *MEcu72*, a single accession out of the 6,592 currently kept at CIAT (Bellotti, 2002). In rice, after the screening of 6,700 accessions, only one accession of *Oryza nivara* Sharma & Shastry was found resistant to grassy stunt virus (Khush and Ling, 1974). *Oryza rufipogon* has been identified as valuable source of genes associated with grain yield and its component and other traits (McCouch *et al.*, 2007). A wild rice accession of *O. rufipogon* from China provided the principal source of cytoplasmic male sterility used in hybrid rice programs (Lin and Yuan, 1980). In common bean, the evaluation of thousands of cultivated materials did not result in any resistance to bruchids, while 25 accessions of wild *Phaseolus vulgaris* L., all of Mexican origin, were found highly resistant (Cardona *et al.*, 1990).

A third challenge is related to the utilization of the vast genetic diversity found in nature in most crop species. In the case of rice, it is estimated that only 25 % of the total genetic diversity available has been used by breeding programs (McCouch *et al.*, 2007). Besides, genetic diversity stored in rice genebanks does not represent very well what is actually found in several key regions. Emphasis has been placed on germplasm conservation but more attention and funding should be devoted to collecting germplasm in strategic key areas and in its utilization.

This brings up another challenge related to training of breeders. The main purpose of pre-breeding is to identify genes associated with traits of agronomic importance in exotic germplasm to be introgressed into cultivated gene pools but no to produce a commercial product right away. Therefore selection criteria used in pre-breeding have to be different from those on the other end. It is a step-wise approach to produce a product with commercial value. This calls for time, patience, many observations to identify useful individuals in the inter-specific populations, and adequate resources.

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Sammanfattning

Den växande världspopulationen kräver en kontinuerlig ökning av födovaruproduktionen. Växtförädlarna har svarat genom att utveckla nya och effektivare sorter. Trots de betydelsefulla framstegen hävdar kritiker att denna strategi har bidragit till att minska den genetiska diversiteten på böndernas åkrar. För att minimera dessa problem bör man höja insatserna för pre-breeding och därigenom öka användningen av växtgenetiska resurser. Internationella insatser visar att man bör se mer holistiskt på problematiken genom att knyta samman samlingarna i världens genbanker med förädlingsaktiviteter och dessa i sin tur med försäljningen av frö på marknaden. Uppsatsen behandlar pre-breeding och intilliggande områden som karaktärisering och evaluering, kunskap om genetisk diversitet samt släktskapen mellan arter. Som avslutning behandlas utmaningarna för den framtida pre-breedingen.

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Making efficient and effective use of plant genetic resources

Effektivt utnyttjande av växtgenetiska resurser

Michael C Mackay

Abstract

Of the millions of accessions of plant genetic resources for food and agriculture (PGRFA) conserved in genebanks worldwide, only a small fraction have been thoroughly evaluated for novel genetic variation. Breeding is a critical part of the crop improvement continuum that aims to increase production and overcome biotic and abiotic stresses. The wealth of untapped genetic variation in genebanks can only be rationally utilized if information about its characteristics can be acquired or inferred in some way to quickly identify the limited number of accessions most likely to containing the required traits. Furthermore, ways of aggregating such information from many genebanks into a single portal would provide germplasm users with the ability to more easily locate the germplasm they require at a single site. Progress in both the efficient and effective use of PGRFA, through the use of information, as well as the development of a global portal to access such information, are reported here.

Keywords: Plant genetic resources for food and agriculture (PGRFA), genebank accessions, PGRFA information, trait mining, global information system, utilization.

Introduction

There are some 7,4 million accessions held *ex situ* by 1,750 genebanks globally (FAO, 2010). To date there have been no widely accepted and effective approaches to efficiently identifying the novel genetic variation required by modern crop varieties to address contemporary production challenges. In many cases it seems that new genetic variation is identified in basic research activities where there has not been any common approach to selecting germplasm for evaluation; perhaps bilateral communication between individuals or multilateral communication at scientific meetings have been the common threads for discovery in the past. Some approaches, such as the core collection concept (Frankel, 1984), may be effective in concentrating genetic diversity in subsets of larger collections. However, an approach that is flexible enough in identifying the specific variation required for adaptive traits across crops would have the potential to greatly enhance their swift introgression into modern cultivars.

The Global Crop Diversity Trust (Trust) has identified the need for information about accessions, their characteristics and performance indicators, as a key to facilitating access to and use of plant genetic resources for food and agriculture. This need was identified by a number of the Crop and Regional Strategies, developed with the support of the Trust, and full details are available on their website *(http://www.croptrust.org/main/identifyingneed.php?itemid=514)*. Furthermore, the International Treaty on Plant Genetic Resources for Food and Agriculture (IT-PGRFA) recognizes the role of information for facilitated access to and sustainable use of PGRFA in several of its Articles (see Articles 7, 12, 13 and 17) *(http://www.planttreaty.org/)*.

In recent times plant breeding has tended to become more of a private sector activity, gradually declining in the public sector. In the past the public sector not only undertook breeding but also prebreeding activities, often as part of a larger breeding program. Pre-breeding was not always a significant investment for private sector breeding programs. New genetic variation identified through public sector pre-breeding activities was often partially introgressed into more adapted genetic backgrounds before being included in the mainstream breeding program as 'breeding material'. This breeding material was often made available to, and used by, the private sector in breeding programs.

To guarantee the ongoing utilization of PGRFA to address the various production challenges, including those associated with climate change and food security, two elements are crucial – *a)* ways to make

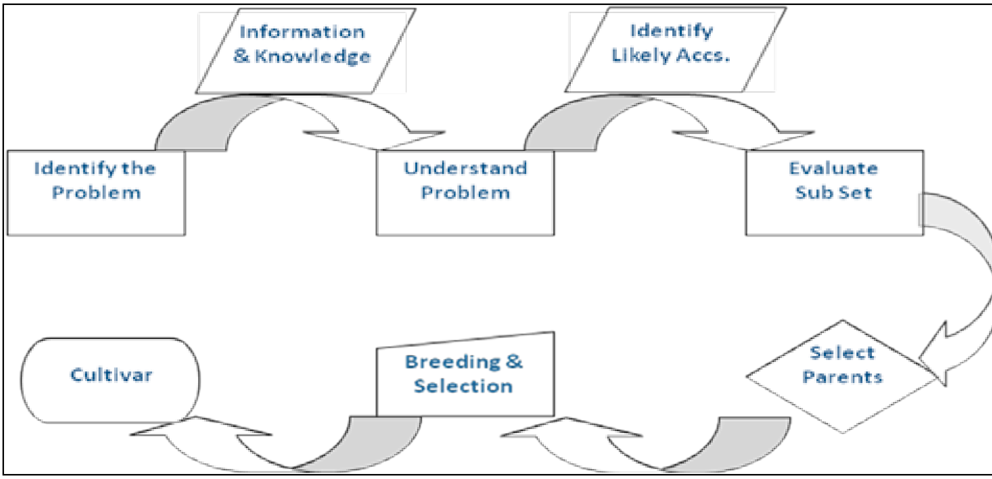

Figure 1. Scheme for utilizing PGRFA (from Mackay, von Bothmer and Skovmand, 2005)
Figur 1. Översikt hur växtgenetiska resurser kan utnyttjas optimalt (från Mackay, von Bothmer och Skvmand, 2005)

use of such data to identify those genotypes more likely to possess the genetic variation being sought by breeding programs and *b)* means to fully document relevant characteristics of PGRFA and make them easily accessible to all potential users. Individuals and institutions, both private and public, will need to work together to achieve these two goals.

Using information to mine PGRFA

Breeders and pre-breeders are continually faced with shifting demands to address production challenges in their focus region(s). In cases where there is no readily available genetic solution to a specific challenge, they will usually seek novel genetic variation from genebanks or other sources. Figure 1 illustrates a logical approach that would assist in identifying new variation and incorporating it into new varieties. This approach is not necessarily new, but rather reflects how breeders and/or pre-breeders typically identify and deploy new genetic variation. The time period from identification of a problem until an appropriate solution is deployed can vary significantly, but the quicker a subset of genotypes that are most likely to contain the required variation is identified the sooner the new cultivar can be developed.

Finding new genetic diversity is rarely a straightforward procedure, indeed it can be a challenging and convoluted exercise. The simplest case scenario would be if an allele that will provide a solution to a given breeding objective is already known in a reasonably well adapted genetic background and only needs to be introgressed through hybridization and selection. The more difficult scenario is when the required variation is not known to exist and one must firstly find the genotype with the appropriate attribute and then introgress it into a suitable background for commercial cultivation. In the latter case the time and/or resources required to identify the specific allele(s) could be equivalent to that for the breeder's contribution. Thus, any approach that minimizes the discovery phase (finding the required new variation), sometimes referred to as 'trait mining' or pre-breeding, has the potential of significantly improving the efficiency of deployment of new cultivars.

Information about the characteristics of PGRFA, the key to its access and utility, is disparate in terms of quality and quantity, often not available online, possibly not even digitilized, mostly managed in a haphazard manner and rarely aggregated. This makes the efficient and effective use of PGRFA a huge challenge. In principle, novel genetic variation can be found in any of the PGRFA categories – cultivars, breeding lines, landraces, wild relatives, etc. Perhaps the richest sources of novel variation are the wild relatives and landraces, which evolved subject to the selection pressures in natural environments. The more 'modern' PGRFA, such as breeding lines, can contain more complexly inherited variation not exhibited in the parents but, generally speaking, these categories have been more thoroughly evaluated in environments targeted by breeding programs and therefore could be considered to be more heavily exploited than the collected material.

One approach to more efficiently exploring PGRFA is the Focused Identification of Germplasm Strategy (FIGS) which could increase the chance of finding the sought after trait by up to 80% (McDonald, 2011). The thesis behind FIGS is to link variation for adaptive traits to the environmental parameters of the site where landraces and wild relatives evolved and were collected. Using this approach has helped quickly identify small (ca. 100 to 1000 accessions from collections of up to 16,000 accessions) discrete sets of PGRFA accessions containing new variation for a number of traits in cereals including boron tolerance, Russian wheat aphid (El-Bouhssini *et al*, 2010), Sunn pest (El-Bouhssini *et al*, 2009) and powdery mildew (Bhullar *et al*, 2009). In the latter case seven new functional alleles were found, using the FIGS approach, at one locus in a short period compared to the previous 100 plus years of classic genetics to find the previously know seven functional alleles.

Of course FIGS is not the only approach that can speed up the plant improvement process by targeting in on the germplasm most likely to possess the genetic variation being sought by breeders and farmers. If, for example, FIGS can reduce the number of genotypes required for evaluation for the particular trait by 90%, and the cost of evaluation per genotype is $200, then immediately there is a potential saving of about $900,000 along with the reduced time required. Furthermore, the FIGS approach (and other approaches offering similar efficiencies) can be assisted by molecular marker technology to quickly confirm the presence or absence of the desired trait from months to a single week. All in all, there are many opportunities to continue to improve the overall effectiveness and efficiency of the breeding process, thereby meeting the production and quality challenges posed by climate change, nutritional requirements and food security.

Aggregating information for access and use

For approaches like FIGS to be most effective a lot of information is required. Most genebanks have reasonable passport data describing the origin, source and other identification information (see FAO/IPGRI, 2001 for full explanation), however there are continuing efforts to improve the quality and accuracy of this information. Most genebanks also collect and manage characterization information about the accessions they hold. Characterization and evaluation data are more useful to users of PGRFA in selecting genotypes for specific purposes. Bioversity International (2007) provides a comprehensive guideline for the development of crop descriptors as well as an explanation of the various categories – passport, management, environment and site, characterization and evaluation.

Until 2011 the information relating to genebank accessions were held, documented and managed primarily by individual genebanks with a few exceptions where communities of genebanks aggregated their information into a single web site. Three of the larger communities, which represent about one third of the estimated 7.4 million accessions held in genebanks, are EURISCO (the European catalogue of national inventories of *ex situ* PGRFA in Europe), SINGER (the CGIAR System Wide Information Network for Genetic Resources) and GRIN (the Germplasm Resources Information Network of the United States Department of Agriculture's Agricultural Research Service). In a joint initiative of Bioversity International (Bioversity), the Trust and the IT-PGRFA a project was initiated in 2008 to develop a global accession-level information system. The primary goal was to facilitate access to and use of PGRFA through a single web portal that used EURISCO, SINGER and GRIN as the foundation data providers for Genesys, the name given to the accession-level information portal. In addition to providing access to passport data, Genesys created a new paradigm by including environmental, characterization and evaluation categories of data in a single portal in which users (especially pre-breeders and breeders) could query some 2,4 million accessions across all four data categories. The first phase of development of the Genesys portal will be finalized in mid 2011 and contain some 22 million records of environmental, characterization and evaluation data to assist pre-breeders and breeders to identify the germplasm they require to meet the challenges of their breeding programs. Genesys has been developed using an iterative approach whereby it has been available online as a prototype and all potential users are asked to provide comments and feedback to help ensure it delivers the data and functionality required by the user community (see G at *http://www.genesys-pgr.org*). It contains online documentation, including a 'Quick Start Guide' and an 'In-depth Tutorial' to help users take full advantage of the available data and functionality. User input is encouraged, especially for the enhancement of the portal in Phase II, anticipated to commence in the second part of 2011.

Conclusion

The efficient and effective use of PGRFA has at least two main ingredients – a system that provides access to aggregated information at a single web site and a sound approach to using the available information to identify the specific genotypes most likely to possess the genetic variation required by users, especially pre-breeders and breeders, to meet the challenges of their breeding programs. As described here, considerable progress has been made with these two ingredients in recent times. However there are a number of critical issues to further address in order to fully achieve the goal of facilitating access to and use of PGRFA. These include increasing the number of data providers to G, adding functionality for the inclusion of pedigree/geneological analysis and breeders' material similar to that pioneered in the International Crop Information System (ICIS), as well as a multitude of linkages to allied data sources. These should include international and national molecular information portals, phenotyping and trait mining initiatives, breeding programs and so forth.

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Sammanfattning

Av de miljontals accessioner (fröprover) av växtgenetiska resurser för mat och jordbruk (PGRFA) som bevarats i världens genbanker har endast en bråkdel evaluerats för ny genetisk variation. Förädling är en viktig del i kedjan som syftar till att öka matproduktionen och klara av biotisk och abiotisk stress. Den rika genetiska variationen i världens genbanker kan bara utnyttjas optimalt om information finns tillgänglig om vilka egenskaper som accessionerna innehåller samt att man snabbt kan få uppgifter om ett begränsat antal accessioner som mest sannolikt innehåller de önskvärda egenskaperna. Informationen från världens genbanker bör vara tillgänglig genom en gemensam portal som ger användaren, förädlaren eller forskaren, möjligheten att enkelt och effektivt få fram den önskade informationen. Uppsatsen behandlar hur en effektiv användning av PGRFA underlättas genom tillgången på information om egenskaper i en gemensam global portal.

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Nordic pre-breeding strategies

Strategier för nordisk pre-breeding

Anders Nilsson

Abstract

The traditional approach has been to perform pre-breeding in-house at Nordic plant breeding organizations, companies as well as public institutions. With structural changes in the industry it has become evident that there is a need to collaborate. This situation was addressed in an investigation on what could be done to strengthen Nordic plant breeding established by the Nordic Council of Ministers (NMR) in early 2008. The mission included to investigate the need for measures and the possibilities of collaboration and co-ordination. The investigation resulted, among others, in a proposal on the set-up of a Nordic PPP on Pre-breeding after discussions with stakeholders, plant breeding entities as well as others, in the Nordic countries. Possible collaboration with the plant breeding community in the Baltic republics was also discussed as part of the investigation.

Keywords: public-private partnership, pre-breeding, structural changes.

Introduction

Over time the strategies for Nordic Pre-breeding have changed. The traditional approach has been to perform this work in-house at the different plant breeding organizations, companies as well as public institutions. From the 80's the collaboration with universities and institutes has become more and more important and joint projects and other efforts were established. These activities include identification of sought after genetic characteristics, characterization of genetic sources and the introduction of identified genes into adapted germplasm. The activities also include development of different tools for a more efficient breeding process – protocols for the production of DH lines, quick and robust methods for selection on different quality traits, molecular tools, etc. With this development it was also natural to start collaboration between plant breeding companies in this pre-competitive context, to a considerable degree facilitated by the universities and public institutes involved in these efforts.

Good examples on traditional in-house pre-breeding efforts can be found in the resistance breeding, e. g. the development of race specific resistance to mildew in spring wheat in Norway which has been performed in Graminor and its predecessors, partly in collaboration with Svalöf Weibull and NLH, now UMB. However, this development is also a good example on the need to take on more ambitious schemes as the resistance was broken down by new races of mildew very quickly. A step in that direction is the long-term development of resistance to net blotch in barley in collaboration between Boreal and MTT in Finland, initiated already in the late 80's and now resulting in new varieties with improved and durable resistance.

Structural changes

With the sharpened international competition in plant breeding, structural changes in the industry, the quick development of plant biotech with its promises, and relatively costly development of molecular tools it became evident for mid-size and ambitious smaller plant breeding companies that they had to collaborate in the development of technologies in order to compete with the 'big players'. This development increased its pace from the mid 90's. Accordingly, a number of large, international networks for different pre-breeding efforts were established from this period and on. Initiatives were often taken by research and the costs could be kept at a reasonable level with several participating companies and considerable national support to the research environments doing the job. The tasks were mainly related to development of molecular tools. In some cases the initiatives were also established as part of the business model of research-oriented service providers, such as KeyGene. In many cases plant breeding companies joined these consortia as an insurance not to be left behind in the development of competitive new tools, which initially only would become available to the members of the consortia. Several of the Nordic plant breeding companies joined such collaborative efforts.

In UK LINK-projects have been initiated from the research community, mainly John Innes Institute but also from other environments. Several large projects have been established where the contribution from the breeding companies mainly have been in kind. Nordic breeding companies have joined projects, i. e. on resistance to *Ramularia* in barley and to *Septoria* in wheat, for quality in wheat, and for molecular tools in oats. GABI in Germany is another biotech effort program which has organized large projects on, among others, resistance to *Fusarium* in wheat and increased oil content in winter oilseed rape, also based in the research community and mainly with contribution in kind. The participation has been restricted to breeding programs located in Germany. In Canada large consortia have been organized by AgCanada for the development of resistance to *Phoma* and other traits of interest for the breeding of spring oilseed rape for Canada. Further examples could be given, which are based on the needs for major crops of large markets in UK, France, Germany and Canada, and where public resources are allocated for pre-breeding efforts in collaboration between academia and the breeding industry.

Gemeinschaft zur Förderung der privaten deutschen Pflanzenzüchtung (GFP) is one of few examples where the initiatives to such collaboration are coming from the breeding industry. This German program for pre-competitive breeding efforts is performed in collaboration between academia and industry, where public resources are matched by contributions from participating companies, also in kind, and funding from the organization of the German plant breeding industry (BDP), collectively gathered from the seed market. A scientific committee is a guarantee for the quality of the activities.

A Nordic Public-Private Partnership on Pre-breeding

In the Nordic countries there were no such programs supporting the development of the breeding when we (prof. Roland von Bothmer and I) took initiatives on the re-activation of the interest for public breeding in Sweden in 2006. As a result a mandate was initiated by the Swedish Ministry of Agriculture in summer 2007 to investigate what could be done to strengthen Nordic plant breeding in view of demands expected from Climate Change and a mission was established by the Nordic Council of Ministers (NMR) in early 2008. The mission included to investigate the need for measures and the possibilities of collaboration and coordination. A reference group with representatives from all the Nordic countries, covering different aspects of stakeholders, was established as well as contacts with persons responsible for issues on plant breeding in the respective Ministries. A dialogue with the breeding industry was started where we had meetings with the separate companies as well as with the major companies gathered. Meetings with other stakeholders in the respective countries also took place. Reports on the progress were given at NMR meetings and a final report in June 2009.

Our discussions underlined reasons why plant breeding is important, such as

- Adaptation to Climate Change implying new crops, expansion of present crops in the Nordic countries, increased and changed biotic and abiotic stresses, but the same light conditions
- Need for increased yield over time. FAO is foreseeing a need of +50 % in crop production from 2010 to 2050 to meet demands on food, using no more land and less nutrients and water, not taking into account demands for fuel and industrial uses
- Response to environmental goals with reduced ecological footprint.
- Resistance to pests and pathogens for reduced use of pesticides, taking into consideration the ability of pests and pathogens to overcome more or less durable resistance genes.
- Adaptation to quality demands – techncal / nutritional / sensoric aspects being demanded from different markets.

Also, there is a need for the constant renewal of varieties in different crops. It's only in this way that all the demanded traits and characteristics can be offered in combinations and variations that meet the changing demands from the market, while at the same time incorporating recent advances from research. There is also a need to take into consideration the large climatic differences between different Nordic regions.

Our discussions also underpinned rationales for society to engage in the development of plant breeding, such as

- Climate Change leading to new demands (see above)
- Political targets for growth, environment, bioenergy and regional development all imply need for well adapted genetic resources
- International focus on large crops and markets, the Nordic countries being placed in the periphery and composed of several minor markets, or niches
- The fact that plant breeding is a long term undertaking with small margins, where overall efforts have been reduced with structural changes in the sector
- Nordic co-ordination would be rational in more long-term efforts and in plant breeding for small crops or markets
- Co-operation between society, industry and academia is a prerequisite for success.

Companies in the Nordic plant breeding industry all gave a similar picture of the present situation. The margins are low and continued rationalization and structural changes are necessary elements for sustained operations. Small crops and markets are abandoned in the breeding, unless there is public funding. Also in the crops where the breeding is continued the efforts in-house in pre-breeding are reduced. Thus, there is an interest to collaborate in pre-competitive projects. Difficulties in the recruitment of new breeders have become a concern for the industry, which is acknowledged also in major European markets.

As the breeding companies and entities declared their interest for joint efforts in pre-breeding projects, it was also clarified that there was a need for a broad definition of pre-breeding in this context. Thus, in the further proposals, leading to the establishment of the Nordic Public Private Partnership for Pre-Breeding (PPP), this was defined as

- Broadening of the genetic basis for the breeding of a given species
- Introduction of specific traits in adapted genetic background
- Development of tools for selection.

Further enhancement of collaboration with the Baltic countries has a pronounced place on the agenda of NMR, why the possibilities of including the plant breeding institutes in the Baltic countries in the collaboration within the PPP also were addressed. On this issue the discussions ended in a recommendation to include such collaboration, if this brings value to the specific pre-breeding project and if the Nordic project partners agree. It has also been concluded that the plant breeding entities in Estonia and Lithuania have organization and funding that make participation as project partners possible.

Based on these observations, discussions and other input conclusions and proposals on the establishment of a Public-Private Partnership were given in the report "Measures to promote Nordic plant breeding", TemaNord 2010:518.

Sammanfattning

Det vanliga angreppsmetoden vid nordiska företag eller publika institutioner är att bedriva pre-breeding i egen regi. Med de strukturella förändringar som sker inom växtförädlingsindustrin har det blivit tydligt att samarbeten måste initieras. Detta beskrevs i en utredning som tillsattes 2008 av Nordiska Ministerrådet (NMR) med syfte att förstärka nordisk växtförädling och som lades fram 2009. I uppdraget ingick att bedöma möjligheterna för breda samarbeten och koordinering. Efter diskussioner med myndigheter, företag och andra intressenter inom växtförädlings- och jordbruksområdet lade utredningen bl. a. fram förslaget att ett Public-Private Partnership för pre-breeding bör sättas upp. Möjligheter för samarbete inom växtförädlingsområdet också med de baltiska länderna diskuterades även i utredningen.

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Public-Private Partnership for pre-breeding

– a new initiative to strengthen Nordic collaboration in plant breeding and use of genetic resources

Public-Private Partnership för pre-breeding – ett nytt initiativ för att stärka nordiskt samarbete inom växtförädling och användning av genetiska resurser.

Morten Rasmussen

Plant breeding and pre-breeding

Plant breeding is the continuous adaptation of genetic traits in a crop, traits of importance to maintain and improve yield, quality and agronomic performance, allowing the crop to adapt to a given environment, a changing climate, new cultivation systems or new agricultural practices and new technologies. It is a highly time consuming and expensive process, and a basic prerequisite is access to adequate genetic variation. The plant breeders seek to maintain and improve a sometimes delicate balance of desired traits in a given crop, and for this reason they are reluctant to apply un-adapted genetic material in the crossing programs. If doing so, there are simply too may undesirable traits disturbing this balance, and in spite of the introduction of e.g. a new disease resistance gene, the all-over performance of the offspring is often poor and no varieties are produced.

To apply new genetic resources, an even more time consuming process of pre-breeding is needed, transferring step by step a desired trait – or genetic variation – into an adapted genetic background. This allows the plant breeder to apply the trait in a given crossing program with the possibility to produce a new variety carrying the desired trait. The pre-breeding process is therefore an important link between genetic research and practical plant breeding, and a necessary step to facilitate use of conserved genetic resources.

Public-Private Partnership – the PPP

11th February 2011 the Nordic Council of Ministers decided to initiate a new Nordic partnership to strengthen the collaboration in pre-breeding of crop plants between the Nordic countries. Similarities in climate change challenges, in environmental goals and in desires to find solutions for future sustainable food production in the region made a Nordic approach feasible. The report "Measures to promote Nordic plant breeding" by Roland von Bothmer and Anders Nilsson, SLU, had documented the needs and possibilities.

Nordic collaboration in the field of pre-breeding has earlier been carried out e.g. in the structure SNP (Samnordisk Planteforædling), and projects in plant research funded by NKJ as well as the NOVA collaboration formed a step-stone to initiate this partnership.

Based on the above mentioned report, the Nordic Council of Ministers for Fisheries and Aquaculture, Agriculture, Food and Forestry (MR-FJLS) agreed to establish the partnership for a pilot period of three years from 2011 to 2013. Each national ministry has allocated funding for collaborative projects, and the Nordic Council of Ministers is funding the secretariat for the partnership, located at NordGen. It is the intention that this partnership will stimulate collaboration in use of genetic resources, and fill in the existing gaps between plant research, plant breeding and conservation work.

The purpose of the partnership is to support development of Nordic plant breeding addressing the long term needs in plant breeding. In the recent decades such tasks has been increasingly more difficult to fund. When considering the needs of plant breeding facing challenges as adaptation to climate change, as the needs to meet environmental goals set by the Nordic societies, and also adapting to future consumer and market demands, much work is required. The partnership, will address such long term challenges in joined pre-competitive strategic collaboration projects. The content of the collaboration is expected in the following three fields of interest: Base broadening, Introduction of specific traits and Development of efficient tools and methods.

The partnership projects are funded 50% from the Nordic ministries and 50% from the project partners, within a total frame of 23.3 million DKK in the three years of the pilot period. The project partners can contribute *in kind*, and the projects are urged to apply the relevant existing infrastructure and expertise in the Nordic region.

The potential partners in the partnership are all public and private organizations working in plant breeding with variety production, and all agricultural universities and research centers in the Nordic countries can participate in projects that have been set up by the partners. When establishing the partnership during the spring of 2011, 12 out of the 13 Nordic plant breeding companies and entities showed interest in participating, and the following are today members of the PPP:

Denmark: Sejet Plant Breeding, Nordic Seed, DLF-Trifolium and LKF Vandel

Finland: Boreal Plant Breeding and Agrifood Research Finland (MTT)

Iceland: Agricultural University of Iceland (LBHI)

Norway: Graminor

Sweden: Lantmännen, Syngenta, Findus and Swedish University of Agricultural Sciences (SLU)

To establish and administer the collaboration, a Steering committee for the partnership has been nominated. It consists of 10 members: 5 representatives from each national ministry of food and agriculture, 1 member appointed by the Nordic agricultural universities representing the academia, and 4 members representing the plant breeding entities. The NOVA secretariat has been very helpful in the process of appointing a representative for the universities. Appointment of representatives for the plant breeding entities was done after individual contacts were taken, and a joined meeting organized to propose and elect candidates last spring. The chair of the steering committee is appointed by the Nordic Council of Ministers amongst the representatives of the ministries. The current chair is the representative of the Swedish Ministry for Rural Affairs, Anders Nilsson. The other members are: for Denmark, Lars Landbo, for Finland, Tuula Pehu, for Iceland, Þóroddur Sveinsson, and Magne Gullord for Norway. The representative of the Nordic agricultural universities is prof. Roland von Bothmer, SLU. The 4 representatives from the plant breeders are: Kurt Hjortsholm, former managing director at Sejet Plant Breeding; Marja Jalli, senior research scientist at MTT; Idun Christie, managing director at Graminor, and Annette Olesen, director of plantbreeding at Lantmännen Lantbruk.

The Steering committee has a quite comprehensive mandate, and all major decisions and directions are taken here. Amongst the primary tasks are announcing project calls and prioritizing and deciding on project funding, but the Steering committee is also to promote the purpose for the prebreeding collaboration in the respective countries and to work actively for a continuation after 2013. Pre-breeding is not done in three years, and to develop an effective system that can yield results, long term engagements must be ensured. The Steering committee is developing rules and guidelines for the collaboration, developing annual budget and plan for the program, taking decision on evaluation procedures for the project proposals. The committee is deciding on project funding, including approving project budgets, project leaders and project plans. They approve the annual reports from projects, and are consulted before any major changes in ongoing projects can take place. The Steering committee may also decide on project partners involved in specific projects and possible collaboration with non-Nordic partners. An important role is to secure synergy to other relevant national and Nordic activities, and to secure an efficient communication on the function of the partnership and the ongoing activities. Furthermore, the steering committee will develop terms of reference for an evaluation of ongoing PPP and develop a strategy for further development of long-term Nordic collaboration on pre-breeding. The Steering committee is reporting to the partners of the partnership. It adjourns minimum two times per year. All decisions are taken unanimously.

Concerning the specific projects funded by the partnership it is very important for the efficiency and outcome, that the topics are defined by the needs of plant breeding. The questions addressed are therefore formulated by the breeders to ensure that the project results will be integrated in the breeding work and eventually yield more and better adapted varieties for the benefit of agriculture and horticulture in the Nordic region. An important concern from the funding side has been to assure that no legal right issues should occur during or after the projects are carried out, that could hamper any use of the project outcomes. For this reason consortium agreements are required, addressing IPR issues on material and information developed in the projects between the project partners. To secure the pre-competitive nature of the collaboration, a majority of the breeding entities actively performing plant breeding of a given crop, must be partners in a proposal on this given crop. This assures that the project topic is of relevance for as many as possible of the breeding programs, and that the outcomes of the project are as widely used as possible.

As mentioned NordGen holds the secretariat for the partnership, and has the administrative responsibility for the program. This work is funded by the Nordic Council of Ministers, and therefore does not influence the available resources for the project collaboration. The main tasks of NordGen are to act as secretary for the Steering committee, develop the documents required for the process flow, and secure an efficient information flow between partners, Steering committee and the funding structures. NordGen is the contracting partner in the funded projects and all project reporting is forwarded to NordGen; NordGen is responsible for reporting to the funding structures and for the economy of the program. Furthermore, NordGen is actively carrying out information work to both the scientific community, stakeholders of the plant breeding and seed chain and the general public of the Nordic region.

Status of Public-Private Partnership

Since the establishment of the Steering committee in September 2011, the first call for the PPP was announced in October 2011. It was decided to make a targeted call with the three following themes: Barley, Forages and Fruit & Berries. It was of importance for the Steering committee, that all major crop groups were addressed, and that the Partnership would be able to address crops of importance in all Nordic countries. Taking the very narrow timeframe into account, the Steering committee decided to call for three pilot projects to run over two years, with the intention to prolong according to future funding of the collaboration. Three project proposals were developed addressing the three themes of the call, and entered in the beginning of November 2011.

During the autumn of 2011 procedures for evaluation of the project proposals were developed. An external evaluation for scientific quality of the entered project proposals was carried out, followed by an evaluation for relevance for the Nordic region, carried out by the Steering committee. It is the intention to apply the developed procedures for future project calls within the partnership, increasing transparency for all project partners.

This resulted in decision on funding of two projects in December 2011, while for one of the project proposals some adjustments were required. These adjustments have been made and a revised proposal entered.

The project addressing the forages is initiated. The topic of the project is the adaptation of perennial ryegrass to Nordic conditions, and the goal of the project is base broadening of the existing gene pool. A major challenge for increased use of perennial ryegrass in the Nordic countries is the lack of winter hardy and persistent varieties, and an improved level of these traits are intended. All forage grass breeders of the Nordic countries participate, and the project is also collaborating with Estonian breeders. The project is coordinated by the Norwegian University of Life Sciences, and has participation from Århus University in Denmark as well. The project is linked to other relevant projects as the ongoing ”Nofocgran” and “Varclim”.

The project addressing the theme Fruit & Berries is dealing with pre-breeding of apples and network building. The topic is disease resistance breeding, and phenotyping for resistance against the diseases apple canker and storage rot with various techniques are planned. All the Nordic apple breeders participate, and the project is coordinated by the Swedish University of Agricultural Sciences. The project is linked to other relevant projects, such as the ongoing EU project “Fruitbredomics”.

Concerning the revised proposal addressing Barley, the topic is pre-breeding for disease resistance and climate adaptation. Validation of molecular markers for resistance against a number of emerging diseases in the Nordic germplasm is central in the proposal. Final decision on funding is to be taken at the next Steering committee meeting in early March, 2012.

Future perspective for the Public-Private Partnership for pre-breeding in crops

The partnership is now well initiated, and the first pre-competitive, collaborative Nordic projects in pre-breeding are ongoing. Informing about the potential of these activities, and the progress as the projects develop is of high importance and being able to show clear measurable results at the end of the first project period in 2013 is crucial. The funding structures behind the Partnership, the five Nordic Ministries of Food and Agriculture as well as the Nordic Council of Ministers must be able to see that the invested resources are providing results that will benefit the Nordic region. And all layers of the Nordic community involved, political stakeholders, civil servant committees, the scientific community, the plant breeding chain as well as the general public must be informed of the importance of such work in order for our food production to adapt to future challenges. It is important that a general understanding for the so-called seed chain is created. Breeding of new varieties is not happening overnight and without investments, and pre-breeding is not a simple task done and ready by working in a few crops for a few years. Short-term breeding projects will not prepare Nordic food production for the future. Exploring the genetic potential of our crop plants is an important part of meeting the challenges of a changing climate in a sustainable way, providing the base for a more environmentally friendly food production in our region. Such a development requires a long term engagement from all stakeholders, patient funding and steady progress, and it must be able to spread into more crops in order to get the desired effects.

Morten Rasmussen
Head of NordGen Plants

Litterature:

Measures to promote Nordic plant breeding, TemaNord 2010:518, © Nordic Council of Ministers, Copenhagen 2010, ISBN 978-92-893-2000-9 http://www.norden.org/sv/publikationer/publikationer/2010-518

Call for pre-breeding project proposals for the PPP program http://www.nordgen.org/ngdoc/plants/ppp_sekr/call_for_proposals_on_prebreeding_projects.pdf

Agreement between the 5 Nordic ministries of Agriculture to establish the PPP program http://www.nordgen.org/ngdoc/plants/ppp_sekr/ppp_proposal_avtal.pdf

For further information:

GLOBAL PARTNERSHIP INITIATIVE FOR PLANT BREEDING CAPACITY BUILDING
http://km.fao.org/gipb/

International Treaty on Plant Genetic Resources for Food and Agriculture
http://www.planttreaty.org/: ftp://ftp.fao.org/docrep/fao/011/i0510e/i0510e.pdf

Global Crop Diversity Trust
http://www.croptrust.org/main/

The Consultative Group on International Agricultural Research (CGIAR)
http://www.cgiar.org/index.html

The Millennium Development Goals report 2011
http://www.un.org/millenniumgoals//pdf/(2011_E)%20MDG%20Report%202011_Book%20LR.pdf

Integration of the use of plant genetic resources into practical breeding

Integrering av växtgenetiska resurser i praktisk förädling

Mati Koppel

Plant Genetic Resources

To make further improvements in the crops the adequate genetic variation must be available in breeding stocks. Three main germplasm resources are available for plant breeders: commercial varieties, landraces, and wild ancestral species and other wild relatives (Lenne & Wood, 1991). The search for superior genotypes regarding yielding ability, disease and pest resistance, stress tolerance or better nutritional quality is very hard, competitive and expensive. Therefore breeders tend to concentrate on adapted and improved materials, avoiding wild parents, landraces and exotics, available in gene banks and the use of which is time and resource consuming. Modern elite cultivars and their close relatives, especially material that is adapted to local environment, are the most useful genetic resources in practical variety breeding. Adapted, elite germplasm from parallel programs within the same ecogeographical region is often intercrossed to facilitate incorporation of genotypic diversity valuable in breeding programs. Continuous selection over the large number of generations increases the frequencies of favorable alleles (Allard, 1997). Therefore, there has been a general tendency in breeding programs towards elimination of variability, coupled with the notion that strictly uniform crop populations are the universal ideal (Simmonds, 1962). The variation within and between the varieties of traditional agriculture has been replaced by more uniform and higher yielding varieties (Lenne & Wood, 1991). The varieties bred in the Nordic countries have also a narrow genetic base. It has been found that overall phenotypic diversity of Nordic spring wheats is low because newer cultivars have been derived from older ones (Ortiz *et al.*, 1998). Unfortunately, as uniform varieties are grown over wide areas, their vulnerability to disease epidemics increases.

Figure 1. The new Estonian potatoe cultivar 'Anti' - Photo M. Koppel
Figur 1. Den nya estniska potatissorten 'Anti' - Foto M. Koppel

When sufficient variation is not available in the breeding collections, breeders turn to gene banks for exotic material that does not have immediate usefulness without selection for adaptation to the given area. Utilization of exotic germplasm enables to increase overall genetic diversity and to develop breeding material which possesses a high level of resistance for pests, diseases and abiotic stresses. The utilization of plant genetic resources is mainly concentrated to cultivated, wild and weedy forms of a crop species, between which gene transfer is easy (Bothmer *et al.*, 1992).

The conservation of genetic variability for the future and the efficient utilization of available ac-

Figure 2. The Estonian genebank in Jögeva currently comprise 2700 accessions. Here seed bags from the active and the base collection. - Photo M. Koppel
Figur 2. Den estniska genbanken i Jögeva omfattar 2700 fröprover. Här fröpåsar från den aktiva kollektionen och från baskollektionen. - Foto M. Koppel

Figure 3. The AVEQ project of genetic resources. Field trials for studies of diversity in oats. - Photo M. Koppel
Figur 3. AVEG-projektet för undersökning av genetiska diversitet. Fältförsök i havre - Foto M. Koppel

cessions are two important goals of gene banks. Germplasm collection, characterization, evaluation, documentation, exchange and conservation are essential steps that can not be overemphasized. Evidently, there is a gap between available genetic resources and activities of breeding programs. While gene banks try to preserve as much as possible, the genetic variability to be used by practical breeders does not explore efficiently the available diversity, relying almost exclusively on their own working collection. Balancing these activities is required for the gene bank to be effective in maintaining genetic variability and to assure germplasm utilization (Nass & Paterniani, 2000).

Pre-breeding

Pre-breeding is a promising activity to link genetic resources and breeding programs. Activities related to utilization of genetic resources in pre-breeding programs are characterized by high cost and long term return. Pre-breeding refers to basic activities with the goal of facilitating use of difficult material (Simmonds, 1993). Pre-breeding includes research and screening activities before a plant material enters the directed breeding process; primarily, it involves the evaluation of traits from exotic material and their introduction into more cultivated background (Schlegel, 2003). Pre-breeding aims to provide to breeders ready utilization of materials with specific traits of interest as well as a means to broaden the diversity of improved germplasm. For private plant breeders, who generally are under pressure to fulfill short term goals, plant material that underwent pre-breeding are likely to be more useful and certainly more attractive. Consequently, close cooperation between public and private institutions can be especially helpful in pre-breeding programs (Nass & Paterniani, 2000).

Several common pre-breeding programs in widening the genetic base of crop plants have been carried out in the Nordic countries with involvement of Nordic Gene Bank (now NordGen), research institutions and breeding companies. Such programs have been described for timothy (Helgadottir & Björnsson, 1994), red clover (Helgadottir, 1996) and spring barley (Veteläinen, 1994).

Jõgeva Plant Breeding Institute

Jõgeva Plant Breeding Institute has a number of successful pre-breeding programs in various crops. Because pre-breeding activities are time and resource consuming, all these activities are carried through in international or national collaboration. In the following some examples of past or present activities of Jõgeva in pre-breeding are given.

There has been a long lasting collaboration of Jõgeva Institute with N.I.Vavilov Institute of Plant Industry (Russia). The most active collaboration took place in 1970-90. We can note the new ac-

Figure 4. *Triticum militinae* used for crosses in wheat pre-breeding. - Photo M. Koppel
Figur 4. Triticum militinae som anvnds i korsningar för pre-breeding i vete. - Foto M. Koppel

Figure 5. Wheat from CIMMYT used in pre-breeding in Estonia - Photo M. Koppel
Figur 5. Vete from CIMMYT som används i pre-breeding projekt i Estland. - Foto M. Koppel

tivation of cooperation during the last five years when exchange of people, information and plant material has increased. The Vavilov Institute has large collections of major agricultural crops with detailed databases of varieties and accessions and specialized research groups working in evaluation, characterization, description and documentation of the varieties. The Vavilov Institute has pre-breeding programs in several crops and in several directions, including resistance to biotic and abiotic stresses, quality properties etc. The information of available accessions and their major agronomical and other important characters are published in annual catalogues and databases. The breeders of the former Soviet Union had access to these catalogues and were able to order the material of their interest. The primary accessions and material from pre-breeding programs have been delivered for a big number of breeders in different parts of the former Soviet Union. Here we can give a potato late blight resistance-breeding program as a good example from that period. During several decades Jõgeva PBI ordered seeds from 20-30 crosses of involvement of several wild potato species from Vavilov Institute every year. Wild species have played a key role in the development of high-performance potato cultivars with resistance to fungal, bacterial, viral, and nematode diseases. Selection process of potato cultivar 'Anti' is a good example of long lasting pre-breeding and breeding activities needed for use of wild species in resistance breeding (Fig. 1). Late blight resistance of the cultivar 'Anti' is based on crosses of the wild potato species *S. demissum x S. infundibuliforme* made at the Vavilov Institute. Two backcrosses with the modern potato cultivars 'Vega' and 'Unicat' were made before delivery of the hybrid seeds to Jõgeva in 1972. Two additional backcrosses were made at Jõgeva with cultivars 'Bellona' and 'Super'. The whole breeding process from initial crossing of wild species until release of the cultivar lasted more than 30 years (Koppel, 1997). The cultivar 'Anti' was registered in Estonia in 1994 and has been one of the potato cultivars having the best resistance to late bligh until now.

The Estonian Gene bank

The Estonian gene bank of cultivated crops has also played an essential role in pre-breeding activities. The gene bank in Jõgeva was founded in

1999. The activities are carried out according to a national action plan on collection and preservation of plant genetic resources. The main mission of the gene bank is long-term *ex situ* preservation of accessions of cereals, grasses, legumes and vegetables of Estonian origin. Currently more than 2700 *ex situ* accessions of 55 species are in preservation in the gene bank (Fig. 2). The gene bank deals not only with preservation of the accessions, but is also actively engaged in pre-breeding activities. The location of the gene bank within the structure of Jõgeva Plant Breeding Institute and tight links with breeding departments are essential prerequisites for the successful pre-breeding activities.

The gene bank has organized joint expeditions of Baltic gene banks into natural and semi-natural grasslands to supplement collections with accessions of grasses and legumes. More than 350 seed samples of *Agrostis, Dactylis, Festuca, Medicago, Phleum, Phalaris, Poa* and *Trifolium* have been collected during 15 collecting missions organized in 2002-2010. Collected accessions have been studied for economically important characteristics such as yield, quality, growth habit, persistence and disease resistance. The results of studies in natural lucerne populations show that many accessions have several economically important characters, but the general yielding ability is lower than that of current cultivated varieties. Therefore a long breeding process is needed to transfer valuable traits from the accessions into competitive varieties (Bender & Tamm, 2010).

Pre-breeding in oats

Another way of involvement of gene bank in pre-breeding activities is initiation and participation in international projects. The most recent project of this type is AVEQ - *Avena* genetic resources for quality in human consumption, funded within the AGRI GEN RES program. Fourteen breeding and research institutions are involved in fulfillment of AVEQ project under coordination of Federal Centre for Breeding Research on Cultivated Plants, Germany. AVEQ deals with the evaluation, characterization and documentation of more than 600 oat accessions of different origin (Fig. 3). The accessions include modern cultivars, landraces and wild species. The project focuses on traits relevant for the quality of oats in human nutrition and for cold tolerance. The focus is on accessions from European *ex situ* collections. The evaluated traits are of high importance for the breeding of cultivars needed for production of premium quality oat products to meet an increasing demand for healthy food in European societies and for the competitiveness of oats as a crop in European agriculture. Accessions with valuable traits have potential use in pre-breeding programs in several European regions. All project results are documented in the European *Avena* database and are made publicly available in an *Avena* genetic resources web portal.

Pre-breeding in wheat

There has been a good long lasting collaboration between Jõgeva Plant Breeding Institute and Department of Gene Technology of Tallinn University of Technology in pre-breeding of spring wheat. A collection of diploid and tetraploid wheat accessions provided by Vavilov Institute has been used in the program as accessible sources of donors of resistance genes for use in wheat improvement. Some 50 introgressive hybrid wheat lines were selected in the progenies of the wide crosses made in early 1990s between bread wheat cultivars and related species – *Triticum timopheevii*, *T. militinae* (Fig. 4), *T. dicoccum, Aegilops speltoides* when used as donors of disease resistance (Priilinn *et al.*, 1996). A new powdery mildew resistance gene *Pm28* has been identified and localized in hybrid wheat line 146-155-T (Järve *et al.*, 2000). An introgressive line 8/1 having high level of resistance to all isolates of *B. graminis* in adult stage has been selected (Jakobson *et al.*, 2006). Introgressive lines are assessed for agronomical and other properties in field conditions in Jõgeva. They have high level of powdery mildew resistance, but also many unwanted lineages with undesirable traits. The 75 most valuable wheat lines have been taken into use in crossing schemes of a spring wheat breeding program at the Jõgeva Plant Breeding Institute. Combination of disease resistance of these lines with high yield and desirable quality properties is complicated because of unwanted lineage of disease resistance with undesirable traits.

A large number of spring and winter wheat accessions of different origin have also been evaluated for suitability in Estonian conditions in Jõgeva during 1996-2000. These accessions include: 337 genotypes from CIMMYT International Winter x Spring Wheat Screening Nurseries (Fig. 5), 136 genotypes from CIMMYT International Winter x Spring Wheat Screening Nursery, 1900 genotypes from USDA National Small Grains Collection, 50 genotypes from N.I.Vavilov Institute of Plant Industry collection and 18 old Estonian and Finnish varieties. The majority of assessed genotypes have been unsuitable for direct use in breeding programs because of undesirable traits such as: low yield, weak straw and susceptibility to diseases, especially to stripe rust. A number of genotypes with desirable traits showing earliness, high protein content, high protein quality, winter hardiness have been identified for use in further breeding programs. Selected genotypes have been used in more than 100 crossing combinations for widening the genetic base of breeding material.

All listed examples of pre-breeding activities in Jõgeva describe importance of involvement of gene bank in pre-breeding and point out the need for national and international collaboration.

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Pre-breeding in forages on the Nordic scene

Pre-breeding av foderväxter för den nordiska marknaden

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Abstract

There are concerns that the genetic diversity in forage cultivars may have become more restricted in recent decades. This may reduce the adaptive potential of grassland populations in a changing climate and hamper the development of new cultivars more suited to marginal environments. Broadening the genetic base of the present breeding populations will create new genetic resources that can subsequently be used to develop new cultivars for new environments. Successful pre-breeding efforts have been carried out in forage grasses and legumes for the northern areas of the Nordic countries. Marketing of a timothy cultivar in joint ownership of the Nordic plant breeding companies has though been problematic whereas red clover populations developed under the auspices of NordGen have been actively used for further cultivar development in the individual breeding firms and for genecological research. It is important to maintain such pre-breeding efforts on the Nordic scene, especially in the light of climate change.

Keywords: forage crops, pre-breeding, climate change, adaptation

Intraspecific genetic diversity in forage crops

Forage species growing in temperate sown grasslands are predominantly outbreeding. Such heterogeneous populations generally contain ample intraspecific genetic variation. This is particularly true for wild ecotypes and landraces allowing them to adapt quickly to changing environmental conditions (Wedderburn *et al*., 2005). 'Grindstad' timothy (*Phleum pratense* L.), for example, is a landrace, which originates from seed imported from Scotland in the 1860s, and has been extensively grown in Norway ever since, especially in the southern part of the country (Marum & Daugstad, 2009).

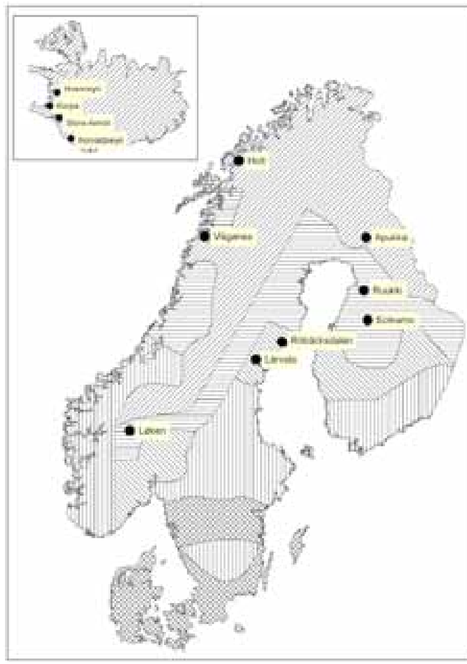

Figure 1. Schematic presentation of growth zones in the Nordic countries, based on results from timothy variety trials (from Björnsson, 1993), and showing the location of the primary testing sites in the *Nordgrass* and *Nordclover* projects.

Figur 1. Växtzoner i de Nordiska länderna, baserade på resultaten från fältförsök med timotejsorter (från Björnsson 1993). Kartan visar också testlokalerna som utnyttjats i Nordgräs- *och* Nordklöver-*projekten.*

It showed poor winter survival when grown in the northern parts compared with locally adapted varieties for the most part of the last century (Schelderup *et al*., 1994) but has been surviving as well or even better as the northerly adapted cultivars, 'Bodin' and 'Vega', in official variety trials over the last 25 years (Arild Larsen, personal communication). This shows that Grindstad contains sufficient genetic variation to be able to adapt to

Table 1. Number of breeding populations obtained in the *Nordclover* project using different sources of material and selection procedures. A: Commercial diploid varieties (10 populations); B: Diploid breeding material and wild populations from NGB (12 populations); C: Commercial tetraploid varieties (5 populations); D: Material with a broad genetic background (238 populations).
Tabell 1. Antalet förädlingspopulationer som utvecklats i Nordklöver*-projektet och där olika ursprungsmaterial och selektionsmetoder använts. A: Kommersiella diploida sorter (10 populationer); B: Diploida förädlingspopulationer samt vilda populationer from NGB (12 populationer); C: Kommersiella tetraploida sorter (5 populationer); D: material med bred genetisk bakgrund (238 populationer).*

Selection method	A	B	C	D
Selection in the field	28	10	18	8
Fusarium resistance	3	2	3	
Sclerotinia resistance	3	1	3	
Frost resistance	2		2	
Total	36	13	26	8

a milder climate in these regions, possibly as a result of changing practice for seed production in the second half of the last century (Daugstad, 2011).

In recent decades the genetic diversity in agricultural grasslands has eroded, mainly because the original landraces and ecotypes have been replaced by productive commercial cultivars with a more restrictive genetic base (e.g. van Treuren *et al*., 2005). The reasons for this are twofold. Firstly, in order to have new cultivars protected with Plant Breeders' Rights (PBR) they have to undergo a strict test for distinctness, uniformity and stability (DUS-test), the principles of which are laid down in the UPOV Convention and the EU legislation. Secondly, breeding programmes often use a limited number of genotypes and synthetic varieties are commonly made up of a few parental genotypes. This approach causes concern as a certain degree of genetic variability is necessary for adaptive evolution and, thus, reduces the adaptive potential of agricultural grassland populations to a changing climate. Further, a restrictive genetic base may limit the success of extending the cultivation of valuable species, especially at the margin of their distribution. One way of broadening the genetic base of the present breeding populations is to cross them with suitable exotic material for recombination of valuable traits. Such pre-breeding efforts will create new genetic resources that can subsequently be used to develop new cultivars for new environments.

Previous pre-breeding efforts in the Nordic region

It has been demonstrated that the Nordic region can be split up into agroclimatic zones (Figure 1) based on climatic conditions for grass cultivation (Björnsson, 1993). The northern areas are thus characterised by a short and variable growing season and harsh winters commonly causing extensive winter damage, especially of cultivars bred for more southerly conditions. The seed market is small in these areas making local breeding efforts uneconomical. Thirty years ago forage breeding for the region was mostly carried out in governmental institutions and in 1981 Nordic Plant Breeding (Samnordisk planteforædling – SNP) initiated a joint Nordic breeding programme, Nordgrass, as it seemed sensible at the time to join forces in forage breeding across national borders. The primary aim was to develop fodder grass varieties that were adapted to a broad range of climatic and management conditions prevailing in northern parts of Scandinavia and Iceland (Helgadóttir & Björnsson 1994). Initially, extensive variety trials with timothy, smooth meadow grass (*Poa pratensis* L.), meadow fescue (*Festuca pratensis* Huds.) and red fescue (*Festuca rubra* L.) were established across the whole region and for timothy, no interactions were found between varieties and sites (Helgadóttir, 1989). Subsequently, a common breeding project for timothy was initiated with the aim of producing a variety that could be used across the region. A polycross consisting of 60 selected genotypes was established in Denmark in 1985 followed by extensive progeny trials at five test stations across the northern region. Two synthetic populations were subsequently created and made available for extensive variety trials (Helgadóttir, Björnsson & Kristjánsdóttir, 1995) leading eventually to the registration of the cultivar 'Snorri' in 2006. However, by that time the plant breeding companies still operating in the region had been privatised, thus making the marketing of a cultivar in joint ownership problematic.

The second pre-breeding programme in forages, Nordclover, was initiated by the Nordic Gene Bank in 1992. The main aim was to provide well-adapted breeding material of red clover (T*rifolium pratense* L.) with a wide genetic base for further cultivar development (Helgadóttir *et al.*, 2000). As for timothy, the focus was primarily on the northern regions. A total of six different base populations were produced, consisting of both diploid and tetraploid varieties and wild populations stored in the Nordic Gene Bank and in other gene banks across the world (Table 1). These populations were subject to recurrent mass selection at four sites and under three different management treatments as well as to tandem selection under controlled conditions for resistance to frost and snow mould (*Microdocium nivale* and *Sclerotinia borealis*). At the end of the programme, seven years later, a total of 83 different populations had been produced (Table 1). It was assumed that they contained relatively large genetic variation and were adapted to the climatic conditions prevailing in the northern environment even though it was not a part of the initial programme to test this assumption.

Further use of the pre-breeding populations from the *Nordclover* project

The Nordic Gene Bank supported the Nordclover project in the attempt to promote the use of their stored material in plant breeding programmes. Indeed, Hill *et al.* (1998) argued that the collection in a dynamic gene bank should be used to initiate sequential plant breeding programmes involving pre-breeding and local selection. Further, it was suggested that the Nordclover populations would provide an ideal material for various genecological studies (Helgadóttir *et al.*, 2000). It is therefore of interest to explore whether the extensive material that resulted from the Nordclover project has been used in breeding or research.

At present the red clover populations have primarily been included in the breeding activities at Graminor in Norway. There they have been used in 18% of pair crosses carried out by from 1998 and at least 36 candivars currently under internal testing (Bjørke, Løken and Vågønes/Holt) contain this material. It is though unclear at present whether they will become registered cultivars as it takes a long time to market new forage crop cultivars. However, the "Nordclover material is now a not insignificant part of our breeding material" (Petter Marum, personal communication).

Secondly, seed from populations resulting from intercrossing for two generations of 283 accessions made up of the entire red clover collection of NordGen (former Nordic Gene Bank), in addition to other populations from other areas (mainly former USSR) (Table 1 – Population D), is the main source of red clover in a new pre-breeding project in Norway initiated in 2003. On-farm conservation of the forage species timothy, meadow fescue and red clover – generation of new landraces in Norway (Daugstad, 2011). The primary aim of this project is to produce seed of 'new landraces' that are adapted to different climates and management practices. The first seed was produced in 2010 in five different locations and this will be used to establish new meadows at the same locations.

Finally, this material has been used for biodiversity studies in forage ecosystems where it has been explored whether (i) composite populations provide a platform for further and sustained positive effects of mixing species, (ii) single varieties display a lower level of 'within population' genetic diversity than composite populations, (iii) composite populations adapt quickly to diverse environments. The results indicate that molecular diversity was comparable for single varieties and the composite populations but the latter showed considerable adaptability to contrasting environments (Collins *et al.*, 2010). Further, Frankow-Lindberg *et al.* (2009) found that using the composite populations had little additional impact on the yield in multi-species mixtures beyond that of species diversity.

Future prospects

Long-term climate change scenarios for the northern regions postulate an extended growth season combined with milder and wetter autumns and winters (Christensen *et al.*, 2007). This raises the question whether we need exotic material into our current breeding stock – new genetic resources – for future cultivar development in order to meet new challenges for forage plant production in these areas. Already a number of research projects have been initiated to answer these questions, both at a national level (e.g. VARCLIM – Adaptation of Norwegian perennial forage crops to future climates, supported by the Research Council of Norway) and in Nordic collaboration (e.g. Phenotypic and molecular characterisation of genetic resources of Nordic timothy, supported by NKJ (Nordic Joint Committee for Agricultural and Food Research); Climatic adaptation of different species and varieties of grass and clover in the West-Nordic countries, supported by NORA; NOFOCGRAN – Nordic Forage Crops Genetic Resource Adaptation Network, supported by NordForsk). However, in the short term forage plant breeders need to meet the requirements of the present farmers for increased profitability by providing them with reliable, high yielding cultivars of good forage quality. In the light of climate change the greatest challenge could be to extend the cultivation of perennial ryegrass into the more marginal areas as this species is renowned for its high feed quality and productivity under frequent cutting. Hopefully, the Nordic Public Private Partnership (PPP) for plant breeding, which has recently been initiated by the Nordic Council of Ministers (Nilsson and von Bothmer, 2010), will be able to bring about progress in this field.

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Sammanfattning

Det finns farhågor att den genetiska diversiteten har minskat i våra foderväxter under de senaste decennierna. Detta kan försämra potentialen för god anpassning i gräspopulationer under perioder av kraftig klimatförändring och kan begränsa möjligheterna för att utveckla nya sorter anpassade till marginella områden. En breddning av den genetiska basen av nuvarande förädlingspopulationer kommer att skapa nya genetiska resurser som kan utvecklas till nya sorter för helt nya områden. En framgångsrik pre-breeding har genomförts i fodergräs och ärtväxter för nordliga områden. Marknadsföring av en ny timotejsort med gemensamt ägande av de nordiska växtförädlingsföretagen har dock visat sig vara problematisk, medan en rödklöverpopulation som tagits fram under ledning av NordGen har använts för fortsatt förädling vid de enskilda företagen och även för genekolisk forskning. Det är viktigt att bibehålla en fortsatt gemensam pre-breeding bland de nordiska länderna, speciellt mot bakgrund av kommande klimatförändringar.

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Climate change as a challenge to Nordic plant breeding

Klimatförändringar – en utmaning för nordisk växtförädlimg

Åsmund Bjørnstad

Introduction

The basic challenge that any terrestrial plant – individual or species – has to face, is that it cannot move and must be able to cope with the living conditions where it has managed to establish itself. The many evolutionary consequences of this trivial point were brought forth by Bradshaw in his famous review from 1972, Some of the evolutionary consequences of being a plant (Bradshaw, 1972). This, of course, applies both to climatic and soil conditions.

In the context of climate a plant cultivar has to deal with seasonal and annual fluctuations, and changes in long term climatic trends. The two are, however, intertwined since trends may have two components: (1) the changes in average precipitation or temperatures, and (2) the magnitudes of annual or seasonal fluctuations, i.e. the stability. In the Nordic context the increases in mean temperatures are not difficult to deal with. It is always possible to select later maturing or less winter hardy cultivars, and as new crops enter the fields and call for testing and gradually breeding. This process is plainly visible in the return of widespread barley cultivation north of the Arctic Circle, the first fields of winter wheat in Iceland or forage maize in Norway. It is no big challenge to breeders to increase average yield potential in this way.

However, the stability in face of fluctuations needs more careful attention. To what conditions will cultivars need to be more resilient? How can they be tested in advance? Will new traits or combination of traits be needed? Is pre-breeding of new genetic variation or a diversity strategy needed to minimize the impacts of extremes? In the present paper I will outline a few cases related to climate as well as soil conditions.

A case for shuttle breeding

The well-tested CIMMYT strategy to deal with fluctuating environments has been to expose plants to contrasting stresses during breeding (Lillemo *et al.*, 2010). This encompasses stress (mostly disease) nurseries or testing in hot spots of the stresses, and shuttle breeding by testing in contrasting climates. In a fluctuating climate the year-to-year variation may be enough, if the breeding station has the fortune of being representative of the expected range of environments. Otherwise shuttle breeding may be along a south-to-north gradient or a maritime-to continental one or both.

One case to illustrate this point is the study by Lillemo *et al.* (2010) of breeding progress in barley breeding in Trøndelag (Central Norway). In this (for barley) marginal maritime environment both temperatures and rainfall during the growing season vary widely. In addition, there has been a conscious, but less visible shuttle breeding through testing in alternating soil types. From 1945 to 2005 both yield level and stability of the yield have increased markedly through breeding for higher resistance to lodging, pre-harvest sprouting and diseases, primarily scald (Fig. 1). The result has been a series of successful cultivars that have been grown from Iceland to Estonia.

A second case is how to increase the winter hardiness of perennial ryegrass. This very valuable forage grass has in the Nordic countries largely been limited to Denmark and southern coastal regions, but its potential is wider. Testing sites that encompass a wider range are needed. Autotetraploid cultivars or *Festulolium* hybrids add to the options, but where should they be tested? The long-term collaborative research program of professor Odd Arne Rognli, Norwegian University of Life Sciences (UMB) has shown the utility of the former breeding site Vågønes close to Bodø in this regard (Larsen *et al.*, 2010). Apparently the climatic con-

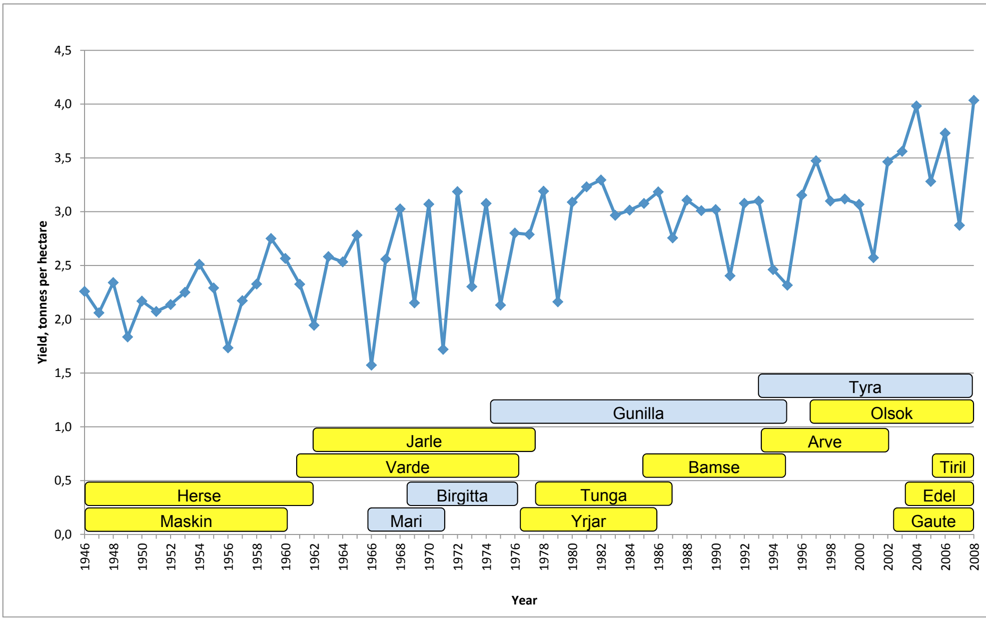

Figure 1. Trends in barley yields in Trøndelag from 1946-2005. Long term checks indicated by bars (yellow = six rowed, blue = two-rowed). The sharp fluctuations during the early combine era from 1960-80 is replaced by a more stable phase, interpreted as due to breeding for more stable and high yields. From Lillemo *et al.* (2010).

ditions span a range of stresses that allow efficient selection (also evidenced in the past from very broadly adapted cultivars like 'Salten' and 'Norild' meadow fescues).

The lessons that may be learnt from these cases are that (1) to meet the expected climatic fluctuations the relevant genetic diversity should be tested through shuttle breeding or in a sufficiently fluctuating environment; and (2) proven good selection sites should not be closed down due to short-sighted budget considerations. Instead a Nordic pre-breeding strategy for climate change should create networks of exchange of such sites for mutual benefit. Imagine a shuttle breeding for e.g. testing Northern timothy or barley cultivars along the Arctic Circle in Bodø and Finland!

New tools for exploring phenotypic data

Most breeding trials are analyzed in classical univariate ways (one trait at a time or simple correlations) and usually end up with selecting genotypes that have high means over sites tested and a minimum of understanding why. In the recent years good and breeder-friendly softwares have become available, that may specifically allow a more exhaustive analysis of adaptation. The one I will describe is the GGE-Biplot, developed by the Canadian oat breeder Weikai Yan (www.ggebiplot.com). Once the user understands that the graphical biplot display contains the same information as in an analysis of variance plus much more, it allows a number of options not easily addressed before, such as:

- To identify groups of genotypes that behave similarly or not
- The "Which-won-where" plot that shows which genotypes "win" in certain environments
- The analysis of e.g. climatic data may allow relating genotype performance to specific independent variables, i.e. adaptation
- The identification of representative, discriminating and redundant testing sites to make testing more efficient.

In Figs. 2 and 3 bi-plot displaying some of these features are illustrated. The GGE approach also allows an analysis of trait relationships and which traits are associated with which genotypes and extends this to a visual and empirical index selection for a desirable genotype. Such tools are widely used by breeders in

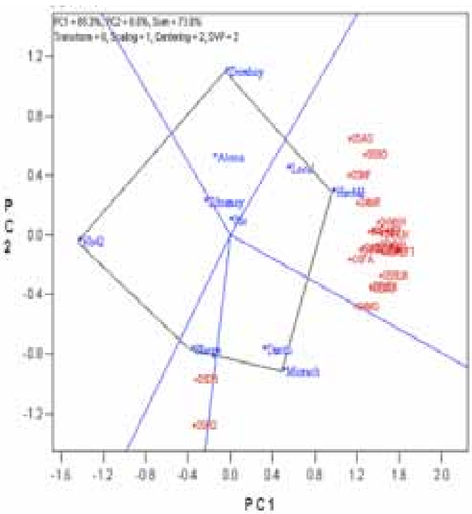

Figure 2. "Which-won-where" bi-plot of 10 barley varieties tested in 21 environments (years x locations) in Ethiopia. A polygon view is drawn for the varieties (in blue) having the most extreme values in yield in different environments (red). It is plainly seen that environments fall in two major groups. Along PC1 the environments in Tigray (mostly on farms) cluster to the right, along PC2 two central breeding stations are another group. The variety on the polygon most closely associated with Tigray is Himblil, meaning it is the highest yielding, while to the far left Hb42 signifies it is the lowest yielding. The varieties that do best in the breeding stations (Misrach, Dimtu) were selected in there. The two groups of environments are weakly negatively correlated (angle >90), signifying that selection in the central part of the country will not be likely to produce suited varieties for Tigray. From Abay and Bjørnstad (2009)

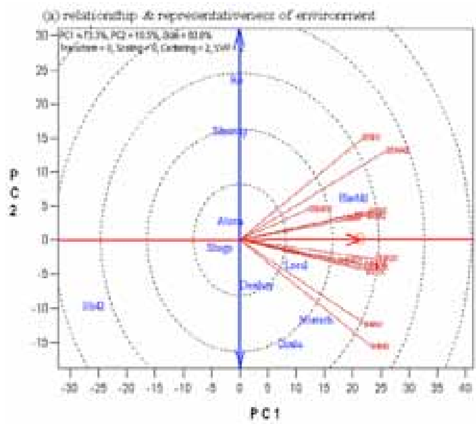

Figure 3. GGE bi-plot displaying a more detailed look at the relations between environments in Tigray. Which environments represent the environmental range? The open circle on the red horizontal line through the origin signifies the average environment. Environments close to this are representative. Two clusters come close, and since the clustering means a narrow angle between the environmental vectors, they are very similar (redundant) and may be represented by one of them. Conversely, environments far from the average (wide angles) are not representative. The length of the vector is a measure of ability to discriminate between varieties (variance). The ideal testing environment then should be both representative and discriminating. The pattern seen here is mainly 2004 below the average, 2005 above.

North-America and in the CG system, but not to my knowledge in the Nordic countries. There is an increasing realization that improved phenotyping is needed to make use of economic resources as well as the plethora of genotypic data that will become available. Efficient multivariate analyses are very helpful in both regards.

Be ahead of fluctuations through targeted genetic diversity

If the environments are to be less stable, it is important to predict the likely fluctuations. Can they be met by breeding "risk aversion" into the cultivars? Some examples will be mentioned.

Reproductive frost tolerance in barley. Barley cultivation is rapidly expanding northwards – again. It became extinct from its Northern limit – Alta in Finnmark (at 69.6 degrees N in Norway) in the 1920s. In the old times frosts during grain filling was a dreaded event, and frost tolerance at this stage appeared non-existing (it should be kept in mind that sowing was later than today). Harry V. Harlan found such tolerance only in barleys from high altitudes, never high latitudes (Harlan, 1957). Mapping studies in Australia (Reinheimer *et al.*, 2004) show that a major QTL is located in or close to the well-known vernalization locus *Vrn-H1* on chromosome 5HL. This means that markers are available. It may be a commendable pre-breeding target to introgress this QTL in Northern barleys to avoid possible losses, which could have been the case with a significant frost night that occurred in the inland of Eastern Norway in July 2010.

Early summer drought in oats. An important climate prediction is an increasing frequency of early season drought. To breed for tolerance is an obvious response, and I will use oat as a case. It is a common perception by oat breeders that the Nordic gene pool is limited in diversity. This was recently shown by Tinker and coworkers using DArT markers, displaying the Nordic oats as one dense cluster (Tinker *et al.*, 2009). A more detailed study by He & Bjørnstad (submitted) showed that this primarily relates to the active breeding gene pool. A large(r) share of the oat gene pool existing about 100 years ago was left behind, including the black hulled oats. They had a reputation for early summer frost tolerance, due to a specific phenology (Mattson, 1997). Instead of elongating tillers it develops stronger root systems, making it more robust on sandy and light soils. The trait appears highly heritable, can be subjected to early generation selection and awaits new pre-breeding efforts (Larsson, 1982).

Water-logging tolerance in barley. Although climate change predicts more early summer drought, another prediction is excessive rainfall. Combined with insufficiently drained soils this may lead to increasing problems with water-logging. One species particularly susceptible to this is barley. Tolerance has been identified in Chinese germplasm (Zhou, 2007) and has been shown to be mainly additive and be clearly heritable, but subject to the testing system applied. In the Nordic countries Nils-Ove Bertholdsson in SLU, Sweden has developed screening methods and shown clear differences among current barley cultivars.

Nutrient efficiency. Water-logging and drought also affects nutrient uptake efficiency. Many breeders now seem at last to make a serious attention to breed for "the other half" of the plant. Since nitrogen efficiency seems related to root system size and ability to capture the nutrient, there are less GxE interactions (adaptation): Efficient oat genotypes tend to be the same at both high and low input of nitrogen (Atlin and Frey, 1989). Phosphorus efficiency is, however, highly genotype dependent. A Nordic study of great relevance is that of Hannu Ahokas (Ahokas and Manninen, 2001), who found large differences between Finnish barley genotypes in the phosphorus acquisition strategies. Some excreted acid phosphatase to release bound P, others organic acids. This study waits for a follow up in soil (it was done in an axenic system). Another strategy is endomychorriza formation. In her Diploma thesis, Annie Jensen (now Nordic Seed) showed significant differences between pea cultivars and landraces in their ability to stimulate endomychorriza colonization (Jensen, 1985). Together with variations in root mass there appeared to be good scope to breed for the trait, but it has not been followed up. The coming scarcity of phosphorus (Cordell *et al.*, 2009) makes it imperative to do pre-breeding of such traits.

Conclusions

While some aspects of pre-breeding attract much attention (but not necessarily funding), like marker development and associated disease resistance, the scope should be broader and also encompass efficient phenotyping. To meet a more fluctuating environment the shuttle breeding concept has much merit for the Nordic plant breeding – whether if integrated into commercial collaboration or as a precompetitive sphere.

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Sammanfattning

Medan vissa aspekter inom pre-breeding får mycket uppmärksamhet (men inte nödvändigtvis finansiering), som till exempel utveckling av markörer, måste målsättningen vidgas och även omfatta phenotyping. För att möta stora variationer i omvärldsfaktorerna bör ”shuttle breeding” metoden på olika sätt användas mer inom nordisk växtförädling.

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Perspectives for genetically modified cereals in Europe

Möjligheter för genetiskt modifierade cerealier i Europa

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Abstract

GMO technology has been the issue for large debates throughout Europe. However, at the moment the use of the technology is at large neglected in most countries. Though this for some people seems to be the right decision, it to others looks like unnecessary hindrance towards a more sustainable agriculture. Whatever point of view, the technology is here and we owe it to ourselves to deal with the issue in a fair manner. This requires looking at the topic from a holistic point of view combining many aspects related to the use of technology.

Introduction

For the last decade or more, genetically modified plants (GMOs) are seen as either the tool that will secure the World's future demand for food, or as something made by multinational companies with the potential to destroy our nature.

However, GMOs are not going to save the World, nor are they simply a tool by which multinational companies gain monopoly on our food-supply. But the technology to transfer genes from one species to another is here and it is relevant. This is because use of GM technology offers possibilities for more targeted and efficient plant breeding. But GM technology is not the only answer to our efforts for a secured sustainable food supply in the future.

The last 10 years' progress in biotechnology has clearly demonstrated that GM technology as the main source of improvement is not a good gamble. Of the ~90 approved GMOs in the US (http://cera-gmc.org/), Bt-resistance, glyphosate and/or glucosinolate-tolerance accounts for more than two-thirds. Though all three traits are beneficial for as well the farmer as the environment, they are not the breakthrough neither scientists nor industry has promised should come from GMO.

However, getting steady improvements in yield and quality, preferably in an even higher speed than now, requires increased investments. With the current regulations and intellectual property rights (IP) system, GMO technology offers a good chance for return of investment. Therefore, investments are likely to be done in developing GMOs. So whether we in Europe like it or not the GMO technology deserves to be considered a part of our toolbox in plant breeding.

Objective of the GMO debate in Europe should therefore not be on whether we will accept genetically modified crops, and foods made from them. But rather be on asking the question; how do we as a society get the best of the GMO technology? To answer this question requires that politicians, the public, media and industry start dealing seriously with the GMO issue. Not as a series of isolated topics feasible to create top stories, but from a more holistic point of view. That means addressing the GM technology from different directions, and combining them.

One of the issues that has to be considered relates to biology. Though biology has to be seen in a broad sense covering all topics related to either biological or technical features, such as limitations due to physiological aspects, species barriers and transformation techniques. It also includes matters related to agronomy, i.e. whether a trait is actually relevant to the farmer, and offers opportunity to secure a better and more stable yield.

Regulation is another direction from which GMOs has to be discussed. This covers not only permissions for sale, production and use of GMO plants, that currently are in place in Europe, but also questions on liability and stewardship, issues mostly overseen in the present debate. Although the question on liability and stewardship of released GMOs might end up determining our potential to benefit from GM-bred crops.

The last perspective in the GMO debate looked upon here is IP (Intellectual Property). This issue covers the rights to control commercialization and development of new improved varieties. The introduction of patents related to plants has the potential to inflict on the farmers right to own harvest. Today, plant variety protection (PVP) is based on UPOV convention. However, whereas the breeders' right under this system is limited to seed and propagated material, patents can be related all the way through to end-use. IP rights on genetically modified plants might therefore seem as a straight forward discussion but, when the GMO issue is seen in a context of the whole society patent-rights on plants become much more complex. On the one hand we want to protect the farmers' right over their harvest, and ensure open access to the genetic resources for the breeder. While at the same time there is a need to attract and protect the necessary investments, thereby enabling development of new varieties.

To these three views on GMO, the public opinion and concern could have been added as a fourth. However, here I will only deal with these three issues, and mainly focus on the biological side.

Cereal value chain

Imagine a chain going from the breeder to the end-user or consumer. The individual parts of the chain, between the breeder and the end-user, consist of the parties involved in handling and/or dealing with the grain. The role of each step of the chain is adding value to the grain. This value can be added either directly, as the end-part of the chain, where the flour is more valuable than whole grains. Or more indirectly in the beginning where the added value comes from new varieties representing genetic improvements, and a potential for increased yield. This enables the seed-producer to sell the seed to a higher price based on an expectation from the farmer of a better and more valuable harvest.

In addition to the parts indicated above, other parts of the chain consist of a regulatory system controlling new varieties entrance to the market, for example, through DUS and VCU testing, seed certification, field inspection etc. A function of these mechanisms is to ensure that the next part in the chain is actually getting a product with the added value it is paying for. This means that the new variety represents genetic improvements or that the seed is from the chosen variety and will germinate. In the other end of the chain it also functions as a guarantee that grain bought for malting is actually suited for malting. Plant breeding is the first part of the chain, and it serves to ensure the foundation of the added value all the way through the chain.

To make the chain work each part of the chain has to reward the previous parts of the chain, for the added value. For example, a maltster pays more for a harvest from a recognised variety sown with certified seed, than he will do for a harvest from farm-saved seed of unknown origin. However, in the beginning of the chain breeders input into the chain is not of a physical matter. Therefore the breeder relies on an effective IP system, in order to enable the collection of royalties, and thereby funding for future trait and variety development.

It is onto this chain GMO technology has to be added, as a separate step before the breeding part. For a GMO to be successful it therefore has to add value that can be recognised by each part of the chain. Furthermore, all the regulatory and IP related matters related to the release and use of a GMO also has to fit the chain. This is why the GMO issue cannot be dealt with only by looking at its impact on isolated parts of the chain. It is not just a matter of better regulations – whether that means less or more regulations – or whether the farmer can save some insecticides.

Requirements for a successful GMO

Developing a successful GMO requires more than satisfying the farmers' wish for higher yield with lower input. A GMO has to be developed in a context of the whole value chain. This includes considering how the GMO will be affected by IP and regulatory systems, and the chance of the effort being rewarded by later parts of the chain.

Today the regulations dealing with access to cultivars containing a genetically modified trait into the market, are very costly, and can easily sum up to several million euros. Therefore it is relevant to analyze whether the trait can be reached without the creation of a variety classified as a GMO. For some traits the answer to this question is straight forward, whereas for other traits the answer is more difficult to obtain. Physiological traits regulated by several genes might usually be considerably more difficult to change than traits controlled by single genes. A look at either the US based CERA database or the European GMO-Compass (www.gmo-compass.org/), shows that the vast majority of approved GMOs are related to traits controlled by single genes. Most of the traits comprise resistance or tolerance to insects, viruses or herbicides. In other words traits that are easy to monitor, and do not impose changes on the physiology of the plant. Another reason for the success of these GMOs is that the traits are not confined to a single plant species. Round-Up tolerance can be useful in more or less all species, as its main restriction lies in the agronomy practice by the farmer. As for GMOs containing *Bt*-resistance, this trait is obtained by different alleles of the cry gene derived from *Bacillus thuringiensis*. This gene confers non-species specific resistance to various insects.

Another class of GMOs that have reached the market contains traits related to quality. Examples of such GMOs are increased lysine-content in maize, high oleic acid in soybean and canola, delayed ripening in carnation flower and melons, or the well-known Flavr Savr® tomato. In common for these GMOs is that they have been obtained by expression of a single gene not changing the physiology of the plant.

All these examples can be seen as a first generation GMOs, where the common feature is that they have been obtained by expression of a single gene. These GMOs are characterised by the benefit of the introduced trait being directly accessible for the farmer. When the farmer gets a benefit from planting a crop containing GMO, it means that he is willing to pay extra for the seed, thus sending money backwards in the chain. In other words the seed containing the GMO represents an added value compared to other seed he could have used, and thereby the value-chain is functioning.

Second generation GMOs

Although the first generation GMOs have been on the market for nearly 20 years, the step towards GMOs with more complex traits has yet to be achieved, but it is difficult to draw a sharp edge between first and second generation GMOs. One way to divide GMOs is to define the complexity of the trait altered. The first generation GMOs, as described above, is characterised as being controlled by single genes, and without affecting the whole plant physiology. The second generation of GMOs contain traits governed by multiple genes, and/or with a large effect on plant physiology. Examples of such traits are enhanced nitrogen use efficiency, functional nodule formation, and lodging resistance. The insertion of whole pathways, enabling synthesis of secondary metabolites, can also be seen as second generation GMOs.

Herbicide tolerance can be achieved by expression of a single gene, as in the case of the Roundup Ready® technology developed by Monsanto. Compared to this traits related to plant physiology requires controlled expression of several genes. The genes might also only be expressed under specific environmental conditions. This, together with the often more quantitative nature of the traits, makes them much harder to phenotype, than for example herbicide-tolerance. Furthermore negative side effects arising when altering the plants own fine tuned balance have to be minimized.

Another group of second generation GMOs consists of plants were the insertion of whole pathways enables production of new compounds not found in the plant before. Developing this kind of GMOs requires the insertion of several functional genes in a pathway. However, these compounds might turn out to be toxic or otherwise harmful to the plant and thus, a demand for a targeted expression and location of the compound, perhaps followed by specifically designed extraction methods. As novel compounds require genes not present in the chosen species, it is obvious that this production can best be achieved through GMOs. Due to the complex nature of traits related to plant physiology it is a question whether GMO technology is the best way to achieve the wanted improvements. For some of these traits the necessary genetics might already be present within the species, and the goal can be reached with targeted breeding. Involving relevant biotech tools such as genetic markers and metabolomics, this approach is likely to give a better result for the same investment, at least for some of traits.

Who will pay?

After dividing GMOs into first and second generations, it is relevant to look at other aspects deciding which traits are relevant to work with by looking on how well the GMO fits into the cereal value-chain. Most first generation GMOs contain traits from which the farmer gets an immediate benefit, usually due to a larger harvest, or the same harvest but with a lower input. The farmer is thus motivated to pay more for the seed, enabling funding for development of new varieties. For these traits there is no requirement for an additional pay later in the chain, as the farmer has already gained the benefit of the improved variety. Opposite with the traits related to the end-user, for example, in the form of improved quality. For these GMOs the benefit of the improved trait lies with the consumer or processor, i.e. maltster, baker etc. Therefore it is much more complicated to ensure a reward to the trait-developer and/or breeder for the added value. The reason is that the added value will not be recognised and acknowledged before the end part of the chain. In many cases varieties containing such a trait might also be lower yielding than the conventional varieties already on the market. Because of this, the need for added value, and the pressure to assure the functionality and control of the value-chain increases. This issue has partly been solved with GMOs being protected by patents, which enables the patent holder to control larger parts of the chain, than is possible under UPOV protection.

Finally, the market size is an important driver for trait development. Herbicide tolerance or insect resistance are valuable traits in most crops and most areas, independent of climate zone or soil type. For traits related to agronomy and plant physiology, such as lodging resistance, it is much more complicated to transfer the trait between species and geographical areas. Thus the potential market and chance for return of investment becomes smaller. For nitrogen use efficiency the success of a GMO is influenced not just on how species-specific the trait is, but also on the availability and price on nitrogen fertilizers. In some countries restriction on use of fertilizers, decides its potential.

Development of novel products as, for example, drugs or secondary metabolites the situation changes slightly. Here the value of the novel product is going to drive the development and release of the GMO, as the grain itself represents an increased value. The seed is more or less useless if the introduced trait is not exploited since the use of the harvested crop can be restricted by patent or other regulatory measures. It may be easier to estimate the added value along the chain which is a good strategy to control the value-chain. On the other hand regulations and patents could serve to ensure the right commitment along the chain. The drawback in all cases is the relatively high cost of getting a GMO approved and onto the market as this puts high demands on either market size or product value, or both.

IP and regulatory constrictions for GMOs

The IP and regulation issues are too large to be described in any detail here. However, I will mention a few points to illustrate how complex it is to balance the need for investment and innovation. While at the same time ensure free competition and prevent monopolization of breeding and food production.

First of all it is important to stress that without intellectual property protection there will be no innovation and development of new improved varieties. At the moment conventionally bred varieties are protected by Plant Variety Protection (PVP) under the UPOV convention and there are two main points differentiating PVP and patents. One is on the exhaustion of rights, in terms of farmer's free use of own harvest – unless for selling it as new seed. The other is the breeder's exemption allowing breeders to cross with competitors' varieties, once they are released. Under the patent law there is no "breeder's exemption" and the way patents related to GMOs mean that access to cross with GM cultivars is prohibited. Because of this, the current IP situation possesses the risk of blocking what was until now a free access to genetic diversity.

Regarding regulations, the main concern is that today's demand for testing is so costly that only a handful of companies worldwide are able to work with GMO development. Such a concentration of investment and development of GMOs into a rather small group of companies increases the risk of a monopolization of the technology.

Summary

There are many challenges to be overcome before a GMO can enter the market. These can be related to its relevance in terms of choice of crop and trait and the combination of these. Depending on where in the value chain the added value is placed, a strategy rewarding intermediate steps has to be considered. Despite all these challenges, GMO assisted breeding offers many opportunities to overcome species barriers and do targeted breeding for selected traits. Therefore, the technique ought to be recognised as a natural part of our toolbox in breeding, and thus deregulated.

At the moment the energy is spent on endless discussions on what is to be considered natural crops. How many restrictions on innovation and development of organic farming should be allowed to place on the rest of society? Instead we should start discussing what type of GMOs we want, i.e. from where we want to transfer genes, or if we want medicine to be produced in our food crops. Our unwillingness to deal with the GMO issue holistically is only pushing investments and control to parts of the world having a more relaxed view on the technology. There is a need for a discussion on how we can assure that society gets the most out of the technology. This means balancing regulations and IP matters, in such a way that it is possible for more traits to get access to the market. Yet, at the same time keep control of the released crops. Furthermore IP systems have to be updated to cover plants classified as GMOs. But in a way that motivates investment on one side, without limiting free access to genetic resources on the other.

But pretending we can keep GMOs out of Europe, by denying the issue or trying to prohibit use of the technology will only make things worse for ourselves.

Sammanfattning

GM teknologi har varit föremål för intensiva diskussioner i Europa och användningen av GMO är för närvarande mycket låg i området. Några anser detta vara rätt beslut men för andra är det ett stort hinder mot utvecklingen av ett uthålligt jordbruk. Oavsett vad man anser är den nya teknologin här och vi bör hantera frågan på ett opartiskt sätt. Detta innebär att man bör ta ett helhetsgrepp på GMO-frågan och inkludera många olika aspekter för att kunna bedöma teknikens framtida användning och möjligheter.

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Links to marketing efforts

Koppling till marknadsinsatser

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Abstract

Pre-breeding efforts in a company context are handled from several different perspectives, above all on income opportunities, such as the size of the actual market which is addressed and the competitive situation. Could the results give short-term effects, or is it more to be seen as a necessary tool for the mid- or long-term development? Are there issues on intellectual properties? Should the project be performed in-house or in collaboration with other companies? Or is it preferable to support public research in this area? Examples are given on how pre-breeding efforts are handled in a commercial context, mainly based on experiences from Svalöf Weibull (SW) during the period 1990 – 2005.

Introduction

Decisions on pre-breeding efforts in a company context are handled from several different perspectives. In the following such issues are discussed, also with examples from how Svalöf Weibull (SW) handled such issues in 1990 – 2005, the period I can relate to and when I had a position in the management of the company, mainly as Research Director.

Above all, decisions and undertakings on pre-breeding are based on income opportunities, such as the size of the actual market which is addressed and the competitive situation. The crop-wise strategies are outlining mid-term directions, revised with 3-5 year intervals and annually updated. With this basis decisions would be taken in the annual budget process on different projects and their start, continuation or closing. Important questions to address in this process are not only the scientific challenges and results, but also the importance for the market positions. Could the results give short-term market effects, or is it more to be seen as a necessary tool for the mid- or long-term development? Are there any patents that need to be considered or other issues related to intellectual properties? Should the project be performed in-house or in collaboration with other companies? Or is it preferable to support public research in this area?

For a number of traits there is a constant need of pre-breeding efforts. This is the situation for resistance to pathogens with swift development of new patotypes, such as blackleg (*Phoma*) on oilseed rape, powdery mildew on wheat and barley, rust diseases on cereals, *Septoria* on wheat, late blight on potatoes, etc. Here more or less all commercial breeders in these species are actively pursuing efforts on different levels.

Examples on links to marketing efforts

For breeding companies that have a position as market leader, or the ambition to reach this position, pre-breeding for new traits or tools is attractive. Thus, many of the international network projects gather the leading breeding companies. This is especially the case for projects on development of genomic tools and hybrid systems. As examples SW joined projects on development of genomic tools for oats (OatLink), Canadian consortia for resistance to blackleg in oilseed rape and HybriTechs partnership for the development of a hybrid system in wheat.

Pre-breeding for new disease resistances has become important for leading companies. Examples on network projects or efforts are resistance in wheat to *Fusarium* in European wheat programs with Climate Change, changed cultivation systems such as reduced tillage and increased maize cultivation, etc and in barley to *Ramularia*, a disease where the importance has been upgraded in the last years. Another example on joint efforts is the international work on resistance to the new race of stem rust on wheat, *Ug 99*, which is coordinated through Cimmyt.

Pre-breeding for abiotic tolerance has become more important, also then involving biotech. Among traits of interest are nitrogen use efficiency

(NUE), water use efficiency and plant architecture for yield stability, and winter hardiness, adapted to new conditions and cultivation systems with Climate Change. In this context there is a renewed interest for trial design and for different selection tools or screens that can reduce the need for costly field trials.

Regarding qualities, the traits in demand from major food markets are more or less unchanged over time and quite conservative. However, new preferences on bread or beer can make differences as well as new technologies in these industries. The preferred fatty acid profile in rapeseed oil has been the same for the major uses as food since the erucic acid was eliminated. Regarding feed and energy markets for cereals and rapeseed no traits with enough values to have a more decisive impact on the seed market have been identified, as of yet.

New qualities such as changed starch composition, contents of dietary fibres or new fatty acid profiles can give new market opportunities. Until these have developed into major market segments the breeding industry can't be expected to make any more important investments into pre-breeding of these new traits. Such initiatives will, thus, be dependent on public support or down-stream involvement from industries aiming for control of the value chain in question.

For leading breeding companies another reason to be active in international network projects or in cooperation with research at universities and institutes is to keep up with the general technological development in plant breeding. Attractive activities could involve genetic analysis and genomics at different levels for trait linked markers, characterization of germplasm, QTL-mapping, associative mapping, genome wide analysis, Tilling, etc. It could also involve more cost effective production of DH-lines and new technologies for the screening of different phenotypes, such as image analysis and physiological screens. Keeping in contact with the development in such fields is recognized as important in many companies to be able to make use of the opportunities that become available over time.

Sammanfattning

Pre-breeding insatser i ett företag bedöms ur många perspektiv, framförallt de ekonomiska möjligheterna, som t. ex. marknadens storlek och hur stark konkurrensen är inom det aktuella segmentet. Ger insatserna endast effekt på kort sikt, eller kan man förvänta sig också mer långsiktiga resultat? Är insatserna en grund för immaterialrättsligt skydd? Skall projektet genomföras helt i egen regi eller kan det göras i samarbete med andra företag? Eller föredrar man att stödja publik forskning inom området? I uppsatsen ges exempel på hur pre-breeding-insatser kan hanteras på en kommersiell bas, huvudsakligen med exempel från Svalöf Weibull AB (SW) under perioden 1990-2005.

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Fruit and berry breeding in the Nordic countries

Frukt- och bärförädling i Norden

Hilde Nybom

Abstract

The already existing market for fruit and berries in the Nordic countries is many times larger than the contribution from domestic production. Considerable improvement of the cultivated plant material is, however, needed in order to realise the potential for enlarging the domestic production and the industrial processing of harvested fruit and berries. Plant breeding of these vegetatively propagated crops is expensive and takes a long time. Pre-breeding projects, centered around the evaluation of a genetically diverse material and the undertaking of crosses to introduce, e.g., valuable sources for resistance to pests and diseases, or increased levels of bioactive compounds, would help to provide a sound basis for the applied breeding programmes that are carried out in close co-operation between publically funded institutes and university departments in the Nordic countries.

Keywords: Cultivar development, Gene bank, Horticulture, Plant breeding, Preebreeding

Introduction

The domestication of plants is probably the most important step even taken by our own species. Production of edible plants allowed us to stay in permanent settlements for extended periods of time, and to produce a surplus of edible goods. This surplus enabled us to pursue cultural development in addition to staying alive and healthy. Several fruit and berry species have contributed to the earliest crops that were developed for human consumption, like grapes and apples. Recent research has now proved that fruit and berry crops not only provide tasty and refreshing desserts and snacks, but are also instrumental in the provision of healthy foodstuffs (Yang & Kallio, 2002; Seeram, 2008; Grey *et al.*, 2010; Andersson *et al.*, 2011; Widén *et al.*, in press).

In agricultural production statistics, comparison among crops is usually based on cultivated acreage. This often leads to a misconception about the relative economical values produced in agriculture versus horticulture. In horticultural production, acreage is comparatively small but the economical turn-over and value of end-products is very high. The possibility to develop value added products from fruit and berries is especially interesting in the Nordic countries where an internationally competitive bulk production is less feasible.

The market potential

Most of the fruit and berries consumed in the Nordic countries are imported. Even crops that have been grown successfully in our countries for centuries, are now being imported to a very large extent. As an example, the most commonly grown fruit crop in Denmark, Finland, Norway and Sweden is apples. Nevertheless, only about one fifth of the fresh apple consumption in Sweden is domestically produced. Processed fruit and berry products, like juice, cider, wine, vinegar, jam, sauce, yoghurt, muesli, tea etc, are being imported to an even higher degree.

Presently, we however see a growing awareness of the importance of food quality and other aspects linked to the choice of foods. Fruits and berries have received much interest as a major contributor to a healthy diet. In connection with the awareness of global warming and the need for environmental protection, there is also an increased interest in locally and/or organically produced foods. A growing segment of consumers are willing to pay high prices for value added products. This extra value can consist of, e.g., desirable production methods and/or quality parameters.

The development is very fast in some areas, like in the case of the small but fast growing wine industry, especially in Denmark and Sweden. Another,

Figure 1. Selection of black currants amenable for organic growing takes place both at Balsgård and at Öjebyn (picture). Plant adaptation, resistance to pests and diseases as well as fruit quality and suitability for mechanical harvesting is equally important. Photo K. Rumpunen
Figur 1. Selektioner av svarta vinbär för ekologisk odling sker vid Balsgård och i Öjebyn (bilden). Anpasning, sjukdomsresistens, fruktkvalitet och lämplighet för mekanisk skörd är lika viktiga egenskaper. Foto K. Rumpunen

somewhat 'exotic' crop that is now being planted and utilized in especially Latvia, Estonia, Finland and Sweden is sea buckthorn. But also the more conventionally grown fruit and berry crops enjoy increased interest due to the huge potential for a diversified production of value added foodstuffs. At Balsgård in Sweden, the recent implementation of a centre for innovative beverages has initiated a large number of co-operative projects with growers and small-scale producers of high-quality fruit- and berry-based products.

To conclude, the market is presently much larger than the contributions from domestic production, and consumer attitudes definitely have the potential to promote an increase in domestic production. This increase, however, depends on the successful implementation of a competitive cultivation (including choice of cultivars as well as methods for harvesting and storage) and marketing programme. We already see some progress now in berry production using, e.g., plastic tunnels in order to expand the season and increase the quality of the harvested produce. The planting of a fruit tree orchard or a berry field is, however, very expensive, with large costs both for the plant material and for the orchard or field set-up including irrigation and often also stakes or wires and sometimes covering with plastic. Choice of plant material is therefore extremely important, and growers are often reluctant to plant new and unknown cultivars.

The plant material

Almost all fruit and berry crops are vegetatively propagated. This means that once a superior plant has been found, either as a chance seedling in an orchard or a home garden, or has been developed by purpose through a breeding programme, this plant is then propagated (runners, cuttings, grafting etc) to produce large numbers of copies of the initial genotype. Occasionally a beneficial mutation is found, e.g., a branch with better coloured fruits, and this branch is then used for propagation of a 'sport' cultivar.

Fruit and berries are generally grown as perennial crops. The shortest turnover is usually found in strawberry fields, where plants are often discarded after two years, or sometimes even after only one year. By contrast, fruit tree orchards are often kept for 20 to 30 years, often even longer although fruit quality decreases with increasing tree age.

Production of long-lived crops unfortunately leads to a build-up of high levels of detrimental pests and diseases, especially in orchards where the use of chemical pesticides and fungicides is avoided or at least kept to a minimum. Therefore, resistance or at least tolerance to the major pests and diseases is a prerequisite in organic production but of high importance also in integrated production (IP). This importance is likely to increase with the new EU directive on integrated plant protection starting in 2014.

Pest and disease resistance is especially important since the Nordic countries have, overall, much more stringent regulations for pesticide and fungicide use than many other fruit-producing countries. As an example, postharvest dipping of fruit in fungicides is prohibited, which results in serious harvest loss due to storage diseases in many cultivars. Consequently, there has been virtually no interest abroad in the breeding of cultivars with a high level of tolerance to storage diseases. Nordic pre-breeding therefore has the potential to provide applied Nordic breeding programmes with very valuable traits, that would otherwise be difficult to access.

PLANT BREEDING OF FRUIT AND BERRIES

Need for cultivar improvement

The combination of extreme yearly daylength variation and a relatively mild temperate climate is unique for the Nordic countries, and cultivars developed elsewhere often produce inferior results when grown in our countries. In addition, weather conditions often change considerably between years in the Nordic countries, which creates problems especially for longlived crops like fruit trees and berry bushes. A single, unusually cold winter, or an unusually dry spring with fluctuating temperatures, has the potential to kill a whole orchard or berry field that would otherwise have been expected to produce for many more years.

In spite of these limitations, most of the fruit and berry cultivars grown commercially in the Nordic countries have actually been developed elsewhere. Consequently, these crops are usually grown in restricted areas where the climate is sufficiently beneficial. Climatically well-adapted, domestic cultivars can often be grown in a much larger area in the Nordic countries but are seldom found outside home gardens due to inherently insufficient productivity, quality, storage capacity and shelf life.

Figure 2.'Lotta' – a semisweet sea buckthorn cultivar released in 2011 from the breeding program at Balsgård, Sweden. – Photo K. Rumpunen.

Figur 2. 'Lotta' – en halvsöt havtornssort som släpptes 2011 från Balsgårds förädlingsprogram. Foto K. Rumpunen

Figure 3. The blueberry cultivar 'Arto' from MTT, Finland. Photo MTT Archive

Figur 3. Blåbärssorten 'Arto' från MTT i Finland. Foto MTT Arkiv

The predicted changes in our climate – which are likely to become even more unpredicted due to global warming – together with the anticipated, interlinked changes in food and bioenergy production, trade and marketing, will most likely limit the feasibility of continual cultivation of many existing plant varieties which already suffer from poor adaptation. Therefore, we need to develop more resilient cultivars, that can be locally – and

Figure 4. Ru974 a new raspberry selection from Graminor in Norway. Photo D. Røen
Figur 4. Ru974 en ny hallonselektion från Graminor i Norge. Foto D. Røen

Figure 5. Apple cultivar 'Heta' from MTT in Finland. Photo MTT Archive
Figur 5. Äppelsorten 'Heta' från MTT i Finland. Foto MTT Arkiv

preferably also organically – produced, with crops that can be used both for fresh consumption and for the production of various foodstuffs. The development of better adapted plant material has the potential to assist in increasing both productivity and quality as well as provide the growers with Nordic cultivars that do not have to compete with imported fruit of the same cultivars (Figs. 1-4).

Public or private plant breeding

Traditionally, cultivar development of fruit and berry crops has depended on chance seedlings to a very large extent. In the last century, science-based breeding programmes based on experimental crosses between selected cultivars have, however, been implemented in many university departments and research institutes around the world. By contrast, breeding efforts conducted by commercial enterprises have been very restricted. In, e.g., apple, privately funded breeding projects have mainly been conducted by tree fruit nurseries and have often centered around the identification and patenting of sports from already existing cultivars. A number of international breeding companies are, however, active in breeding strawberries. The main reason is the need for continuous exchange of production plants every 1–4 years, which opens up for royalty-based income for newly released cultivars (Figs. 5-7).

Recently, co-operative breeding programmes have been initiated with input from both publically and privately funded entities, usually university departments and plant nurseries, respectively. Such projects are, however, feasible mainly in countries where there is a strong domestic plant nursery industry that can capitalise quickly on the new cultivars. Still, the breeding of fruit and berry cultivars has, on the whole, been regarded as an un-attractive enterprise by commercial interests. Major reasons are of course the costs involved, caused by large size of the plants and long generation times.

Another problem is the fact that legal protection of plant variety rights (the UPOV convention) cannot be obtained for more than 25 or 30 years (the latter applies to vines, potatoes and trees). Due to the slow plant turnover in orchards and berry fields, and the reluctance of growers to plant an insufficiently known cultivar, new cultivars are not likely to reach high productivity levels in time to produce big revenues. Especially the fruit tree crops, like the Swedish apple cultivars 'Aroma' and 'Katja', often increase in production long after the plant variety protection time has elapsed.

Plant breeding in the Nordic countries

Fruit and/or berry breeding is presently undertaken with 100% public funding in three of the Nordic countries: by Graminor AS at several locations in Norway, by MTT in Piikkiö, Finland, and by SLU at Balsgård in Sweden. In each country, only 2–3 crops are being bred at present, and the funding also of these crops is very limited in comparison with publically or privately/publically funded breeding programmes of fruit and berries conducted elsewhere. Additional activities are carried out in several other fruit and berry crops in the Nordic countries including Denmark, e.g., evaluations of previously developed material and/or foreign varieties.

Modern high-yielding and qualitatively superior cultivars, like the Balsgård apple variety 'Aroma' has had an enormous impact on present day production in especially Norway and Sweden, where it is the first or second largest cultivar, and to an increasing extent also in Denmark. Other successful cultivars include e.g. the Swedish/Norwegian pear 'Ingeborg', the Swedish apple 'Frida' and the Swedish plum 'Jubileum' that are presently being planted in increasing numbers. Hardy cultivars of, e.g., apple and blueberry, have recently been developed in Finland for a more demanding climate (Figs. 3-5).

Availability of suitable Nordic cultivars is, however, lacking for many crops and many potential production areas within these countries. In some crops, like strawberry and raspberry, almost all the Nordic production is still achieved using non-Nordic cultivars (Figs. 4, 7). Growing of foreign tree fruit cultivars is especially prevalent in Denmark where the climate is more similar to the large fruit production areas in other parts of Europe.

Gene banks

A prerequisite for plant breeding is the availability of collections of carefully identified and evaluated genetic resource collections, i.e. gene banks. In contrast to the more easily managed seed-propagated crops, responsibility for the collection and preservation of vegetatively propagated crops like fruit and berries, is, however, often unclear and the funding inadequate. NordGen manages information data bases for gene banks of fruit and berry crops in the Nordic countries, but the actual preservation of the plant material is left to national agencies.

In many European countries but not in, e.g., North America (Postman *et al.*, 2006), the recently popularized concept of 'mandate cultivars' or 'heirloom cultivars' has resulted in ear-marked funding for selected cultivars that are either indigenous or have (or used to have) considerable socio-cultural interest in that particular country (Nybom & Garkava-Gustavsson, 2009). The major aims are usually to preserve the mandate cultivars for future generations, and to provide the general public with propagation material and educational experiences like field demonstrations and fruit exhibitions. By contrast, possible importance for current plant breeding programmes is seldom a concern when

Figure 6. Apple selection B: 1458 developed at Balsgård and presently under observation in commercial orchards and plant nurseries. Photo H. Nybom

Figur 6. Äppelselektionen B: 1458 som utvecklats på Balsgård är nu under observation i kommersiella äppelodlingar och i plantskolor. Foto H. Nybom

Figure 7. The strawberry cultivar 'Valotar' from MTT, Finland. Photo MTT Archive

Figur 7. Jordgubbssorten 'Valotar' från MTT i Finland. Foto MTT Arkiv

the status of 'mandate cultivar' is bestowed on selected cultivars.

Public funding of national gene banks is nowadays limited to mandate cultivars for several fruit and berry crops in the Nordic countries. Fortunately, additional plant material, mainly foreign cultivars with particularly valuable characteristics like disease resistance, has sometimes been preserved in connection with the ongoing breeding programmes. The largest of these gene banks is found at Balsgård, SLU in Sweden, but funding is inadequate for the majority of the crops represented in these collections.

Figure 8. Manual pollination of apple flower at Graminor, Norway. Photo D. Røen
Figur 8. Pollinering av äppelblommor vid Graminor, Norge Foto D. Røen

PREBREEDING OF FRUIT AND BERRIES

The already existing market for fruit and berries in the Nordic countries is many times higher than the contribution from domestic production. Obviously there is a large potential for increasing this production, especially if a co-ordination is made with the developing industry for manufacturing of fruit and berry-based value added products. Considerable improvement of the plant material is, however, needed for a successful development of this sector. Carefully defined pre-breeding projects would help to provide a sound basis for the applied breeding programmes carried out in close co-operation between different research institutes and university departments in the Nordic countries.

In applied breeding programmes, most crosses are usually conducted between two well-known, high-standard cultivars due to the need for obtaining marketable cultivars as quickly as possible. By contrast, a long-term pre-breeding undertaking creates opportunities for making wider crosses, involving wild material or sub-standard cultivars with a special trait of interest. After two or three backcrosses to commercial cultivars, truly superior cultivars can be obtained that combine high productivity, marketable quality and a hitherto unavailable level of hardiness and/or resistance to pests and diseases.

The planning of a pre-breeding project must be fashioned according to the crops and goals defined. Still, some general points can be mentioned. Activities aiming to improve a particular crop should always start by the definition of an ideotype, i.e. a goal for the improvements to be made.

Secondly, a method must be chosen. Considering the extremely high costs for obtaining approval of material derived through gene transfer, a biotechnological approach is, as yet, not feasible for crops with a long turnover and a restricted production like fruit and berries in the Nordic countries. Instead, breeding programmes are still based on crosses between carefully chosen genotypes (Fig. 8). Such crosses can result in superior offspring through beneficial recombination of the parental genes. Choice of parents and evaluation of the resulting seedlings can be augmented by the use of molecular markers when available.

Availability of plant material

To provide material for plant breeding and pre-breeding activities, a basis must be created of properly identified, characterized and genetically diverse genotypes. Unfortunately, the existing plant collections often contain material with an undocumented origin. The resulting problems with mislabelling of the accessions in tree fruit gene banks in Sweden, have now to a major extent, been cleared up through the use of DNA-based markers in apple, pears and cherries (Garkava-Gustavsson *et al.*, 2008; unpubl. data at Balsgård). A similar project has also been carried out for currants and gooseberries in a Nordic-Baltic-Polish project (Antonius *et al.*, 2009; unpubl. data at Balsgård). Similar analyses need to be conducted for the remaining fruit and berry collections in the Nordic countries.

Although much material is already available in the Nordic countries, complementary material should also be obtained from other countries for comparison and for widening the gene pool. For some crops, major sources of disease resistance are, e.g., found mainly in wild species and must then be transferred through crosses to cultivars of commercial value. Presently, there is very little material of these sources in the national gene banks in the Nordic countries but they can be obtained from other gene banks and breeding programmes, as well as from nature.

Character evaluation

For plant breeding of fruit and berry crops destined for the Nordic countries, climate adaptation is a major goal, especially when a geographic widening of the commercial production area is desired. Sources of climatic adaptation can often be found among the domestic cultivars, but material from other countries should also be investigated.

Figure 9. Infection of European canker in cv 'Priscilla' in the Balsgård genbank. Photo L. Gustavsson
Figur 9. Infektion av äppelkräfta i sorten 'Priscilla' i genbanken vid Balsgård, Sverige. Foto L. Gustavsson

Basic traits like yield and quality must be carefully quantified in growth trials conducted at several locations and evaluated over several years. Increasing knowledge about the genetic regulation of genes involved in growth and development can help to speed up the analysis of these traits (Sansavini *et al.*, 2004; Nybom *et al.*, 2008a).

Many fruit and berry crops are self-incompatible. DNA marker-based determination of self-sterility genes can be helpful in order to assure that crosses are only undertaken between compatible cultivars (Nybom *et al.*, 2008b; Røen & Nybom, 2010).

Resistance or tolerance to major pests and diseases can be ascertained through carefully conducted inoculation tests (Sehic *et al.*, 2009; Kellerhals *et al.*, 2012; Nybom *et al.*, 2012; Garkava-Gustavsson *et al.*, in press) or through the use of DNA-based methods if available, whereas determination of levels of polygenically controlled field resistance often has to rely mainly on repeated observations in field trials (Jönsson & Tahir, 2005; Tahir & Jönsson, 2005).

Expertise in e.g. biochemistry and food processing may be needed depending on the crop and the goal for cultivar improvement (Rumpunen, 2007; Røen *et al.*, 2009), and consumer acceptance must of course also be taken into consideration (Jönsson & Nybom, 2007).

Figure 10. Infection of European canker after inoculation in cv 'Elise' in Balsgård, Sweden. Photo L. Gustavsson
Figur 10. Infektion av äppelkräfta efter inokulering i sorten 'Elise'. Foto L. Gustavsson

Pre-breeding in apple

Funding has recently been approved by the Nordic Council of Ministers (NMR) for a two-year (2012–2013) Public Private Partnership project 'Pre-breeding for future challenges in Nordic apples'. This project will target two of the most detrimental diseases in Nordic apple production: storage rots and fruit tree canker (Figs. 9-10). The project will be conducted jointly by Graminor AS in Norway, MTT in Finland and SLU in Sweden. Genetic variation in disease tolerance among some important and/or promising apple cultivars will be investigated with inoculation tests. Phenotyping data will then be analysed in co-operation with the EC-funded 'Fruitbreedomics' project to identify genes involved in the resistance/tolerance reactions.

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Sammanfattning

Marknaden för frukt och bär i de nordiska länderna är flera gånger större än den inhemska produktionen. En avsevärd förbättring av det odlade växtmaterialet är nödvändig för att kunna tillgodose den inhemska produktionen av frukt och bär. Förädling av dessa vegetativt förökade växtslag är kostsam och tar lång tid. Pre-breeding-projekt som utgår från utvärderingen av ett genetiskt mycket variabelt material och korsningar för att inkorporera värdefulla resistenskällor mot sjukdomar eller ökad koncentration av bioaktiva substanser är en god grund för de tillämpade förädlingsprogram som nu genomförs i nära samarbete mellan publikt

finansierade förädlingsprogram och universitetsinstitutioner i de nordiska länderna.

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Discussion summary from a workshop on Nordic PPP on Pre-breeding

Sammanfattning av diskussionen vid Nordisk workshop om pre-breeding

Agnese Kolodinska Brantestam, Magnus Göransson and Roland von Bothmer

The main goal for the workshop discussions was to identify target areas for collaboration within frames of Private Public Partnership in Pre-Breeding (PPP) planned to start during 2011 and to set up priorities for the coming work.

Future demands for pre-breeding

During the first part of the discussions, workshop participants focused on future demands of importance for pre-breeding activities for plant improvements considering the challenges posed by climate changes common for all Nordic and Baltic countries. The discussions were carried out in three groups aiming at different crop groups: field crops, forages and horticultural crops (Table 1).

Field crops

The discussion group on field crops agreed that focus should be set on: disease resistance; nutrition; drought; water logging; cold tolerance and winter hardiness. It was also proposed to work on identifying sources of traits of interest, developing markers for selection and to produce plant material ready to use in breeding programs. Concerning the work on disease resistance it was recommended to screen and identify particular gene sources and carry out pathogen evaluations. The group agreed that one should start work on barley disease resistance, e.g. resistance to *Ramularia* and *Fusarium*. It was emphasised that the phenotypic tools should be developed and improved for increasing the throughput. Further, simple markers should be localised and applied for major genes and to initiate work on quantitative gene manipulation for development of durable resistance. Phenotyping for water logging and for efficient use of nutrients identifying useful genetic resources should be carried out. Finally, populations which could be used directly by breeders should be built up. At a later stage of the PPP collaboration partners should start working also on winter hardiness including cold tolerance. It was mentioned that breeding and pre-breeding approaches will change over time following the development of tools applied (e.g. phenotyping tools) and an increasing role of genomics. It was suggested that work on insect resistance might become more important as one of the consequences of climate change.

Forages

The participants of the discussion group on forages noted that they met a challenge defining the species to work on to match the interest of all partners. It was agreed that Perennial ryegrass (*Lolium perenne*) would meet the requirements, since it is grown in all Nordic and Baltic regions, has good quality and is high yielding. However, there is a problem of winter hardiness in perennial ryegrass. It is connected with damages caused by *Fusarium* (snow mould), frost, autumn growth – re-growth, ice encasement and de-hardening. The steps for further work were identified:

1. assessing diversity (materials in genebanks)
2. gathering information about the collections
3. carrying out evaluation trials (how and where)
4. developing breeding populations.

For the long term perspective work on introduction and evaluation of legumes (clover) was suggested. It was acknowledged that the collaboration between the public and the private sectors for this work has a number of advantages. It gives access to input from breeders and facilities for evaluations required by the private sectors. The PPP collaboration will include experts with a wide range of skills. It gives the possibility for sharing the work load, train students in real life scenario and give input in research issues (e.g. genetic studies, methodological developments).

Table 1. The distribution of workshop participants in thematic discussion groups

Discussion groups (Part 1)	Participants	Moderator (m) and secretary (s)
Field crops	Inger Åhman, Åsmund Bjørnstad, Roland von Bothmer, Paul Brennan, Ahmed Jahoor, Rasmus Lund Hjortshøj, Nigel Kilby, Alge Leistrumaite, Michael Lyngkjær, Isaak Rashal, Lars Reitan, Alan Schulman	Outi Manninen (m), Agnese Kolodinska Brantestam (s)
Forages	Niels Christian Nielsen, Elcio Guimaraes, Magne Gullord, Áslaug Helgadóttir, Mati Koppel, Nikolė Lemežienė, Eero Nissilä, Morten Rasmussen	Søren Rasmussen (m), Axel Diederichsen (s)
Horticultural crops	Kirsi Heinonen, Gunārs Lācis, Anders Nilsson, Risto Tahvonen, Teemu Teeri	Hilde Nybom (m), Magnus Göransson(s)
Discussion groups (Part 2)	**Participants**	**Moderator (m) and secretary (s)**
Private Sector	Niels Christian Nielsen, Magne Gullord, Ahmed Jahoor, Mati Koppel, Alge Leistrumaite, Rasmus Lund Hjortshøj, Michael Mackay, Morten Rasmussen, Lars Reitan	Eero Nissilä (m), Magnus Göransson (s)
Public Sector	Roland von Bothmer, Paul Brennan, Áslaug Helgadóttir, Gunārs Lācis, Michael Lyngkær, Hilde Nybom, Søren Rasmussen, Alan Schulman, Risto Tahvonen	Åsmund Bjørnstad (m), Axel Diederichsen (s)
Public & Private Sector	Inger Åhman, Elcio Guimaraes, Nikolė Lemežienė, Outi Manninen, Anders Nilsson, Isaak Rashal, Teemu Teeri	Kirsi Heinonen (m), Agnese Kolodinska Brantestam (s)

Horticultural crops

The discussion group demonstrated that the market for horticultural crops has a large potential to increase, including increase in area of production. The horticultural production is very competitive with field crops in value per acreage, where local production and local cultivars are value adding factors. There are strong consumer demands on increased supply of cultivars (with tomatoes and potatoes as examples where consumers are willing to pay more for "unusual" cultivars). Another aspect of consumer demands discussed were attitudes to GM crops. There is a future potential for consumers to open up for GM in organic production, e.g. disease resistant GM potatoes, health aspects and taste properties. Future food crises may increase public awareness of advantageous GM crops. The crops of interest for PPP collaboration were identified: apples, strawberries, black currants, ornamentals, berries, potatoes and vegetables. The challenges of practical breeding of horticultural crops (e.g. fruit tree breeding is a long term business) and access to genetic resources (need of alternative conservation methods that are not provided in traditional seed gene banks) were recognised. The focus for horticultural crops should be set on quality characters and increased numbers of available cultivars. It was emphasised that many challenges in growing horticultural crops are connected with climate change (e.g. emerging diseases, insects, spring frost during flowering). The specific focus areas for the crops of interest were recognised: resistance to storage diseases and fruit canker for apples; taste, texture, industrial and grower demands for strawberries; disease resistance, taste, colour, frost tolerance for potatoes; and health aspects for the functional berries (e.g. black currant and native Nordic berries). The group also discussed the further funding possibilities and challenges for projects on horticultural crops where most breeding is carried out by public institutions.

The Private Public Partnership

The second part of the discussions was focused on the role of PPP in a regional and global perspective and future possibilities and limitations of this collaboration. For this discussion again three groups were formed representing private sector, public sector and one representing both public and private sectors (Table 1).

Private sector

The group representing the private sector recognised that there is a need for a long-term perspective for PPP collaboration. The challenges identified are *Fusarium* resistance in oats; nutrient use efficiency and drought tolerance. The society can benefit from the PPP initiative, e.g. developing resistant cultivars will lead to less use of pesticides. An important aspect is access to information, although in some cases there may be a need to restrict access, e.g. "black box storage" of data in 5 years. The group noted also that they have no interest to patent traits and that there are differences in willingness to share information with different organisations, e.g. public institutions vs. private competing companies. It was emphasised that the information should be pre-competitive, like access to pedigree analysis, information on trait identification within old breeding lines evaluation data. A potential project idea was also presented using the core set of resistance lines in barley, where collaboration among partners would include identifying traits, e.g. disease resistance (one trait per partner), creating 3-4 BC lines and distribution of these lines to other partners. Participants from the private sector suggested that the role of the public sector could include developing markers, genomic tools and primary basic information and data-sharing tools like GENESYS as well as education of future breeders. There could also be collaboration with universities on marker development through student projects.

Public sector

The group representing public sector identified tasks for public institutions, namely delivering tools for germplasm characterization to private sector and create awareness for the opportunities the public sector has, building a communication platform and increase interaction. It was suggested for the nearest future to invite private breeders for teaching, e.g. in NOVA courses, to develop personal contacts to breeding industry, to chose a topic about pre-breeding for the next Nordic breeding course, invite breeders to the Nordic cereal society conference in Uppsala and place students in companies to work on projects. It was noted that it is important that students are guided to produce results that can be applied. Further it was recommended to establish a joint research school with focus on pre-breeding and approach chairs at Nordic universities on this issue. As challenges were mentioned:

1. the education in plant breeding serves at present mainly the developing world and there is lack of Nordic students in plant breeding
2. governmental funding agencies seem more reluctant to support funding in crop research
3. the sharp dichotomy between basic genomic research on model species (*Arabidopsis*) and crop targeted research needs is not sufficiently addressed in some countries

It was noted that there are differences in funding procedures between Nordic countries, e.g. in Denmark and Finland agricultural ministries supply funding directly whereas in Norway funding is available only through the Research Council. A discussion among participants recognised that sources of funding that allow long term commitments need to be found, e.g. levies on crops produced and that the producer groups decide on projects. However, that may not be possible at a Nordic level. It was also recommended that funding needs to be allocated more strategically, research should take practical needs into consideration and continuity in research needs to be secured. One should consider that long term activities would require public investments, since companies have no possibilities to do that on their own. The discussion group expressed a concern about the reluctance of private companies to collaborate with public sector if several private companies are involved.

Private – public sector

The discussion group where both the private and public sectors were present agreed that the PPP is a 'must'. It is of importance to find a common interest; prioritize tasks, find a common language and share work load. It was also noted that the planning horizon in most cases both for the public and for the private sector is maximum 10 years. As an advantage the necessity for collaboration in complex problems was recognised. It was mentioned that not only monetary contribution is important, but also exchange of technology and 'know how'. One of the main tasks for the PPP collaboration is filling the gap between research and breeding. The areas of collaboration would include both development of tools and education. There are, however, some limitations as well as challenges: the society should be convinced on the importance of this work since there is a public funding included, the knowledge and awareness should be increased. The global perspective should also be considered, e.g.

in some cases specific expertise is not available in the Nordic countries.

Final discussion

Overall discussions gave various suggestions for the target areas and crops for PPP collaboration. It was agreed on two target areas/crops for the initial phase of PPP projects, namely disease resistance in barley and winter hardiness in ryegrass. Workshop participants agreed that 3 years for the initial phase is a very short time for such long term activity as pre-breeding, so projects for this phase have to be carefully selected having realistic goals and achievable deliverables within the given time frame.

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