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European perspectives of organic plant breeding and seed production in a genomics era

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Abstract

For further optimisation of organic agricultural systems, more focus is required on organically produced seeds and the development of better adapted varieties. Organic plant breeding and seed production need to comply with the concept of naturalness as applied in organic agriculture, which not only includes the non-chemical and agro-ecological approaches, but also the integrity of life approach. As organic environments are less controllable and are more variable, breeding should aim at improved yield stability and product quality by being adapted to organic soil fertility as well as sustainable weed, pest and disease management. Also the ability to produce economicacceptable seed yield avoiding seed-borne diseases should be included. On the short term, organic plant production can gain better yield stability by increasing within-crop diversity by the use of mixtures of conventionally bred varieties or crop populations. Because of expected genotype by environment interaction more research is needed to define the best selection environment for selecting organic varieties. To arrive at better adapted varieties for organic farming systems the role of practical participatory plant breeding may be crucial.

Although organic farming is clear on excluding the use of genetically modified organisms and their derivates, the use of molecular markers is still under debate. Questions arise with respect to their efficiency in selecting the most important organic traits, such as yield stability, and on the compounds and substances to produce and apply them. A major concern for a GM-free organic agriculture is an increasing contamination with genetically modified organisms in organic production and products, i.e., the problems related to co-existence of GM and non-GM agriculture. This paper discusses some important factors with regard to possible impact of co-existence on organic farming. Perspectives to a global scale of organic plant breeding and seed production are given from a European point of view.

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1 Introduction

Plant breeding for organic agriculture needs to meet the prerequisites of the sector. These are based on ecological and ethical principles. In several aspects, these prerequisites are in conflict with the direction modern plant breeding for conventional agriculture is developing. Organic management systems differ substantially from the conventional ones. This difference is largely due to refraining from high-levels and readily soluble fertilizers and from chemical pest, disease and weed management. Instead, much emphasis is put on soil fertility management and broad crop rotations. Organic farmers aim at resilience and buffering capacity in their agro-ecosystem by stimulating internal self-regulation through functional agro-biodiversity in and above the soil, instead of external regulation through chemical protectant (Mäder et al., 2002). Therefore, traits required for varieties in organic agriculture will differ from the ones for varieties in conventional systems (Lammerts van Bueren et al., 2002; Welsh et al., 2002). As the expression of a phenotype depends on the environment, varieties with the desirable traits for organic agriculture may not be found when the breeder selects under conventional management systems. Similarly, the farmer may not be able to identify the optimal varieties since an official variety testing (VCU-testing) under conventional conditions will not value the relevant traits and thus not reveal the desirable varieties (Osman and Lammerts van Bueren, 2003). Another problem arises when the organic principle of diversity is employed on crop, plant and genetic level. Modern plant breeding has aimed at pure lines and increasingly use of hybrids, resulting in a decrease of genetic diversity in conventional varieties. Also genetic diversity at the regional level is decreasing with few varieties grown over large areas. The rapid spread of GM crops in some countries (e.g. in Argentina) has contributed to this (Knudsen et al, 2006). In search for implementing more genetic diversity on different levels as a tool for improved yield stability under organic conditions, the possibilities of landraces and variety mixtures are explored. But such variety concepts do not fit easily into current official testing and certification systems (Welsh and Wolfe, 2002). And as worldwide plant breeding research is very much focused on exploring the potential of genomics and gene technology, there is alsothe concern that the modern conventional breeding and seed production techniques may not be appropriate for organic products since it does not reflect the concept of naturalness (Alföldi, 2001; Verhoog et al., 2003).

As the organic sector largely depends on varieties bred for the conventional agriculture, the organic sector needs to identify such above mentioned critical points in the conventional plant breeding process and seed production phase to guide further improvement towards better adapted varieties for organic farming systems. In this paper we will elaborate on the desired characteristics of organic plant breeding (OPB) and organic seed production (OSP) based on the concept of naturalness, and will discuss these critical points in relation to the conventional system. Therefore, we will at first discuss the required breeding aims in interaction with the organic environment and some aspects of breeding strategies, such as the role of genetic diversity in gaining better yield stability for organic varieties and the role of the organic environment in the breeding and variety testing process. Besides, the question whether and in which way OPB can benefit from the modern breeding strategies, e.g. by applying molecular markers in the selection process, will be discussed. Next to the critical points for organic plant breeding we will address the consequences of the organic principles for organic seed production. As the sector has not the means to rapidly develop appropriate varieties and seed, we will point out the strategies for a step by step transition from conventional to organic varieties. And as organic agriculture excludes the use of genetically modified organisms (or genetic modification, hereafter GM), also the question whether a GM-free organic agriculture, including GM-free breeding and seed production, has a future surrounded by GM agriculture, needs to be addressed. Although the authors mainly discuss European perspectives for OPB and OSP in a genomics era, also comments are made on relevant issues for developing and transition countries.

2 The framework of values

A clear framework of the ecological and ethical values and principles of organic agriculture should form the basis to further develop OPB and OSP. A analytical framework has been described by Verhoog et al. (2003) by means of the concept of naturalness as applied in organic agriculture. This concept of naturalness encompasses three approaches: a) the non-chemical approach, b) the agro-ecological approach, and c) the ethical approach in which the integrity of life is taken into account. In Lammerts van Bueren and Struik (2004) the consequences of naturalness for organic seed production and plant breeding have been discussed. Thenon-chemical approach requires the replacement of synthetic and chemical inputs in organic farming systems, including seed production, post-harvest seed treatments and during the breeding process. It also implies that the use of colchine is questioned. The agro-ecological approach focus on a broad rotation and a good soil fertility management, being the core of organic farming systems to keep the disease pressure at a low level and to enhance a high level of self-regulation in the organic agro-ecosystem. This approach leads to the need of producing seeds under organic farm conditions and to the question whether the breeding process for varieties better adapted to organic conditions should take place under organic conditions. The third component of naturalness, the concept of integrity of life, is expressed in the fact that organic farmers not only depart from the instrumental values of farm animals and crops, but also base their management decisions on their respect for intrinsic values being the autonomy, wholeness or completeness of living organisms, their species-specific characteristics and their being in balance with their species-specific environment. To be able to apply the integrity of life approach to assess the appropriateness of breeding techniques criteria at four levels are set: i) integrity of life, ii) plant-typic integrity, iii) genotypic integrity and iv) phenotypic integrity (Lammerts van Bueren et al., 2003b). The respect for integrity of life is one of the reasons why the organic sector rejects the use of genetic engineering and other DNA-techniques like protoplast fusion often used to obtain cytoplasmic male sterility, e.g. in cabbage hybrids.

Albeit only as a draft, OPB standards have been published since 2002 by IFOAM. According to the IFOAM draft standards for OPB, organic plant breeding should be conducted under organic conditions applying only those breeding techniques that allow crossing, pollination, fertilisation and seed formation on the whole plant itself. In 2005 IFOAM published standards for organic seed production (IFOAM, 2005).

3 Breeding aims in interaction with the organic environment

Although for many crops organic farmers profit from modern breeding efforts, concerns nevertheless remain whether modern varieties possess the right combinations of traits to ensure stable and acceptable yield and quality when grown under different organic growing conditions. Many modern varieties have been developed with the aim of combining high productivity and uniform product quality under high levels of chemical input conditions.

Refraining from chemical disease and pest management and applying a relatively low level of organic manure instead of a high level of readily soluble mineral fertilisers determines the organic environment to a large extent. And because organic farming systems cannot easily mask the variability in micro-environments with a ‘chemical umbrella’ against pest and diseases or a ‘nitrogen blanket’, the environments of organic farming systems are characterised by a large variation over years and between and within locations. In organic growing systems, biotic and abiotic stresses have to be controlled by growing appropriate varieties with good yield stability and by good, multilevel farm management practices supporting a high level of self-regulation within the organic farm ecosystem. For OPB, this implies special focus on breeding for varieties that are able to perform with a good yield level and good yield stability under organic farm management, as have been described by Lammerts van Bueren et al. (2002). The main aspects are:

- *Adaptation to organic soil fertility management*

Especially the dependence on the mineralisation dynamics of a low-input of slow-releasing organic stable or green manure makes the nutrient flow in different soils less controllable, and requires varieties adapted to such soil fertility management. Deep, intensive root architecture may contribute to a more efficient capturing of water and nutrients (Løes and Gahoonia, 2004). Experiments have also shown that varieties may differ in efficiency of nutrient uptake and use (Baresel et al., 2005). The ability to interact with beneficial soil micro-organisms can support this efficiency (Bosco et al., 2006).

- *Adaptation to organic weed management*

Rapid early growth can improve the weed competitiveness, as can good ground coverage - for instance through a prostate growth habit, high tillering capacity or through tall plants. Some crops, such as cereals and onions, can profit from selection for a good allelochemical ability to suppress weeds (Bertholdsson, 2005). Despite such characteristics mechanical weed control will still be needed and will affect the physical soil fertility. Crops should be selected as to be robust enough to allow and resist mechanical weed control without too much crop damage. Genetic variation for crop tolerance to post-emergence weed harrowing has been found to interact with yield and leaf area index (LAI) of spring barley in organically grown fields; taller and higher yielding cultivars with high LAI tended to be less tolerant than shorter and lower yielding cultivars with low LAI (Rasmussen et al., 2004).

- *Adaptation to organic pest and disease management*

Tolerance and resistance to pests and diseases may be monogenically or polygenically inherited and involve many different traits ranging from those based on specific recognition between host and pathogen to the ability of the plant to escape from severe loss by diseases through morphological or physiological traits. Examples of such traits are a long stem to enable the ear (cereal) or fruits (beans) to ripen above moist canopy, a wax layer against fungi (onion, cabbage), or trichomes against aphids (potato), a shorter crop growth period and/or early ripening to escape fungal infections such as late blight (potato).

- *Adaptation to organic seed production management*

The earlier mentioned breeding aims do not apply only to the crop production but also to organic seed production. Some pests and diseases are manifest during the seed production phase and cause unexpected problems compared to conventional seed production. Consequently, breeders will have to take into account the ability to produce an economic seed yield under organic conditions especially avoiding seed-borne diseases. Also seed quality in terms of fast and high germination rate and seedling vigour is important characteristics, because without chemical seed coatings seedlings may also be vulnerable under cold and wet conditions.

- *Adaptation to organic quality requirements*

Consumers of organic products expect good quality and taste. Therefore varieties need to be selected for a good taste and for instance for good baking quality under low input conditions (Kunz et al., 1995). Because organic farmers refrain from chemical sprouting inhibitors on onions and potatoes a high storage potential is essential.

4 Genetic diversity within the crop

As organic farmers have few tools to interfere during crop growth, an important strategy to improve yield stability is to enhance diversity at all levels and thus to facilitate an optimal use of natural regulation mechanisms, including biodiversity at the field level and genetic diversity at the crop level. Therefore, it is important to explore the role of genetic diversity in the variety concept for organic farming systems as also discussed in a recent workshop (Østergård and Fontaine, 2006). Breeding within the last 50 years has focused on developing genetically uniform crops/varieties for farmers to be able to produce a homogeneous product for the market. The principles of organic farming do not support this thinking. Therefore, especially for selfing crops like wheat and barley, where nearly all plants in a field are genetically identical, specific tools have to be applied to ensure the availability of genetically diverse crops. One suggestion has been to use older less intensively selected varieties or landraces where some variation is generated by mutations and rare outcrossing and maintained by a combination of natural selection and breeders/farmers selection (e.g. Horneburg, 2003, Murphy et al., 2005) More variation may be introduced by production of composite cross populations from a base population where many varieties are forced to outcross (Phillips and Wolfe, 2005). Finally, a more controlled way of generating variation is to combine a few selected varieties in a variety mixture which have been used at varying extent in wheat and barley for many years (Finckh et al., 2000). As an example, certified variety mixtures of spring barley have been grown in Denmark since 1979;

recently this also includes certified seed for organic production (Østergård and Jensen, 2005).

Growing variety mixtures has the potential of increasing grain yield more than 20 % compared to the average of the component varieties as well as of increasing stability in yield over environments (for a review see Smithson and Lenné, 1996). The importance of variety mixtures for reducing development of foliar diseases like cereal powdery mildews is well known (for a review see Mundt, 2002). However, variety mixtures have so far been studied mostly under conventional farming conditions and with focus on reducing disease severity by combining varieties with different disease resistance genes. Therefore, we do not have the final solution for how to combine varieties when also other biotic and abiotic factors are largely uncontrolled, i.e., we need more information on the ability of different varieties to complement and compensate for each other under the range of different environmental conditions as found in organic farming. Different conclusions as to yield stability and mixing effects has been observed in organic field trials of spring barley (Østergård et al, 2005) and winter wheat (Clarke et al, 2006). Also quality traits are important for organic production and an investigation of bread wheat concluded that the different bread qualities did not differ between mixtures and the average of the components (Osman 2006). Data from many published and unpublished trials for small grain cereals are being collected to summarise, by meta-analysis methods, associations between mixing effects, component varieties and environments aiming at clarifying principles for how to combine varieties in variety mixtures in the best way (Kiær et al, 2006).

A strategy for crop improvements based on mixtures has been suggested for subsistence agriculture (Smithson and Lenné, 1996). This strategy is based on selecting appropriate mixture components (disease and pest resistance, superior competitors) to enhance mixture yield and stability. In the long term perspective, this includes making backcrosses of sources of disease and pest resistance into local germplasm that have been evaluated for competitive ability.

5 Plant genetic resources

As mentioned above, there is a need to identify appropriate genetic resources among the older varieties or landraces either for direct use or as potential parental lines in breeding programmes for better adapted varieties (Hammer and Gladis, 2001; Lammerts van Bueren *et al.*, 2005). Evaluating and exploiting accessions from genebanks can be of use because required characteristics for organic, low-input farming might have disappeared by selection under modern, high input conditions, such as low-input tolerance and deep or intensive root architecture. Many non-profit organisations dealing with in-situ conservation of genetic resources maintain their populations under organic conditions (Negri et al., 2000).

6 Breeding and testing under organic growing conditions

To arrive at better adapted varieties for organic farming systems, an important question is the choice of selection environment for organic plant breeding programs, but little research has been done on this issue. In general, the issue of defining the optimum environment for selection during the breeding process has been much discussed by plant breeders (Hill et al., 1998), i.e. choosing an environment with optimal conditions for the crop or choosing the target environment (e.g. an organic environment or a stressed environment) for the crop, or even an alternation of these two. More than fifty years ago, theoretical considerations by Falconer (1952) established that direct selection, i.e. in the target environment, is almost always more efficient than indirect selection.

Experiments set up to analyse response to selection for yield in stressed environments are scarce; an example is selection for yield of barley under water stress (Ceccarelli et al. 1998). Selection experiments comparing selection results in conventional and organic systems have rarely been conducted. Some conventional breeding companies are interested in this question and a few experiments are under progress, such as for onions in the Netherlands (Tiemens-Hulscher et al., 2006) and for barley in Latvia (A. Kokare, pers. comm.). Some breeding companies look for a compromise and include selection under organic conditions in a later stage of the breeding process, e.g. F6, after selecting first under their 'regular' conventional conditions (Löschenberger and Lafferty, 2005).

The important factor in the discussion of selection in targeted environments is the interactions between genotype and environment (Fig 1).

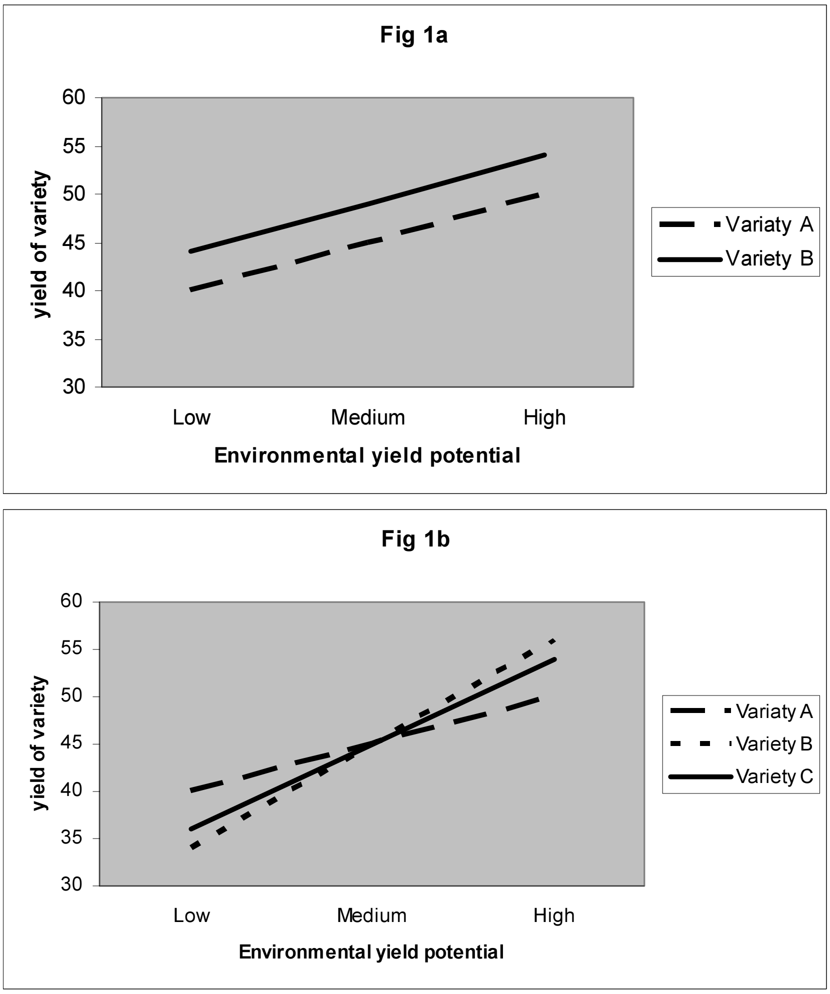

Figure 1. Regression of variety yield on environmental yield potential, e.g., given as a gradient of water supply. Genotype-environment interaction absent (1a) and present (1b), see also text.

When varieties respond equally to changes in the yield potential of environments (e.g. varying stress factors like drought or nutrient shortage), there is no genotype-environment interaction (Fig 1a). However, if varieties interact differently with the environment there will be crossover points where the ranking of the variety changes (Fig 1b). Depending on the range of environments considered in a specific breeding or testing situation, crossover points may not be recognised and one variety will always be evaluated to be the best, e.g. Variety B in medium to high yielding environments. Breeding during the last 40 years has to a large extent aimed at varieties which perform on average good over a large range of environments (Variety C) instead of targeting the varieties to different environments (negative versus positive use of genotype environment interactions (Ceccarelli, 1996)).

With respect to organic environments in industrialised countries, it remains unclear to date whether the differences in levels of input between conventional and organic growing systems are large enough to economically justify breeding and official variety testing in both environments, or rather just to include additional characteristics, of relevance only for organic farmers, into conventional breeding and tests. As demonstrated, genotype-environment interaction very much depends on the varieties and systems chosen (Fig 1). In several countries of Europe, research projects have been conducted to gain more insights into whether it is important to evaluate characteristics of varieties under organic conditions compared to the performance under conventional conditions. These data are being collected for a combined statistical analysis of potential differences between ranging of varieties in conventional and organic growing systems in a European Network on sustainable low-input cereal production: required varietal characteristics and crop diversity (SUSVAR, 2004). One example is a study of a large number of German variety trials under high input, low input and organic growing conditions. Here, substantial differences in ranking of the varieties were found (Baresel and Reents, 2006).

In a Danish study of genotype-environment interactions for grain yield involving conventional and organic farming systems including 72 spring barley varieties and 17 combinations of location, growing system and year, choice of variety was found to be as important a factor for grain yield as other factors in the management (Østergård et al., 2006). Within a group of ten organic environments, nearly 40% of the total variation in grain yields was explained by varieties or by their interaction with environment. Within a group of four conventional environments, the variation among varieties was similar to that in the former group but the variation in yield among environments was less. In both groups the genotype-environment interaction contributed with about 35% of the total variation among varieties. In another group of organic environments without application of manure, only the 24 best varieties were grown. For these extreme environments, the average variation among varieties was very little, and the variation in yield among environments was large. Furthermore, the genotype-environment variation contributed under these low-input conditions the most to the total variation among varieties (about 80 %). This supports the idea that genotype-environment interactions are most important in extreme environments, e.g. marginal conditions in developing countries.

7 The use of molecular markers in organic selection programmes

As pointed out earlier, the concept of naturalness will have consequences for the applicability of conventional breeding techniques and substances in certified OPB (Lammerts van Bueren and Struik, 2004). Although the standards for organic agriculture are clear on excluding GM for organic production, there is much discussion on the applicability of DNA-based molecular markers. Molecular markers are often suggested as a diagnostic tool in breeding programmes to supplement phenotypic trait selection methods in the field (e.g. Collard et al., 2005). However, their potential for organic agriculture has yet to be proven.

In the organic sector, the question about molecular markers concerns the production methods for molecular markers as well as the application of molecular markers as elucidated at a recent workshop (Lammerts van Bueren et al., 2005). With respect to the production methods of markers problems arise in cases where components may be applied that are not permitted according to the organic standards, such as the use of radioactive isotopes and (cancer-inducing) chemicals. Conflict with the principles also arises in the process of marker development when genes may be silenced by genetical modification to learn more about traits at the molecular level. Also the use of double haploid plants, often produced with the help of in-vitro techniques, brings problems. In conclusion, these techniques are very much the subject of debate within the organic sector with respect to the violation of plant integrity.

With respect to the possibility and usefulness of applying molecular markers in organic breeding programmes, the question is whether DNA markers can be developed for those traits that are desirable for organic varieties. This would concern for instance yield stability, broad disease resistance, nutrient uptake and use efficiency and weed competitiveness. These characteristics are quantitative - and thus complex and difficult to select for, as more genes on different chromosomes may be involved. Further, the QTL by environment interaction is expected to be larger under organic growing conditions. Therefore, in the short term, it is expected that molecular markers cannot be of value in the search for traits in practical organic agriculture breeding programmes (Lammerts van Bueren et al., 2005). This may be different in conventional agriculture where the environment can be controlled to a further extent than in organic agriculture and the effect of QTLs are expected to be more consistent.

A more obvious area for application within OPB could be in backcross programmes to include certain monogenetic disease resistances from wild relatives avoiding undesired linkage drag as this is done in conventional breeding. Such resistance genes may also be important in organic agriculture. However, in many cases organic agriculture is not primarily aiming at absolute resistance but at a broader disease tolerance combining morphological and physiological traits.

Next to operative use, molecular markers may be of importance in fundamental research aiming at understanding underlying mechanisms. It could be of interest to study 'micro-evolution' of composite crosses or variety mixtures (Fraj et al., 2003; Østergård and Backes, 2006) or to analyse breeding progress retrospectively in order to learn from the past.

8 Seed production

The IFOAM Basic Standards as well as many regulations on organic farming make the use of organic seed obligatory to organic farmers and growers. Organic seed is usually defined as seed which is derived from mother plants that have been grown under organic conditions for at least one generation for annual plants or in the case of perennials for two growing seasons. Derogation for the use of conventional seed will only be granted for those species of which the assortment of seed from organically propagated varieties is still not adequate or the quantities of seed not yet sufficiently available. Organic and non-organic seed used in organic growing can only be treated with substances not listed in the organic production rules.

In the European Union Regulation (EC) 1452/2003 obliges EU Member States to set up data bases in which the available organic seed in the respective territory shall be listed. Farmers and growers may only get permission by the inspection authority to use non-organic seed if no appropriate variety for their use is listed in the respective national data base. On the other hand, farmers and growers cannot be compelled to use organic seed that is not listed in the data base even if it is the very variety they request. Those data bases have been introduced as a tool to stimulate both the organic seed producers to produce organic seed and the farmers and growers to use the organically produced seed (Wilbois, 2005).

To date organic seed production faces more problems when compared to conventional (Lammerts van Bueren et al., 2003a). As a rule the degree of the difficulties depends on the respective crop and is usually more distinct in perennials (e.g. carrot, onion, sugar beet) than in annuals. The major difficulties in organic seed production are i) production costs, ii) seed health and vigour and in the future possibly iii) the seed impurities due to the presence of GMO (cf. see below). While in most annual arable crops (e.g. cereals) the costs for organic seed are not much higher compared to untreated non-organic seed the price difference due to higher productions costs can be considerably higher for certain organic vegetable seed (a multiple for certain crops), especially for hybrid varieties of biannual crops such as onion, carrots etc. This fact may negatively affect the market for organic seed of those crops (Van der Zeijden, 2004).

Since organic seed cannot be treated with chemical seed sanitation products seed borne diseases deserve special attention in the organic seed production. Therefore, seed tests for diseases and in inevitable cases also direct treatment measures, play an important role in organic seed production. For direct seed treatment only physical methods like hot water, hot air treatment, electron treatment etc. and allowed substances like natural compounds, plant extracts and micro-organism preparations (e.g. essential oils, Pseudomonas chloraphis, Bacillus subtilis) may be used for seed sanitation in organic farming (e.g. Groot et al., 2006, Jahn et al., 2006). While for some important seed borne diseases like for instance common bunt of wheat (*Tilletia caries* (DC) Tul.) treatments with hot water, hot air or with yellow mustard-powder are highly effective (Wilbois et al., 2005) there are still seed borne diseases which cannot be adequately treated (e.g. loose smut of wheat (*Ustilago tritici* (Pers.) Rostr.).

9 Strategies for transition from conventional to organic varieties

On a short-term basis, the organic sector still largely depends on conventional varieties and seeds. So the varieties available to organic farmers may be categorised in three groups: i) conventionally bred varieties which may be suitable for organic production, ii) conventionally bred varieties which have been developed specifically for low-input environments and iii) organically bred varieties. The development towards organically bred varieties suited for organic farming conditions will have to be taken in steps (Table 1).

Table 1. A time schedule for steps and results towards organic varieties and seed production (adapted after Lammerts van Bueren and Verhoog, 2006).

Time	Activity	Product
Short term`	Defining desired traits per crop; organic variety trials; development of organic seed production and non-chemical seed treatments; no use of GM	Conventionally produced varieties and seeds, but post-harvest not chemically treated, next to organically produced seeds of conventionally bred varieties
Longer term	Development of organic VCU-testing protocols; conventional plant breeding programmes including low-input selection criteria	Varieties bred for low-input conditions and organically produced seeds
Long term	Organically certified breeding, maintenance and seed production programmes	Organically bred varieties and organically produced seeds

As a first step, defining organic crop-specific ideotypes (i.e. specific combinations of desirable traits for different organic growing conditions) and conducting variety trials under organic farming conditions may help to select the best varieties available in the pool of existing (conventional) varieties so as to be propagated organically. On a slightly longer-term basis, adaptation of protocols to test varieties on their value for cultivation and use (VCU) for organic farming conditions may enlarge the chances that new varieties will be released from conventional breeding programmes that match the requirements of low-input farming systems to a better extent. On the basis of experiences in several European countries, a handbook for adapting organic variety testing has been described for cereals (Donner and Osman, 2006). On a long-term basis, the organic sector will head for a true and maybe even certified OPB chain, including selection, maintenance and seed production of varieties under organic conditions.

Currently, only a small number of breeding programmes are specifically focused on organic production (for an overview see Legzdina and Skrabule, 2005). Some are conducted by (co-operations of) farmer-breeders and some by commercial breeding companies, or in combination with established and farmer-breeders.

Due to the fact that the organic sector still has limited acreage, many commercial breeding companies are reluctant to start breeding programmes specifically for this sector. Farmers are therefore looking for alternative options to enhance availability of a broad spectrum of varieties. Specifically in this respect we may learn from the decentralised and farmers' participatory approaches already applied in developing countries for areas with small and subsistence farmers neglected by the green revolution (e.g. Kudadjie et al., 2004, Zannou et al., 2004). Such approaches offer an opportunity to combine a farmer's knowledge, daily experience and developed intuition (farmer's eye) with knowledge, experience and developed breeder's eye of formal breeders (Ceccarelli, 2000; Desclaux et al., 2006). Morris and Bellon (2004) have described four breeding models in which farmers are to a smaller or larger extent involved in the different steps of a breeding process. In contrast to the traditional model adhered by the formal breeding sector of industrialised countries, a complete participatory breeding model involves farmers in all activities relating to the selection of source germplasm, to trait identification (pre-breeding), to cultivar development, and finally to varietal evaluation. In an efficient participatory breeding model, formal breeders involve farmers in the phase of selecting parent lines and in the end phase of evaluating potential varieties. In the participatory varietal selection model, farmers only deal with varietal evaluation at the end.

Benefits derived from new varieties bred by farmers require a legal system of common ownership that allows equitable access and benefits sharing. In many countries, examples may be found of networks including organic farmers and breeders that provide such a system (Henatsch, 2002; Rios Labrada et al., 2002; Ramos Garcia et al., 2004).

10 Current situation and legal framework regarding the use of GM in European agriculture

A major problem for the future development of organic agriculture and organic seed production is the co-existence with GM-agriculture, as the organic sector does not want contamination with GMOs in any product or process on the farm (cf. e.g. IFOAM 2005, Regulation (EEC) No 2092/91). The difficulties involved with the avoidance of GM contamination are due to i) that GM-plants disperse their genes in time and space through pollen flow by wind and insects as well as through seed dispersal), ii) impurities in seed lots and iii) contamination during sowing, harvesting, transportation, storage etc. In practice, co-existence becomes a highly complex issue under the prevailing conditions of a rather small-scale European farming structure (cf. Tolstrup et al., 2003, Devos et al. 2004; Van de Wiel and Lotz, 2006). Compared to countries such as the USA, Canada and Argentina, the use of GM in European farming is relatively marginal and in most countries present only on the level of field trails.

Nevertheless, more and more genetically modified varieties (mainly insect- and herbicide-resistant crops) become listed in the Common EU Catalogue of varieties, indicating that the cultivation of those GM varieties could accelerate in the near future. GM varieties need to be authorised in accordance with Directive 2001/18/EC (former: 90/220/EEC) before they are included in this Common Catalogue and potentially marketed in the EU. By doing so, this directive intends to provide a freedom of choice between GM and non-GM products, not only for consumers but also for the food and feed producers. 'Co-existence' refers to the farmer's ability to choose between conventional, organic and GM production, in compliance with relevant legislation on labelling rules and purity standards. Subsequently, regulation (EC) No 1829/2003 on GM food and feed provided the legal basis for the national and regional implementation of rules on co-existence in the EU, and came into force in April 2004 (Anonymous, 2006a). Various countries have since then implemented measures to be taken to ensure co-existence. As an example, in Denmark based on this regulation, more elaborate education of potential GM farmers into measures of how to control spread of genes and seeds is enforced (Tolstrup et al., 2003).

Furthermore, regulation (EC) No 1829/2003 defines a threshold level for GM labelling for GM contamination in food of 0.9%. Above that threshold level products need to be labelled as consisting of, containing or produced by GM. The threshold level has been determined irrespective of the food production systems (organic or conventional). However, as yet, there is no threshold level in place in the EU for traces of GM in seeds. As a consequence, any seed lot containing a traceable proportion of GM seeds has to be labelled as containing GMOs in order to be authorized for cultivation and subsequent marketing in the EU. (Anonymous, 2003). The de-facto seed threshold for GM contamination in seed lots is, therefore, the detection level, which is at the moment 0.1 %. The organic sector advocates taking the current detection level as the basis to determine the legislative threshold level for GM impurities for either conventional or organic seed.

As a conclusion we could state that the whole co-existence legislation is still surrounded by many practical problems for the organic sector which still need to be solved (Anonymous 2005 and 2006b).

11 Organic farming and co-existence

The measures to be taken to ensure co-existence of GM and non GM farming - in order not to exceed the maximum level of GM contamination in food and feed – are by definition rather complex and more or less expensive depending on the respective crop, the relative share of GM plants in the region and specific farming situations. Therefore, for organic producers especially these measures are often perceived as economical threats for the following reasons:

- In general the market value of organic farming goods is higher than in conventional farming and thus the economic damage caused by contamination is usually greater.
- Since consumers of organic products expect organic food to be without any GM contamination, organic food processors demand agricultural commodities without any detectable GM-contamination in private contracts. Therefore, beyond the legal framework, in practice there often are de-facto threshold levels that are much lower, mostly at the detection level, for GM contamination of agricultural commodities. These levels have to be met by organic farmers.
- Organic farmers, unlike conventional farmers who may use herbicides, are unable to control volunteer plants from contaminated plants in the field (e.g. in oilseed rape) or volunteers which may originate from field-to-field transfer by machinery (e.g. combine, harvester).

These aspects only refer to the organic production of food and feed. Much more vulnerable activities in terms of GM contamination - like seed production including farm saved seed and plant breeding - are found in organic agriculture, too. Some organic farmers consider the repeated use of farm saved seed to be the only way to obtain varieties adapted to their site and farm-specific management. The impact of neighbouring GMOs might not be substantial in the case of pre-dominantly self-fertilizing species but could be considerable with regard to ‘vulnerable’ crop species with high rates of outcrossing, small seeds and long seed dormancy (e.g. oilseed rape). The accumulation over time may, therefore, lead to unmarketable products (Tolstrup et al., 2003).

These latter aspects of seed production and saving as well as breeding on farms contribute to the fear of organic farmers that for them difficulties - and hence costs – in the prevention of GM contamination may increase substantially in future agriculture with potentially high areas of GM plants. They also fear that this process may even render these highly vulnerable farming activities such as organic breeding and seed production next to impossible. This is a world wide problem.

12 Outlook

Summing up, what are the perspectives of organic plant breeding and seed production in a genomics era? Although organic agriculture is a growing sector, both in industrialised countries and in developing and transition countries, organic plant breeding and seed production is still conducted at a very small scale.

Plant breeding for the organic sector will need more time and substantially more money to be raised. However, even at the short term, organic plant production can take advantage of conventionally bred varieties by increasing within-crop diversity by the use of variety mixtures or crop populations. In non-industrialised countries with less seed regulation, the use of landraces may be supplemented by including such varieties into the landrace populations.

As the development of conventional agriculture moves towards a more sustainable way of farming, the conventional plant breeding industry will become more and more interested in developing varieties for lower-input such as varieties with a broader disease resistance and improved weed suppression. Such varieties need, obviously, be produced without genetical modification techniques if used for organic farming. Although policy makers tend to except that organic agriculture excludes the use of GM, they are nevertheless very eager to make the organic sector embrace DNA markers as a diagnostic tool in breeding programmes, and thus to promote genomics as a green tool. As the development and application of markers can be very costly and the benefits for the organic agriculture has not yet been proven, the organic sector is still critical when it comes to setting high priorities for these methods within the limited budgets for organic research.

To arrive at better adapted varieties for organic farming systems, not only science can play an important role, but the role of practical participatory plant breeding may be crucial. This is exclusively an area where the industrialised countries can learn from participatory approaches applied in developing countries.

As to organic seed production in Europe, the official EU Regulation has put more and more emphasis on becoming less dependent on conventional seeds.

Therefore, the conventional seed industry is (gradually) becoming interested in contributing to a larger availability of organically produced seed. Also in the US such regulations are coming into force, but harmonisation between the two parts of the worlds is needed (Sundstrom, 2004). For developing countries, such European regulations may cause problems for the development of certified organic agriculture because of a lack of harmonisation concerning private standards and official regulations (Hermoso, 2004). Many small farmers in developing countries use uncertified seeds bought on the local market or exchanged among farmers. The concern here is focused on the question when or to which extent such countries need to comply with such European or US regulation in order to be able to export their products to Europe or to the US. In all cases more research seems to be needed to support the optimisation of organic seed production and the development of effective seed treatments that comply with the organic standards.

Finally to the concerns for the future in relation to GM: For a variety of reasons, the impact of a possible GMO spread in the environment will affect organic farmers to a larger extent than conventional, non-GM farmers. Those include (i) the fact that often diverse organic practice of plant production (including continued farm saved seed, on-farm breeding etc.) is more vulnerable to GM contamination, since seed lots are not completely renewed by certified, i.e. non-contaminated, stock yearly; (ii)the risk of losing markets is greater for organic farmers since many consumers require not only the rejection of GM use by the organic sector but also the general avoidance of genetically modified material in the produce is seen as an important added value. Therefore, in the future, even with the help of suitable co-existence measures some (organic) farming activities - especially seed multiplication, continued seed saving and breeding related to ‘vulnerable species’ - could become feasible only in GM free areas or regions. For this reason the continued establishment of GM-free areas or regions merits special attention. However despite all signalled problems, the development of a GM-free plant breeding and seed production for improved varieties meeting the needs and values of organic agriculture is a challenging task for practice and science in the future.

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