Organic propagation of seed and planting material: an overview of problems and challenges for research

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Abstract

By 1 January 2004, as a result of EU-regulation 2092/91 for organic farming, the organic sector needs to have developed efficient schemes to be able to use adequate quantities of organically produced seed and planting material. Market problems and agronomic problems that are related to obtaining sufficient quantities of adequate quality are reviewed. For successful production of organic seed and planting material intensive communication between and mutual commitment of farmers, traders, breeders and governmental organizations are necessary. Farmers together with traders should be involved in variety testing and in designing crop ideotypes by identifying the desired cultivar(s) and variety traits. Breeders can contribute by incorporating the desired organic traits in future breeding programmes. In addition, a great effort is needed to develop empirical knowledge and research-based information on adapting and improving cultural practices for organic seed production, developing resistant cultivars for healthy seed production, developing protocols for seed health testing, assessing disease threshold values, and designing organic seed treatments. The EU-regulation should be strictly enforced, no longer allowing derogation of the use of conventional seeds after 2003 for those crops for which diverse, high quality seed or planting material of organic origin is available. It is expected that by 1 January 2004 enough seed or planting material will be available for most crops. But continuous optimizing of organic seed production management will be required to enlarge the cultivar assortment and to control the quality of organic seed and planting material.

Additional keywords: organic agriculture, seed-borne diseases, variety testing, seed health, crop ideotypes, organic plant breeding, EU regulations

Introduction

On principle, organic farmers have to use organically produced seed and planting material (Anon., 1991). Not enough organically propagated material being available, for many years a general derogation of EU-regulation 2092/91 made it possible to use conventionally produced seed. The only restriction was that the seed had not been treated post harvest with chemical-synthetic fungicides and that cultivars were not of transgenic origin.

The organic sector is closing the entire organic production chain for its credibility, consumers' trust and transparency. Therefore, the general derogation enabling the use of conventional seed will expire on 1 January 2004 for those crops for which sufficient quantities of organically produced seed of suitable cultivars are available.

For the time being, as a kind of transitional measure, the mentioned EU-regulation qualifies seed as organic if it is produced by a crop that is planted and raised organically for at least one generation in the case of annual crops, and for two growing seasons for biennial and perennial crops. In other words, conventionally produced basic seed, provided it is not treated post harvest with chemical-synthetic fungicides, can be used to produce organic commercial seed. However, in the long term the entire seed production programme has to be organic.

Also organically propagated plant material has to meet the current regulations on quality aspects of propagated material. The main quality criteria are genetic quality (varietal trueness, true-to-type), physical quality (varietal purity, free from seeds of other species and from other types of impurities), health quality (free from diseases and pests) and physiological quality (e.g. germination percentage and vigour).

This paper discusses the problems and challenges of obtaining sufficient quantities of quality organic seeds and a sufficient diversity of cultivars for the organic sector. These problems and challenges cover three areas: (1) market aspects, (2) technical aspects relating to quantity, and (3) technical aspects relating to quality standards. The three problem areas will be discussed to develop short and long-term strategies for organic production of seed and planting material. We will not only focus on the propagation of conventionally produced cultivars, but will also include the necessary further closing of the chain towards organic breeding and maintenance of cultivars suitable for organic agriculture.

Materials and methods

The data presented are from research conducted at the Louis Bolk Institute (Driebergen, The Netherlands) and include surveys and variety trials in the period 1993–2002 (Lammerts Van Bueren, 1994; Lammerts Van Bueren *et al.*, 1999; 2001; 2002a, c; Osman *et al.*, 2000; Lammerts Van Bueren & Van Den Broek, 2002; Osman & Lammerts Van Bueren, 2002; Osman & Van Den Brink, 2002), or are derived from experiences of Dutch seed companies. They are completed with data from literature. The limited number of peer-reviewed articles and other documentation on organic seed production shows that we are dealing with a relatively new research area. At the same time the pressure to make rapid progress is enormous. Much information is therefore extracted from secondary literature or is empirical.

Although many examples are from Dutch organic agriculture, they are representative for Northwestern Europe.

Market: limited assortment and quantities

The number of organically propagated, modern open-pollinated and hybrid cultivars from the conventional seed companies is still very limited. Several surveys have been done to identify barriers and problems for conventional seed companies to enter the organic market (Lammerts Van Bueren, 1994; Bloksma & Jansonius, 1999; Anon., 2000a; Cook, 2000; Groot, 2002). From a survey in 1993/1994 it became clear that economic concern was the main obstacle. The area of organic farming per country is limited and, therefore, quantities required per cultivar are relatively small (Lammerts Van Bueren, 1994). Another concern was the uncertainty about yield stability and risks of seed-borne diseases.

Recently, interest of seed companies to invest in organic seed production and to enter the market for organic seed has grown, which was triggered by two factors. Especially for companies without large investments in gene technology, it was important that EU-regulation 2092/91 clearly states that organic agriculture will not allow transgenic engineering, so that there is a market that demands cultivars bred without using such technology. Secondly, most European countries decided to strive for an organic area of at least 10% of their total agricultural area (Anon., 2000b), which makes organic seed production economically feasible. Furthermore, most seed companies expect that building-up expertise with organic seed production will sooner or later have a spin-off to conventional production methods aiming at a reduction of chemical inputs.

However, this potentially larger area of organic farming does not necessarily mean that the economic barriers are removed. Cook (2000) states that because of expected higher seed costs some seed companies are worried that their efforts in this limited market segment might be frustrated by organic farmers who save their own seed to keep production costs low. Most organic farmers realize that producing good quality seed is a skill in itself and they rather rely on professional seed producers. On the other hand, to close the cycle as part of a quality control strategy in organic farming, some farmers regard it as a challenge to integrate the production of seed of one or more crops in their farming system (e.g. Spiess, 1996).

For most crops, seed companies focus on the international market, which usually demands different cultivars adapted to local agro-ecological, agronomic and cultural conditions. For example, to provide the different onion market segments in Europe with at least two cultivars per segment, a total of roughly 70 onion cultivars are required. Assuming that in 2004 some 4900 ha of onions (5% of the total European onion area) will be grown organically, an average of 1.4 ha per year per onion cultivar will be required for seed production. This means that providing the relatively small organic market with a sufficient diversity of cultivars is economically and technically challenging. It results in higher seed production costs and therefore higher seed prices than conventional seed production. The increase in price varies from 10 to 30% for annual crops to 200 to 300% for some biennial crops with hybrid cultivars (Brakeboer, 1999). In the case of onions the production costs per ha for arable farmers will be 15% higher. Given a yield of 30 t ha^{-1} this means an increase of 3% of the retail price. For annual greenhouse crops like tomato the increase in costs caused by organic seed production is much lower and proportionally less significant. For a greenhouse grower this can result in a 0.5% increase in costs per m^2, leading to an increase in the retail price of 0.25% to cover the additional expenses (Lammerts Van Bueren, 2003).

With the limited area of organic agriculture and therefore the relatively higher cost than with conventional seed production, the assortment of organically propagated cultivars per crop will be limited. To attune further development of an adequate assortment to different farm management and market requirements, communication between seed companies and farmers is very important. Moreover, variety trials under organic conditions are needed to screen existing cultivars for their suitability for organic farming.

A general list of desirable variety characteristics to suit the organic farming system, where no chemical-synthetic inputs are applied, was already discussed by Lammerts Van Bueren *et al.* (2002b). These authors indicated that cultivars should give a reliable and stable yield and quality, be able to cope with low nitrogen levels from organic manure, have sufficient weed suppressive ability, and adequate disease and pest resistance or tolerance. This general list has to be specified for each crop and market segment. A principal tool for assessing the suitability of cultivars for organic farming are the field meetings where farmers and breeders together assess and discuss the variety trials under organic farm conditions. In that way conventional breeders who are not (yet) familiar with organic farming get a more complete picture of the demands per crop. These demands not only include a set of resistances, but also a different plant morphology and crop architecture, like for example a better root system, an earlier canopy closure, or a longer peduncle to enable the cereal spike to ripen higher above the moist leaf canopy. This approach can lead to (1) the development of more suitable ideotypes for each crop and market segment, (2) the identification and subsequent propagation of the most adequate cultivars present in existing collections, and (3) the development of new cultivars (Lammerts Van Bueren *et al.*, 2001; 2002b, c; Lammerts Van Bueren & Osman, 2002; Osman & Lammerts Van Bueren, 2002).

The assortment needed is determined not only by the suitability of a cultivar for organic market crop production, but also by its ability to produce healthy seeds under organic conditions without chemical-synthetic crop protectants. Of several well-known (hybrid) cultivars currently used by organic farmers it is difficult to produce enough, high-quality seed under organic conditions, because the cultivars are very susceptible to certain diseases. An example is the carrot hybrid Nerac, which has been one of the main cultivars among organic and conventional growers during the last few years. Nonetheless the seed company concerned has decided not to propagate it organically, because under organic conditions this is too difficult. Here we meet the technical limits of organic seed production: the regulations are more restrictive than most seed companies had initially realized. In short, not only suitable cultivars are required but also sound cultural practices for organic production.

Development of sound cultural practices for organic seed production

As organic farming does not allow the use of chemical-sythetic inputs, it is of great importance that seed and planting material for organic farming are of the highest quality possible. Organic seed production therefore makes high demands on expertise, disease management, and location in relation to climate and cultivars.

Below, the state of the art of organic production of seeds and planting material of the following important crop(s) (types) is discussed: cereals, potato, grass/clover, vegetables and fruits. These crops (or crop types) are included in several research projects of the Louis Bolk Institute on variety trials or improvements of organic production of seed or planting material. The crops also represent a wide diversity of seed-borne diseases and traits related to physiological performance.

Cereal seed

Most experience with organic seed production has been obtained and documented for cereals. Due to variation in weather and (partly site-specific, partly farmer-specific) cropping conditions, the quality of cereal seed can differ very much from year to year and from seed lot to seed lot. Experience with organic cereal seed production so far has learned that seed lots are most frequently discarded because of contamination with common bunt (*Tilletia caries)*. Other reasons are insufficient grading of the seeds by not excluding the smaller, usually infected ones, slow germinability and the presence of the seed-borne pathogens *Fusarium* spp. and *Septoria nodorum* (Dornbusch *et al.,* 1992; Rüegger *et al*., 1998; Hartl *et al*., 1999; Borgen & Davanlou, 2000; Thomas & Wyartt, 2002).

If the disease level is hard to control with cultural practices and if resistant cultivars are not yet available, development of post-harvest treatments is an important complementary measure. During the past 10 years many studies have been conducted on alternative, post-harvest seed treatments to control common bunt and other cereal fungal diseases in organic farming (e.g. Winter *et al*., 1998; Borgen & Davanlou, 2000; Spiess, 2000). These authors mention several alternatives that are effective (i.e., > 95% control) with limited effects on seed germination. Alternatives include several ways of using warm- or hot water treatments, and seed dressings with mustard flour, milk powder or treatment with acetic acid. The warm- or hot water treatments are very labour intensive and therefore relatively expensive in the case of cereals, and are only feasible in exceptional situations.

For some (experienced) organic farmers, saving seed from the previous cereal crop is a measure to keep control of seed quality. In that way wheat cultivars have been successfully propagated for 20 years and longer without a significant loss in yield potential or quality, applying mass selection to avoid excessive heterogeneity or degeneration of the cultivar (Prior, 1993; Heyden & Lammerts Van Bueren, 1999).

Seed potato

In organic seed potato production soil-borne and air-borne fungi are the main problems; nematode and virus problems are rare. Like with organic cereal seed, there is already a long experience with organic seed potato production.

In a three-year survey among 15 Dutch organic farms producing seed potatoes, the most important problems appeared to be *Rhizoctonia solani* (soil-borne and seed-borne) and late blight (*Phytophthora infestans*) (seed-borne, air-borne, and in some cases also soil-borne) (Hospers, 1996a, b). The quality of seed potatoes in terms of tuber size, and number and vigour of *Rhizoctonia* sclerotia on infected tubers, clearly differs among farms and not only influences the yield but also the quality of market crop production (Karalus, 1999). Many organic farmers prefer to produce their own seed potatoes for reasons of farm hygiene and disease control (Hospers, 1996a; Hoekman, 1998). These farmers found that after several years of on-farm propagation of potato seed a decline in *Rhizoctonia* contamination occurred. Whether this was a result of natural site-adapted, soil-borne antagonists is not known yet. Further research on the mechanism behind this phenomenon could provide tools for sound propagation strategies. This may be important as the use of the bio-control agent *Verticillium biguttatum* has not yet been officially permitted. Moreover, the production of this antagonist is expensive. Nevertheless, the results with *Verticillium* in organic trials are positive, showing reduction of the vigour or number of *Rhizoctonia* sclerotia present on the seed tubers (Hospers, 1996a).

In the Netherlands late blight is a smaller problem in seed potato production than in market crop production. In organic agriculture late blight is not expected to be a soil-borne problem, because after 4 years its oospores are inactivated (Turkensteen *et al.*, 2000) and organic farming systems in most cases have a 6–7 year rotation cycle. For the same reason nematodes do not occur as a problem in organic (seed) potato production either. Because of the combination of less organic nitrogen use (and therefore less lush growth and a tougher leaf surface), use of chitted seed potatoes and virus resistant cultivars, a lower density of aphids is often experienced. Therefore aphid-borne viruses will spread less rapidly (Kölsch & Stöppler, 1990; Hospers, 1996a). So also virus infection of potato is a minor problem in organic agriculture.

Grass and clover seed

Growing seed of perennial ryegrass fits well in an organic farming system with cattle. Access to slurry manure is essential for crop performance in the year when seed harvesting takes place. Some problems with weeds and diseases need to be solved. Attention is paid to enhancement of the seed crop's competitiveness with weeds to enable mechanical weed control with minor crop damage using a larger row distance, or by intercropping with green manure crops (Lund-Kristensen *et al.*, 2000; Boelt *et al.*, 2002; Deleuran & Boelt, 2002).

In the Netherlands, because of the lower nitrogen level used on organic grassland, some diseases occur less frequently in organic grassland than in conventionally managed grassland. However, black rust (*Puccinia graminis*) does occur during seed set and reduces organic seed production so much that other cultivars with more resistance to this fungus, like some of the French cultivars (M. Nas, pers. comm.) are required. As chemical protection in conventional grass seed production is standard, breeders so far have not focused on such a trait for seed production of Dutch grass cultivars. Furthermore, in the organic sector the choice of grass cultivars largely depends on the possibility to grow grass in a mixture with white clover, and thus on the clover's ability to establish and persist in the grassland so that the use of nitrogen fixed by the clover in the grass can be maximized (Van Eekeren, 2001).

More problematic is the production of white clover seed without considerable loss of yield due to damage by *Apion* spp. and weeds, both varying from year to year and from farm to farm (Lund-Kristensen *et al.*, 2001; Boelt *et al.*, 2002). Further research on organic white clover seed production is urgently needed.

Vegetable seed

With organically propagating vegetable seed the main focus is on gaining experience with managing seed-borne diseases. Research to further optimize cultural practices is required. Table 1 summarizes the current experience of several Dutch seed companies with organic vegetable seed production. Most seed-borne diseases are just as severe in organic systems as in conventional ones. A few are less problematic, like *Fusarium* spp. in carrot, and some are even more severe, like *Xanthomonas campestris* in carrot, due to lack of experience and lack of possible treatments. Research on alternative seed treatments is necessary to solve the problems on the short term.

Extra attention is needed for the organic seed production of biennial crops such as *Brassica* spp., onion and carrot. The development of diseases in the first year and a continued increase of the disease pressure in the second pose a special problem. Hybrid seed production forms another complication. Of conventional propagation it is known that seed production of hybrids can be more difficult than that of open-pollinated cultivars, because of the need to synchronize flowering of both parental lines in separate rows, and sometimes because of less growth vigour of the parental lines. This can even be more difficult under organic conditions where the plant's development is less easy to control.

Nursery stock for fruit cultivation

Bloksma & Jansonius (1999) concluded that in the Netherlands it is possible – for a slightly higher price per tree – to propagate fruit tree nursery stock that is based on organically grown rootstocks and conventionally produced scions. For such a small market organically produced scions are not expected to be available because of the sanitary need to keep the material virus-free. Further research is needed to fill a number of gaps in current knowledge with respect to cultivation techniques, especially those relating to reducing the risk of canker (*Nectria galligena*) and to obtaining good branching. Conventional nurseries use hormones to stimulate early branching, whereas an organic nursery has to realize growth-enhancing conditions risking a higher canker incidence or has to choose for less lush growth, and therefore less canker incidence, but with an extra year of growth before the first fruits can be harvested. By lack of experience it is not yet clear what the best and economically feasible nursery strategy is, and how much loss can be expected (Bloksma & Jansonius, 1999; Bloksma *et al.*, 2002).

Table 1. Seed-borne diseases of several vegetable crops in conventional (Conv) and organic (Org) seed production systems: their economic importance and relevance of treatments in relation to the growth phase in which the disease occurs (after Groot, 2002).

Crop	Pathogen	Growth phase					
		Germination/ emergence		Market crop production		Seed production	
		Conv	Org	Conv	Org	Conv	Org
Brassica spp.	*Xanthomonas campestris*	±[1] , ph[2], ss[3]	± , ph	++	++	++	++
	Phoma lingam	+ , ss	+ , ph	++	+/++	± , s	±/+
	Alternaria brassicicola	± , s	± , ph	+ , s	++	++ , s	++
Onions	*Botrytis aclada*	± , ss	± , ph	++	+/++	++ , ss	++
	Botrytis spp.	+	± , ph	+	±	++ , s	++
	Fusarium oxysporum	±	–	+	–	±	±
	Stemphylium spp.	+ , ph	± , ph	+ , s	±	±	±
Carrots	*Alternaria radicina*	++ , s, ph	++ , ph	++	++	++ , s	++
	Alternaria dauci	+ , s, ph	+ , ph	++ , s	++	++ , ss	++
	Fusarium spp.	± , s	–	±	–/±	+	±
	Xanthomonas campestris	± , ph	± , ph	++	+/++	±	++
Beans	*Ascochyta* spp./ *Phoma* spp.	+ , ss	±/+	++	±	+	–/±
	Pseudomonas syringae	+	–	++	–	++	–
	Fusarium solani	++ , s	–	±	–	±	–/±
Lettuce	Lettuce Mosaic Virus	–	–	+	+	+	+

1 – = not important; + = important; ++ = very important; ± = importance not (yet) known or not clear.
2 ph = physical treatment important (incl. warm or hot water; steam).
3 s = standard chemical treatment; ss = chemical treatment essential.

Seed quality

In organic agriculture it is essential that seed and planting material are of good quality, because there are fewer possibilities to protect seeds in the vulnerable germination phase. Apart from the existing criteria for genetic purity, physical purity, absence of undesirable weed seeds, and a minimum germination rate, in organic farming especially aspects like seed treatment against seed-borne pests and diseases, vigour, and seed standards need more attention.

Seed selection, grading and treatment

Organic agriculture requires a system approach and is therefore primarily focused on systemic solutions (Alrøe & Kristensen, 2002) and on prevention at the level of pre-harvest cultural practices rather than symptomatic and technical solutions for seed treatment. Nonetheless the organic seed sector also needs post-harvest seed treatment options for specific crops to be able to sell enough seeds free from, or with an acceptably low level of seed-borne diseases. There are several methods to grade and to separate infected from healthy seeds in order to keep the level of contamination in marketed seeds low. This can be achieved by selecting on seed weight or seed size, as is known for reducing the percentage of *Fusarium*-contaminated cereal seeds. New techniques are being developed that are capable of separating ripe from immature seeds on the basis of their chlorophyll fluorescence (CF) with a CF-analyser (Jalink *et al.*, 1998; Konstantinova *et al.*, 2002).

Another method is to disinfect the contaminated seed with hot or warm water, or steam. Some seed companies already have promising experiences with the use of such physical treatments, but these methods still need improvement in order not to reduce the physiological seed quality.

Besides disinfecting coatings, like mustard powder for cereal seed, there are developments in growth promoting and resistance-inducing seed coatings ('biologicals') using micro-organisms (Van Vliet, 1997; Van Den Bulk & Bino, 1998), or priming methods to promote rapid and uniform emergence. More research is needed to determine under which organic farming conditions such costly solutions will provide cost-effective benefits in terms of higher levels or rates of germination that may help to overcome problems with crop establishment and weed competition (Groot, 2002).

The number of alternative seed protection techniques (antagonists, coatings or physical methods) that are permitted according to the positive list in Annex IIb of EU regulation 2092/91 for organic agriculture is still very low.

Physiological seed quality

Seed quality not only implies the absence of seed-borne diseases. For instance, not well-ripened seeds – possibly due to disease pressure during seed production – are more susceptible to stress during storage and sub-optimal field conditions after sowing than fully matured seeds. Particularly for organically grown crops that may be exposed to adverse germination conditions, like spring wheat or beans and maize in early spring, it might be important to test the seed for vigour. Apart from germination rate, seed vigour includes the sum of seed properties that determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence (Hampton & Tekrony, 1995). High-vigour seed lots are more likely to be able to withstand stress than low-vigour seed lots; so vigour is positively related to the ability of a seed population to establish an optimal plant stand, in optimal as well as sub-optimal soil environments (Tekrony & Egli, 1991). Optimal emergence and plant stand are important for organic weed management and for preventing diseases due to sub-optimal growth.

Seed standards and testing

Seed treatment does not need to be applied standard if seed health tests are used to ascertain their necessity, and if accurate information on threshold values is available. Official sanitary regulations for seed-borne diseases in the seed production system differ per crop. For some arable crops maximum levels of contamination of certain pathogens have been set. For most vegetable crops no exact levels are given in EC regulation 70/458 (Anon., 1970), but 'good quality' is required. Untreated cereal seed cannot be recommended unless every seed lot has been tested and the contamination rate by pathogens is below certain given threshold values. The official threshold values are not adapted to organic farming conditions. They are inadequate for trading of undressed seeds, and urgently need adjusting. This is confirmed by the Dutch general inspection service for seed control (NAK). A clear example is given for cereal seed. In case of conventional cereals, NAK has stopped standard testing for *Fusarium* and *Septoria*, because standard seed treatments have taken care of these problems in conventional cereal seed production (Anon., 2000a; G. Van Den Bovenkamp, pers. comm.). According to the official Dutch regulations for certified cereal seed, seed lots with more than 25% *Fusarium* contamination have to be treated or discarded. Between 10 and 25%, treatment is advised and is mentioned on the certification label but is not compulsory. This is not an acceptable situation to guarantee good quality of organic seed. Thus, in some countries action has already been undertaken to revise such threshold values for organic agriculture (Nielsen, 2003). In Austria, the organic sector has adapted the threshold values for organic cereal seed on the basis of both research and years of experience (Hartl *et al.*, 1999). For pathogens like *Septoria nodorum, Fusarium* spp. and *Helminthosporium* spp., the conventional threshold value in Austria has been set at a total of 20% contamination. For organic seed there is a special threshold value for *Fusarium nivale* of 10%, and if this value is crossed adequate treatment is required. For *Septoria nodorum* the value has been raised from 10 to 20%. Also for seed potato the threshold value has been adapted on the basis of experience. In the Netherlands, for a better control of *Rhizoctonia* the official threshold value of 25% contamination of seed potatoes has been lowered to a maximum of 10% (Hospers, 1996a). More and systematic research is needed to adjust the threshold values for marketing organic seed and planting material of good quality.

Discussion

Until recently the seed industry and main stream science have paid very little attention to organic propagation. The expertise of conventional seed companies to produce organic seed without the use of chemical-synthetic protectants and inorganic (easy-releasing) nitrogen fertilizers is still limited and causes initial problems and failures with organic seed production. Besides (regular) basic and technical expert knowledge on seed production in general, additional knowledge and expertise need to be built up for scaling-up and optimizing organic seed production. The main problems encountered are (seed-borne) disease and pest management, and weed control.

The short-term strategy consists of selecting and testing cultivars suitable for organic propagation from among the assortment of the conventional seed companies, and designing alternative seed treatments. In organic seed production chemical-synthetic inputs need to be replaced by natural compounds, which requires more research than developing 'alternative' seed treatments. Seed treatment is expensive and does not always guarantee a high seed quality. Seeds that are contaminated with fungi may have less vigour and can be disastrous to organic farmers. Because the plant breeding industry could mostly rely on chemical protection during seed production, not all cultivars that are available are suitable for organic seed production. Sometimes, as discussed for black rust in Dutch grass cultivars, substitute cultivars are available, but these are not always optimal in terms of other desired traits. The ability of producing healthy seed without chemical protection is the first aspect that needs reconsideration. The ability of producing seed organically is a trait that should be included in the organic crop ideotype. This aspect, which requires more attention from future breeding programmes, should be part of a long-term strategy.

A second aspect for further research on the short and middle long term is developing sound cultural practices for organic production of seed and planting material and for keeping the disease pressure as low as possible. Farmers who have knowledge of organic farming should organize the production of organic seed. In some cases there are good arguments for using intercropping systems, like in grass seed production. A better understanding of the interactions between natural, beneficial organisms in the system and the crop – as was discussed for Rhizoctonia on potato – and of the expected interactions with certain soil antagonists may optimize the system. In some cases the climate is an important bottleneck for an economical production of healthy seed. If a low disease pressure is required this can be so crucial that moving the seed production to warmer and drier climates is the best solution, as is the case for the seed production of onion and carrot, both requiring a long ripening season. But it is not the solution for all crops. For staple crops like cereals it is important that each European country is able to produce a sufficient quantity and quality of seed for national use. For diseases such as Fusarium, completely resistant cultivars are not available and maybe are not even the first option for a sustainable solution of organic agriculture. More benefit is to be expected from an interdisciplinary approach to better understand the epidemiology of the fungus. This is necessary to be able to design adequate cultivation techniques and to be able to look for plant morphological characteristics (longer peduncle, leaf angle, etc.) that make cultivars more tolerant to such a disease.

It should be realized that for the time being EU-regulation 2092/91 defines organic seed as seed that has been produced by a crop planted and raised organically for at least one generation where annual crops are concerned, and for two growing seasons in the case of biennial and perennial crops. If the organic sector will keep on growing and improving its system, further closing of the organic production chain can be expected by also demanding organic maintenance of the cultivars suitable for organic farming systems as a step towards organic plant breeding. This will require even more emphasis on breeding and research activities so that organic propagation is optimized and seed-borne diseases that can build up over more generations can be coped with.

Conclusions

Overlooking the state of the art as discussed in this paper our conclusion is that organic seed production can be realistic if the following aspects will be taken into account as part of an optimized strategy for the organic propagation of seed and planting material:
- Selecting and developing cultivars with sufficient tolerance or resistance against diseases during organic seed production is crucial;
- Further practical and research work is needed to improve and adapt cultural practices for the production of healthy organic seed and planting material;
- Seed producers should identify the best locations in terms of a low disease pressure;
- Adjusted threshold values for marketing organic seed contaminated with seed-borne diseases should be developed;
- Practical seed health tests and standards should be developed for crops with a high risk of seed-borne diseases;
- Adequate, alternative seed treatment techniques need to be developed, and legislated;
- For the successful development of an organic seed production system, good communication and mutual commitment from farmers, traders, breeders and governments are necessary;
- Clear EU-regulations can stimulate the development of organic seed production by only allowing derogation of the use of conventional, untreated seed if seeds and cultivars are not yet available in a sufficient quantity, and to yearly update the positive list of crops/cultivars for which derogation is no longer valid.

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