Towards an improved variety assortment for the Dutch organic sector

Case studies on onion and spring wheat

Aart M. Osman

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Abstract

Variety choice is an important component of organic crop management. The organic sector pursues to produce healthy, nutritious food without using synthetic inputs and excessive amounts of natural resources. Access to varieties that are able to cope with weeds, diseases and pests, and thrive well under an organic fertility management regime, allows actors in the organic food production chain to achieve these aspirations. In this thesis I analyse how the current breeding, variety assessment and registration process should be changed to provide varieties that fulfil the needs of organic farmers, traders and processors. The research is based on the cases of two crops, onion (*Allium cepa*) and spring wheat (*Triticum aestivum*), that differ in key issues that influence the options for change: breeding and variety registration aspects; organic seed and crop production issues; destination of the harvest; and composition of and relations between actors in the production chain.

Variety trials, in which we evaluated onion and spring wheat varieties for traits prioritized by organic stakeholders, revealed that the variety assortment displayed important weaknesses when grown and processed organically. In the case of onion, farmers needed varieties with improvements for resistances against main diseases, root system, storability and erect plant types in combination with high yield. For spring wheat, weed suppressiveness and baking quality were the key traits that required improvements.

Interviews with conventional onion breeders showed that they focussed on yield and post-harvest traits (storability, bulb quality). In addition to these traits, breeding for the organic sector would require breeders to pay more attention to the selection of field traits like partial resistance against leaf diseases and a better root system. To improve key traits for organic growers, selection should take place in a growing environment without the fungicides and herbicides that are typically applied in conventional nurseries.

Interviewing conventional wheat breeders made clear that selection for the organic market would conflict with achieving the high yield demanded by conventional growers. Breeders have achieved high yields by increasing the harvest index, which goes at the expense of baking quality through a relative decrease in protein content. Based on a literature review, we propose two alternative approaches to improve yield and protein content simultaneously: selection for increased total biomass or/and selection for protein quality. The first approach would deliver taller, leafier varieties that are also more competitive against weeds. Improving protein quality would require selection under low nitrogen input or organic growing conditions as protein composition is strongly influenced by soil nitrogen availability. Analysis of data of our own conventional and organic variety trials, together with datasets from other European countries showed that for other important traits (e.g., yield, disease resistance, plant length) selection for the organic sector could also be conducted in non-organically managed breeding nurseries, which typically refrain from fungicides and growth regulator applications, as genetic correlations for these traits were high (0.8 -1.0).

Conducting variety trials in organic fields and evaluating these for traits prioritized by the stakeholders make results more relevant for the latter. In the specific case of Value for Cultivation and Use (VCU) testing, that is part of the official variety registration procedure of field crops in the EU, adapting the research protocol proved crucial to provide market access to varieties better adapted to organic production. The organic spring wheat VCU testing resulted in the inclusion of varieties in an organic section of the Dutch Recommended List of Varieties, showing that the statutory variety testing system is flexible to address new needs. However, procedures are costly and not in proportion to market size and in this way prohibit the release of varieties for organic and other small markets.

Although specifically wheat breeders proved to be open to consider adaptations in their programme, the relatively small market prevents conventional private sector breeders from investing in selecting varieties specifically targeted at the organic sector. Therefore we elaborate options to set up a way of breeding that is in line with organic principles and overcomes this economic barrier.

Key words:

organic farming; principles of organic agriculture; food production chain;
plant breeding; genetic correlation; plant traits; farmers’ preferences;
variety testing; Value for Cultivation and Use; EU seed legislation;
onion; *Allium cepa*; spring wheat; *Triticum aestivum*; baking quality

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Introduction to the thesis

1.1. Introduction

Variety choice is an important component of organic crop management. The organic sector pursues to produce healthy, nutritious food without using synthetic inputs and excessive amounts of natural resources. Access to varieties that are able to cope with weeds, diseases and pests, and thrive well under an organic fertility management regime, allows actors in the organic food production chain to achieve these aspirations.

When I started to work in the area of organic plant breeding at the Louis Bolk Institute, The Netherlands, in 1999, farmers claimed that for important crops (e.g. cabbage, carrot, onion, wheat) variety choice was limited, as most available varieties were not adapted to organic crop husbandry. Varieties on the market were developed by private sector breeders to match requirements of conventional growers, which for key traits did not converge with the demands of organic farmers. Organic farmers, I consulted, stated that they preferred exploring ways to improve the variety assortment through the existing conventional seed sector over bypassing the current breeding system and setting up a separate organic breeding system. They considered the latter too costly for the small emerging sector and also thought it would be more efficient to benefit from the already existing expertise and logistics of the highly developed conventional breeding and seed industry in the Netherlands. In this thesis I analyse how the current way of breeding, variety assessment and admission process needs to be changed to provide varieties that fulfil the needs of organic farmers, traders and processors.

The research draws on data I gathered and experiences I gained between 1999 and 2010 as a researcher in the area of organic plant breeding at the Louis Bolk Institute. During this period I conducted projects aimed at enhancing the availability of varieties suited to the needs of the organic sector. Projects involved facilitating communication and collaboration between the organic sector and the conventional breeding industry as well as resolving knowledge gaps through research.

The kind of changes required and feasibility to breed varieties suited to the needs of the organic sector vary per crop and type of actors involved in the crop production chain. To broaden the applicability of the findings, I have chosen to analyse the cases of two contrasting crops, onion (*Allium cepa*) and spring wheat (*Triticum aestivum*). These crops differ for main issues that may influence the results of the research, namely: breeding and variety registration aspects, organic seed and crop production issues, destination of the harvest, and composition of and relations between actors in the production chain (Section 1.3.5).

In this Chapter I first review the status of organic plant breeding and its challenges. In Section 1.3 I elaborate the context of organic onion and spring wheat production and the differences between these crops that influence breeding options. This section will be followed by a description of the research (objective, approach and the research questions). A brief overview of the thesis can be found in Section 1.5.

1.2. Organic plant breeding

1.2.1. **The organic sector's view on plant breeding**

As stated in the previous section, a lack of appropriate varieties of key crops is an important argument for the organic sector to demand breeding efforts that address their specific needs. Current varieties are mainly bred to perform well in conventional cropping systems that rely on chemical inputs, like fertilizers and pesticides. In addition, breeders aim to comply with specifications of a food industry that routinely applies artificial food additives to upgrade processing quality. As such chemical inputs are not used in the organic food chain, it is argued that the organic sector would benefit from varieties that are selected for traits that allow them to cope with organic growing and processing conditions (Lammerts van Bueren et al., 2002; Wolfe et al., 2008; Lammerts van Bueren et al., 2011). In literature, frequently mentioned useful traits that should be improved in varieties aimed at the organic sector are nutrient uptake and use efficiency (Baresel et al. 2008; Dawson et al., 2011; Galvan et al., 2011), weed competitiveness (Eisele & Köpke, 1997; Hoad et al., 2012) and more durable forms of resistance that function at crop and/or systems level (Döring et al., 2012).

Complementary to the above, champions for organic plant breeding are also motivated by organic values or principles. From this standpoint, plant breeding and seed production are considered an integral part of the organic production system and hence the breeding of varieties used by organic farmers should comply with organic principles. The organic principles of IFOAM (International Federation of Organic Agriculture Movements) provide a comprehensive description of globally shared organic values (Luttikholt et al., 2007; Padel et al., 2009). Following organic values in breeding has implications for the choice of breeding techniques, socio-economic relationships and the seed legislatory framework (Lammerts van Bueren et al., 2003; Lammerts van Bueren &

Struik, 2004; Lammerts van Bueren & Myers, 2012). Breeders should refrain from using techniques that go beyond the cell level, such as cell fusion and genetic modification and/or disrupt the plant's ability to reproduce itself as these techniques violate the integrity and intrinsic value of plants. In addition, values as equity, respect and transparency require breeders to disclose details of the breeding techniques and refrain from appropriating genetic resources, e.g. through patents. Finally, IFOAM organic principles stress the importance of maintaining and increasing genetic diversity which calls upon breeders to develop and release more varieties that are genetically more distinct and explore new breeding concepts that increase intra-varietal genetic diversity (Finckh, 2008; Enjalbert et al., 2011; Brumlop et al., 2013). The latter would also require seed legislators to modify current variety registration laws and procedures that prevent release of more heterogeneous varieties.

Discussions on organic principles and plant breeding that were initiated in the Netherlands (Lammerts van Bueren et al., 1999) have led to inclusion of a standard on organic plant breeding in the IFOAM norms for organic production (IFOAM, 2012). While IFOAM norms are guiding the organic sector, within the European Union (EU) these are not legally binding. European organic farmers should comply with EU regulations EC834/2007 (Council, 2007) and EC889/2008 (EC, 2008) which only prohibit the use of genetically modified organisms.

The organic sector is highly diverse and therefore actors differ in their views on plant breeding. Based on values explaining organic actor's perceptions of the concept of "naturalness", Verhoog et al. (2003) distinguished three complementary approaches to organic farming: the non-chemical, agro-ecological and integrity approach. Actors following the first approach merely aim at complying with the minimum requisites of the EU regulations, meaning refraining from the use of chemical inputs and replacing these with inputs allowed by organic legislation. Followers of the agro-ecological approach are inspired by ecological principles such as maintaining closed cycles, stimulating energy flows, resilience and self-regulatory capacity of the system. The integrity approach includes recognizing the intrinsic value of all living beings and respecting their integrity. Lammerts van Bueren & Struik (2004) elaborated the consequences of these three approaches for plant breeding. For those following of the non-chemical approach, it will be sufficient that breeders provide high yielding varieties with traits that substitute prohibited chemical inputs, i.e. resistances against diseases to replace fungicides. Followers of the agro-ecological approach want breeders also to select varieties that are adapted to local conditions, interact with other components of the system (e.g. improved association with mycorrhiza, attracting natural enemies) and enhance system resilience (e.g. through increased genetic diversity). In addition, those following the integrity approach will also be concerned with breeding techniques that interfere with the plant's and species integrity. I expect that the latter group will also favour specific organic plant breeding programmes, while the first two groups may also see benefits in collaborating with conventional plant breeders.

1.2.2. **Plant breeding for the organic sector**

Organic plant breeders are scarce. In Europe, first organic breeding initiatives originated in the 1980s, in bio-dynamic circles in Germany and Switzerland. Among these are small scale vegetable breeders, associated in Kultursaat, and five cereal breeders, working together in the *Arbeitsgemeinschaft Biologisch-Dynamischer Getreidezüchter* (Almekinders & Jongerden, 2002; Osman & Chable, 2009; Wilbois & Wenzel, 2011). Most of the breeders belong to the association of bio-dynamic breeders (ABDP), which has elaborated its own bio-dynamic breeding standards (ABDP, 2010). In addition to banning techniques that interfere beyond the cell level and compromise the plant's reproductive ability (see previous section), ABDP standards include a total ban on hybrids. Furthermore, all selection and multiplication steps should be conducted in certified bio-dynamic fields. According to the bio-dynamic movement plant breeding should be conducted in the public domain (Willing, 2007). Therefore these bio-dynamic breeders function as non-profit initiatives that are mainly financed through donations and research grants (Almekinders & Jongerden, 2002). Another form of non-profit organic breeding developed in France. Various farmer groups have started farmer participatory breeding initiatives, which are supported by scientists of the national research institute INRA (Chiffoleau & Desclaux, 2006; Chable et al., 2008; Chable et al., 2014).

In the Netherlands Vitalis Organic Seeds and De Bolster are the only specialised organic seed companies that run breeding programmes for a reduced number of vegetable crops (faba bean, lettuce, pumpkin, ruccola, tomato, zucchini). These are private seed companies, that do not generate their main income through breeding, but through the sales of organically multiplied vegetable seeds, of either varieties licensed from conventional breeders or free open pollinated varieties. In addition, a number of potato breeding companies collaborate with organic farmer breeders (Lammerts van Bueren et al., 2008).

Starting in the 1990s a small number of conventional breeding companies have shown interest in selecting varieties for the organic sector. In the Netherlands, this concerned three vegetable breeders that either tested finished varieties or inbred lines under organic conditions (Driessen, 2006; Van de Crommert, 2009). In other European countries (Austria, France, Germany) winter wheat and maize breeders select for organic in earlier generations (Kempf, 2003; Fontaine et al., 2008; Löschenberger et al., 2008; Goldstein et al., 2012).

1.2.3. **Challenges for breeders**

For conventional breeders unfamiliar with the organic sector, the main issues are the choice of the most efficient selection environment and defining the most relevant selection traits. Because of the associated costs, conventional breeders prefer to combine their conventional and organic breeding efforts in one programme instead of managing two separate programmes. However, the expression of traits and hence selection results may be influenced by the selection environment. Whether this so called Genotype × Environment interaction interferes with selection results depends on the crop, trait and the degree of difference between the organic and conventional environment. To reconcile the issue of costs and selection efficiency, winter wheat breeders have developed selection strategies in which they maintain the first generations in the same nursery and split the programme in an organic and conventional part in later generations (Löschenberger et al., 2008; Baenziger et al., 2011). During the first generations they select for highly heritable traits, like disease resistances, while in later generations they select for traits that may be influenced by the environment, e.g. yield.

Determining the selection traits and priorities requires interaction between the organic sector and breeders. Based on a series of workshops with members of the organic sector and the seed sector, organised in the Netherlands between 1997-1999, it was suggested to set up crop working groups consisting of breeders and organic farmers to achieve information exchange between breeders and farmers (Lammerts van Bueren et al., 1999; Ruivenkamp & Jongerden, 1999).

In the same series of workshops, breeders pointed to the issue of the official variety registration procedure for arable crops (cereals, potato, green manures, etc.) in the EU. As part of this procedure, varieties are evaluated for their Value for Cultivation and Use (VCU). Varieties need to reach a certain yield level to pass VCU. Breeders feared that varieties with traits preferred by organic farmers would not meet the required yield level and marketing of such varieties would be prohibited. The issue of the variety registration procedure is also a concern of organic breeders (Müller, 2008; ECO-PB, 2012) and farmers who want to shift to more environmentally friendly, low-input, cropping systems (Wiskerke, 1997; Wiskerke, 2003).

1.3. Choice and context of the cases of onion and spring wheat

The necessity and options to modify the plant breeding process in such a way that it addresses the needs of the organic sector, depend on the crop and its context (Figure 1.1). To draw broader, non-crop specific, conclusions I have chosen to study two crops that contrast for most components of the breeding system depicted in Figure 1.1. Below I will first present the context of organic onion and spring wheat production and breeding and then elaborate the main contrasting features.

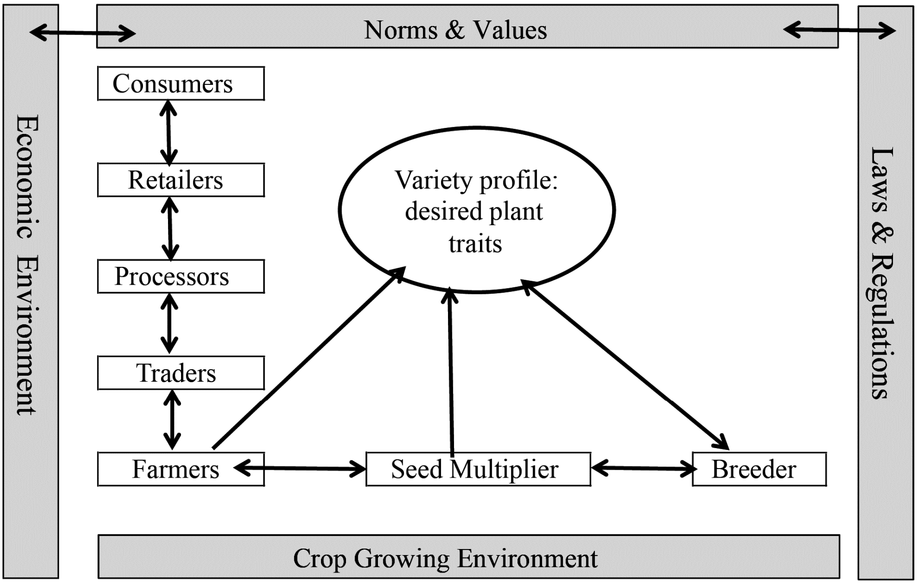

Figure 1.1. The breeding system and its influence on the shaping of a variety.

1.3.1. **Organic crop production in the Netherlands**

Agriculture in the Netherlands is export oriented and input intensive due to relatively high land and labour costs (Meerburg et al., 2009). This is also the case for the major part of Dutch organic farming (De Wit & Verhoog, 2007; Bos et al., 2014). Most organic crops are produced by larger scale (≥ 20 ha) field crop growers and 65 - 75 % of their products are exported, with neighbouring countries as the main market (Wijnands et al., 2005). A small proportion of farmers are small horticulturists that grow for local and regional markets. In this thesis I will focus on breeding for the first group of farmers.

Between 1999 and 2010 the Dutch organic acreage doubled from about 27.000 ha to almost 54.000 ha (Biologica 2003; LEI Wageningen UR, 2011). In 2010 organic farming occupied 2.9% of land allocated to farming. The growth during this period was not gradual. Between 1999 and 2004 organic farming was growing rapidly. The increase in acreage caused overproduction which led to a stabilisation of the number of organic farmers. Since 2008, organic consumption is booming, resulting in scarcity of organic products, growth of the acreage and increase in the number of organic farmers.

Of all organic food crops, wheat covers the largest acreage (Osman et al., 2005; Wijnands et al., 2005). For large scale, export oriented producers another important group of crops are vegetables that can be stored over long periods of time: carrots, onions and cabbages. Of these three crops, onions occupied the largest acreage during the research period. Table 1.1 presents the acreages of organic onion and spring wheat during the research period.

Table 1.1. Acreage (in ha) of organic onion and spring wheat in 1999, 2004 and 2010.

	Acreage (hectares)	
Year	**Onion**	**Spring wheat**
1999	294	705
2004	606	2108
2010	680	1230

Source: 1999 and 2004: CBS, 2005; 2010: unpublished data provided by CBS.

Dutch organic farmers are well organized at regional and national level. At the onset of the research period the majority of arable farmers marketed their produce collectively through the farmers' cooperative Nautilus, of which they were member. Wheat of Nautilus members, and most other organic cereal growers, was sold through the organic department of Agrifirm, a conventional farmers' cooperative.

1.3.2. **Organic onion production and end use**

Onion is a high value, but also high risk, cash crop. The risk is specifically caused by its susceptibility to downy mildew (*Peronospora destructor*), which cannot be managed organically and can devastate the whole crop. Furthermore, weed control is labour demanding and field labour is scarce. In addition, it is relatively inefficient in capturing soil nutrients due to its poor root system. After harvest onions are stored for up to 8 months. The long storage without synthetic sprout inhibitor makes storability an issue.

Like in the conventional sector, onions are sold to onion packers and vegetable traders, who mainly export to mainstream supermarket chains. These chains apply the same quality specifications to organic products as to conventional products, such as uniformity in size and shape.

With hybrids it is easier to produce the uniformity required by the end users. Therefore Dutch organic onion growers prefer hybrid varieties. Seed multiplication of onion hybrids under organic conditions has proven to be difficult as many parent inbred lines perform poorly without synthetic inputs. Therefore seed companies were reluctant to provide organic seeds of their varieties and prices of these seeds were high. Since 2007, the use of organically multiplied onion seeds is obligatory in the Netherlands.

1.3.3. **Organic spring wheat production and end use**

Spring wheat fulfils important roles in an organic crop rotation. Due to its well developed, extensive root system, the crop restores soil structure and fertility. Furthermore, it requires a limited amount of labour and therefore balances the labour demand of the whole rotation. Economic value of spring wheat is relatively low. During the research period farmers aimed at growing baking quality wheat because of its premium price. Low nitrogen availability during grain filling may hamper baking quality. Weed management is the other main crop husbandry issue.

Baking quality of spring wheat varieties is higher than of winter wheat varieties and weed management of a spring sown crop is easier than of an autumn sown crop. Therefore organic farmers prefer spring wheat over winter wheat. In the conventional sector spring wheat is a minor crop, because conventional farmers prefer higher yielding winter wheat.

Dutch organic baking quality wheat is sold to millers that supply Dutch specialised organic bakeries that sell their bread through organic shops. A smaller proportion of organic bread (30% in 2010) is sold in supermarkets (LEI Wageningen UR, 2011). This bread is produced by organic branches of main stream bakeries that use imported wheat due to its better price/quality ratio.

Farmers buy organic certified seeds from the farmers' cooperative Agrifirm, which both produces seeds and trades the harvested grain crop. Agrifirm also conducts its own variety trials. About half of the organic acreage is sown with farm saved seeds. On-farm seed production of wheat is relatively easy, because varieties used in the Netherlands are open pollinated and seeds can be harvested at the same time and with the same equipment as the grain crop.

1.3.4. **Breeders of spring wheat and onion**

The Dutch breeding industry has a long history and is well developed. At a global level, the Netherlands is by far the largest exporter of vegetable seeds (ISF, 2012). The number of seed companies is in decline, though, due to consolidation (Louwaars et al., 2009). The size of the Dutch cereal seed market and margins on seed sales are relatively small. Therefore consolidation has specifically affected cereal breeding in the Netherlands. Due to mergers only two wheat breeding programmes remain, of which only one is active in spring wheat breeding. Dutch spring wheat farmers therefore greatly rely on breeding companies in Germany and Sweden. None of these conventional companies selects varieties for the organic sector. Of the German organic cereal breeders (Section 1.2.2), one started a spring wheat breeding programme at the beginning of the research period.

Five conventional onion breeding companies were selecting for the Dutch market. Two of these merged in 2007. In contrast to spring wheat, the domestic seed market is relatively large and value of onion seeds is high. Two of these five companies were testing inbred lines under organic growing conditions, but one abandoned its programme. In addition, two Dutch organic farmers associated with the German Kultursaat initiative (Section 1.2.2) were breeding open pollinated varieties.

1.3.5. Differences between onion and spring wheat that affect breeding options

Main differences of onion and spring wheat that may influence the need and options to enhance the variety assortment for the organic sector are summarized below and in Table 1.2.

Breeding and seed production

Spring wheat is a self-pollinating crop and hence breeding and seed production are technically less complicated than breeding and multiplication of cross-pollinating onions. In addition, breeding options and perspectives to progress rapidly are considerable more limited for onion breeders than for wheat breeders, because the genetic base of the preferred cultivated onion type in the Netherlands, the *Rijnsburger* onion, is relatively narrow.

On the other hand the variety registration procedure for spring wheat is more complicated than for onions, because it includes mandatory evaluation of its Value for Cultivation of Use (VCU). Within the EU, VCU is mandatory for arable crops and not for horticultural crops. The latter may form an extra hurdle to bring varieties on the market (see Section 1.2.3).

Finally, onion breeding is better rewarded through higher margins on seed sales. Also hybrid varieties can only be multiplied by its breeder and therefore achievements are easier to protect against competitors and evasion of paying license fees.

Economic importance and composition of the production chain

For breeders and farmers onion is a high-value crop while economic returns of spring wheat are low. This should make it more interesting for all actors of the crop production chain to invest time and money in onion improvement.

Another factor is the physical distance between the actors. For wheat, producers, traders and processors are based in The Netherlands, but most breeders are situated abroad. Onion breeders and farmers are based in the Netherlands but end-users are located in neighbouring countries.

Finally, Dutch organic baking quality wheat is mainly sold to millers and bakers who are only involved in organic activities, while organic is not the core business of actors in final part of the onion production chain (packers, retailers).

Table 1.2. Key differences between onion and spring wheat that influence options to adapt breeding to the needs of the organic sector.

	Onion	Spring wheat
Breeding	Cross-pollinating Genetic base relatively narrow Hybrid varieties	Self-pollinating Genetic base relatively wide Open pollinated varieties
Variety registration	No need to submit for evaluation of VCU	Procedure includes evaluation of VCU
Organic seed production	Difficult	Easy
Destination of the harvest	Export; main stream supermarkets	Mainly internal market; millers and bakers specialized in organic processing
Economic importance	High value for both breeders and organic farmers	For breeder: Margins on seed sales are low; For farmer: Low return per hectare

1.4. The research

1.4.1. Objective and research approach

The objective of this thesis is to analyse the feasibility of and necessary changes to enhance the variety assortment through collaboration with the conventional seed sector. With the results, I hope to contribute to the continuing debate in scientific literature and among plant breeders on how to address the needs of the organic sector (Wolfe et al., 2008; Baenziger et al., 2011; Lammerts van Bueren & Myers, 2012; Pswarayi et al., 2014).

This thesis is a retrospective analysis of data and experiences gained during my work at the organic breeding section of the Louis Bolk Institute. While this thesis focusses on the research components of our work, the overarching purpose of the projects was to bring about changes in breeding and varietal assessment systems. Triggering transformations in breeding required participation of key actors and an open ended research trajectory, in which gained insights were used to decide on next research steps. So, the projects followed an approach that falls under the wide umbrella of Action Research (see e.g. Almekinders et al., 2009).

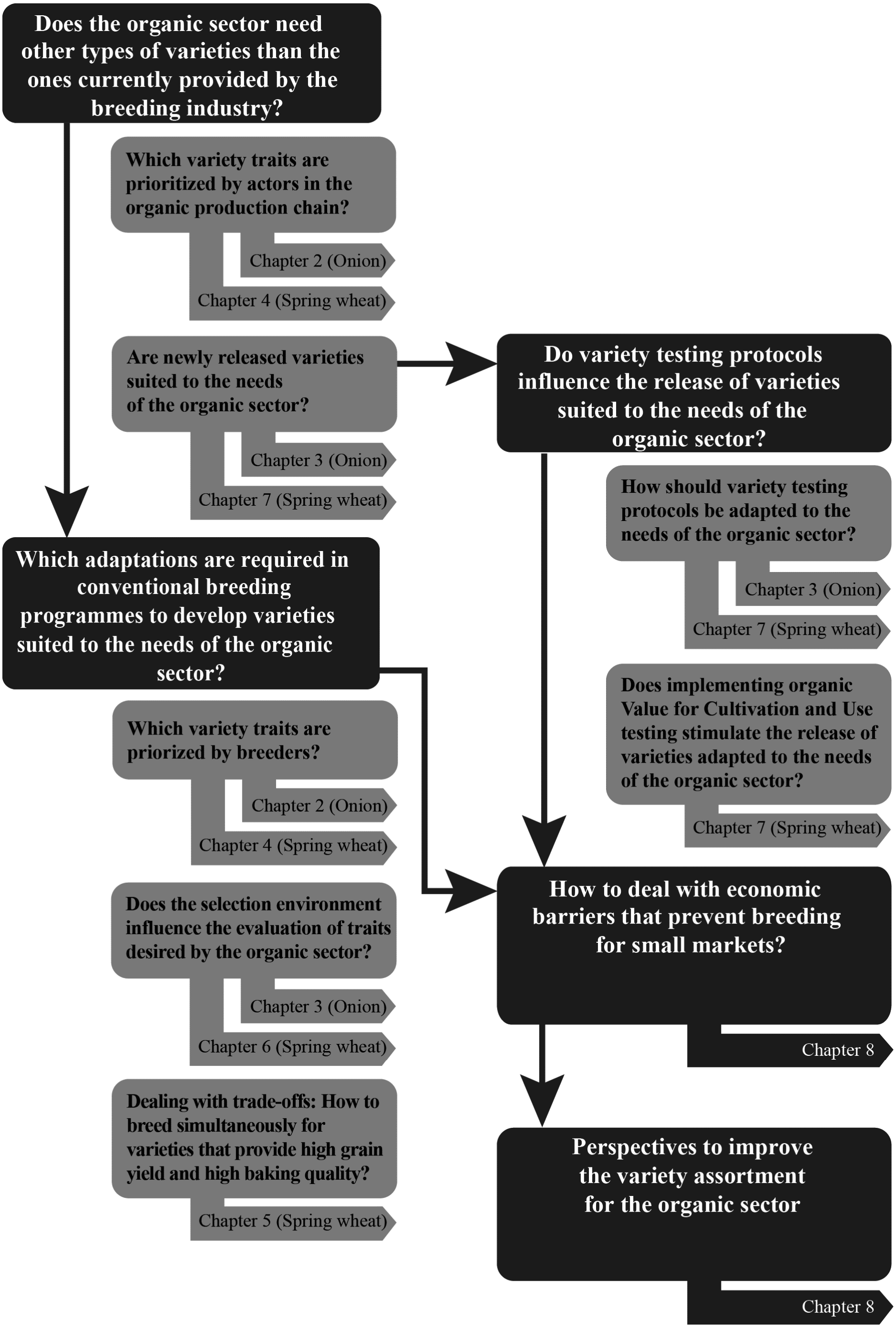

Figure 1.2. Research questions and outline of the thesis.

1.4.2. **Research issues and questions**

Analysing how breeding should and could be changed to enable the release of varieties better suited to the needs of the organic sector requires reviewing the current breeding practice and its institutional context. With the design of their breeding programme, breeders take into account the different components of the crop production system, such as the physical growing environment, crop husbandry and processing practices of the actors of the production chain they are selecting for. Furthermore, breeders' decision making is influenced by the institutional environment (norms, legislation, financing system, etc.) (Figure 1.1). Hence transforming breeding in such a way that it is able to address new needs, is not just a matter of prioritizing other plant traits or adjusting the selection environment, but also involves dealing with (different) institutional constraints (see e.g. McGuire, 2008). Correspondingly, the research presented in this thesis addresses both technical as well as institutional issues of plant breeding. Figure 1.2 provides an overview of the research questions which I elaborate below.

Technological issues

At the onset of my research activities breeders claimed that they would be able to select varieties within their on-going breeding programmes if the organic sector would specify its needs. This assumption holds true when breeders use parents in their crossing schemes that possess the traits demanded by the organic sector and when breeders consciously select for these traits. In addition, breeding goals for organic should not conflict with the goals of the on-going programmes. Finally, variety performance and ranking for these traits under the growing conditions of the conventional breeding nurseries, should be similar to performance and ranking in organic farmers´ fields. To assess the need for adaptations in breeding approaches applied by conventional breeders, the following questions were studied for onion and spring wheat:

1. Does the organic sector need other types of varieties than the ones currently provided?
    1.1. Which variety traits are prioritized by actors in the organic production chain?
    1.2. Are newly released varieties suited to the needs of the organic sector?

As for both crops modern varieties did not entirely satisfy the needs of the organic sector, we also studied if breeding approaches of the conventional breeders prevented the selection of better suited varieties. Therefore I probed the following questions:

2. Which adaptations are required in conventional breeding programmes to develop varieties suited to the needs of the organic sector?
    - 2.1. Which variety traits are prioritized by breeders?
    - 2.2. Does the selection environment influence the evaluation of traits desired by the organic sector?

Improving varieties for some traits desired by the organic sector conflicted with breeding goals for the conventional sector. The incompatibility between breeding for high yield and the high level of baking quality, desired for organic spring wheat proved to be a major obstacle to align conventional breeding programmes to organic needs. Therefore I studied this topic more in depth by reviewing:

- 2.3. Dealing with trade-offs: How to breed simultaneously for varieties that provide high grain yield and high baking quality under organic growing conditions?

Institutional issues

In one of a series of workshops organised by the Technology and Agrarian Development Group of Wageningen University, during 1998-1999, a cereal breeder expressed the fear that the official variety testing system, the so-called Value for Cultivation and Use (VCU) test, would form a major hurdle to release varieties better adapted to the needs of the organic sector (Ruivenkamp & Jongerden, 1999). For spring wheat and other arable crops, VCU is a mandatory step in the variety registration procedure. The breeder assumed that a number of traits prioritized by the organic sector (e.g. resistance against diseases) would go at the expense of yield and therefore varieties enhanced for these traits would not meet the minimum yield level required to pass VCU. The work of Wiskerke (1997) and Louwaars (2007) also indicates that variety testing, together with other components of the seed regulatory framework (testing for Distinctness, Uniformity and Stability – DUS – and seed certification), steers the direction of breeding. This is not only the case for mandatory variety testing, but also when participation in

VCU tests is on a voluntary basis. In the EU, VCU testing of vegetable crops is voluntary. Onion breeders attribute the gradual increase in storage quality level of Dutch onion varieties during the 1970s and 1980s to stringent storage quality evaluation criteria in variety tests, that were set by the conventional onion sector themselves (pers. comm. by S. Hopmans, and K. Hoogzand; SNUIF, 1977). Thus, the example of onion suggests that variety testing can also be used as a policy instrument to steer breeding in a desired direction. The above led to the following research questions:

3. Do variety testing protocols influence the release of varieties suited to the needs of the organic sector?
    - 3.1. How should variety testing protocols be adapted to the needs of the organic sector?
    - 3.2. Does implementing VCU testing, following a specific organic protocol, stimulate the release of varieties adapted to the needs of the organic sector?

Our research and development activities on organic variety testing revealed that the economic context in which private sector breeding companies operate, prohibits collaboration with small market segments, such as organic. Therefore I also explored:

4. How to deal with economic barriers that prevent breeding for small markets?

1.4.3. **Methodologies applied**

The analysis is based on studying plants and people in their institutional context. Consequently different methods were used to obtain and analyse data. These included:

- technical field and laboratory research, following research protocols, statistical design and analysis.
- group interviews, following techniques from participatory research, semi-structured individual interviews and participatory observations during workshops and meetings.
- literature reviews.

1.5. Outline of the thesis

The thesis is sub-divided into an onion and a spring wheat section, both dealing with variety traits preferred by the organic sector, breeding and variety testing.

In the onion section, **Chapter 2** analyses the choices conventional breeders make in their selection programmes and their consequences for selecting varieties that match variety profiles elaborated with organic farmers. Data were gathered through interviews with breeders and farmers.

Chapter 3 studies whether evaluation of varieties, for traits prioritized by the organic sector, needs to be conducted under organic growing and storage conditions. For this research, we evaluated a set of contemporary varieties, proposed by farmers and breeders, during four years, in organic and conventional fields. This chapter gives also insight into the suitability of current varieties for the organic production chain.

In the spring wheat section, **Chapter 4** presents variety traits preferred by organic farmers, traders, millers and bakers and breeders' selection criteria and approach. The research was conducted in a similar manner as the onion study of Chapter 2.

The literature review of **Chapter 5** explores breeding strategies to overcome a conflicting priority between selecting bread wheat varieties for the organic sector and the conventional sector: how to combine high quality required by organic bakers with high yield, pursued in conventional wheat production.

The influence of growing environment on the selection and evaluation of spring wheat varieties is treated in **Chapter 6**. This Chapter was the result of a collaboration with other European researchers working on the same issue. Data from our Dutch variety trials, conducted in a similar way as the onion trials of Chapter 2, were analysed together with datasets from cereal trials conducted in six other countries.

Chapter 7 shows how adapting variety release procedures enhances the availability of suitable varieties for the organic sector. This chapter also reveals that the economic context in which private sector breeding companies operate, prohibits breeding for small markets.

This economic issue is further addressed in **Chapter 8**. In addition, in this final chapter I reflect on how the findings of my research relate to the principles of organic farming and provide perspectives on breeding for the organic sector.

Onion Section

Chapter 2:

Can conventional breeding programmes provide onion varieties that are suitable for organic farming in The Netherlands?

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Abstract

Main stream commercial onion breeders do not specifically select varieties for organic farming, but solely for conventional farming. Seed companies consider the organic market too small to justify investments in breeding efforts for this sector. In order to study if their breeding approach also suits organic farmers' needs we interviewed four Dutch commercial onion breeders on their breeding programme and selection criteria and compared the outcome with a variety profile composed of the priority traits of Dutch organic farmers. Breeders gave priority to the same storage and bulb quality traits that are demanded by organic farmers, because organic onions are exported to conventional supermarkets that apply the same quality standards to organic and conventional onions. However, organic farmers also need varieties that perform well in the field. Breeders give low priority to field selection. Furthermore, three of the four seed companies only breed hybrids. The cytoplasmic male sterility system used to produce these hybrids does not comply with organic principles. We conclude that at present breeders can provide varieties that meet organic farmers' demands for storability and quality traits, but they should give higher priority to field selection to also improve required field traits. The latter will only occur, if in future the organic seed market will grow. If the organic sector wants varieties developed according to its own principles, it should either set up its own onion breeding programme or seek alliances with breeding companies that are prepared to harmonize their breeding methodology with the organic principles.

Keywords:

onion; *Allium cepa*; organic breeding; plant traits; farmers' preferences; organic principles

2.1. Introduction

Organic growers of onion in the Netherlands rely on conventional breeding programmes to obtain new varieties. However, it has been argued that farmers would benefit from plant breeding programmes that specifically develop varieties that are suitable for use in organic production systems (Lammerts van Bueren et al., 2002; Wolfe et al., 2008). Two main arguments are used to support this thesis. The first argument is that organic farmers perceive and value specific variety characteristics differently from their conventional colleagues. Currently, onion breeders select their varieties based on the demands of the mainstream market. Therefore, the phenotypes of these varieties may not match the ideal that the organic farmers have in mind. Secondly, it is argued that if breeding would take place under organic growing conditions, this would result in varieties that are better adapted to organic farming than the current varieties selected under conventional conditions (Lammerts van Bueren et al., 2002). In this article we explore the first reason for the case of onion in The Netherlands.

Organic farmers have a different view on the ideal set of characteristics of a variety compared with conventional farmers because organic cropping systems differ from conventional farming systems. In the temperate climate of the Netherlands, especially in the early part of the growing season, lower quantities of soil nutrients are available for uptake by the onion crop in organic cropping systems than in conventional systems. This requires a better resource capture by the crop, a higher biomass production per unit of nutrient taken up, and in some cases even a more efficient production of harvestable products per unit of biomass produced. In addition, a more diverse rotation scheme, with a lower frequency of onions, and the absence of synthetic pesticides may also lead to a shift in frequency and severity of priority pests and diseases. Furthermore, organically grown onions are stored in a different way compared to conventional onions (no use of sprouting inhibitors), and this will stress the need for more dormancy. Also processing techniques and consumer preferences may differ between the organic and conventional production chain.

Dutch breeders usually question whether the organic sector needs varieties with traits that differ from the traits considered desirable for the conventional sector (first authors' experience in meetings with wheat, carrot and onion breeders since 1999). Most of them share the view that resistances against pests and diseases are top priority for organic systems, because organic farmers do not apply synthetic pesticides. They argue that this is not different from their own aims, because resistance breeding is a priority in a conventional breeding programme as well. Some breeders have slightly adjusted their view over the years because of experiences with organic variety trials. Those who have shown to adjust their views, acknowledge that while the relevant traits are the same, their relative importance may differ between organic and conventional farming. Nevertheless they are confident that they can supply varieties that also possess the specific characteristics prioritized by the organic farmers. This confidence is based on the fact that they breed for many different markets and therefore have many different varieties in stock. According to the breeders, currently available diversity of varieties is large enough to comply with the demands of all markets, including the organic sector in the Netherlands.

Setting up special breeding programmes for the organic sector would require large financial investments. In The Netherlands almost all breeding is carried out by commercial seed companies. These companies consider the organic market too small to justify such investments (Driessen, 2006). Such investments would also not make sense if one can expect that the varieties developed under the current situation are adapted to organic growing conditions and contain the traits required by organic farmers.

In this paper we analyse the selection criteria applied by Dutch onion breeders and compare these with the variety traits prioritized by the Dutch organic growers of onion. The objective of the research was to assess whether the Dutch onion breeding sector can potentially supply the onion varieties demanded by the organic farmers.

2.2. Material and methods

We followed a case study approach. This approach allowed us to study the object of our research, onion breeding for organic farming, in its complexity and within its context (Verschuren, 2003; Yin, 1984). The way onions are produced in the Netherlands, under conventional and organic conditions, and how they are used is considered part of the context. The profile of the ideal onion variety as perceived by farmers was used as a reference against which the breeding goals and practices of breeders were compared. The information was collected by applying different methods. These included semi-structured interviews with breeders and key-informants, group discussions with farmers and literature and internet review.

2.2.1. **The ideal organic variety profile as perceived by farmers**

The traits organic farmers consider crucial in onion varieties were first identified in a meeting with members of the onion commission of the farmers' cooperative Nautilus in 2001. At that time about 140 of the approximately 200 organic arable farmers were member of this cooperative. The crop commissions of Nautilus consisted of farmers with affinity to a specific crop and these were delegated by the other members to negotiate product prices and to monitor new developments in the markets and agricultural research. The results of the discussions with the onion commission were summarized in an organic variety profile. To check whether this profile was representative for a broader group of farmers, it was discussed during public field meetings in the two major onion growing regions (Zeeland, Flevoland). These meetings were organized twice a year from 2001 until 2004 to demonstrate results of organic variety trials in the field and at the end of the storage period. Both organic farmers and breeders participated in these meetings. In total about 30 farmers were involved in the discussion on the onion variety profile.

2.2.2. **Participating breeders and studying their priority traits and breeding approach**

The domestic onion seed market is dominated by five Dutch companies of which four companies agreed to be interviewed. The interviews took place in 2004 and 2005. All four breeders were interviewed at their office, while with three of them a follow-up interview was held in the field at one of their breeding nurseries. In two companies also a member of the commercial staff was interviewed. Interviews were semi-structured and contained the following topics: the breeding programme and selection criteria, their varieties and traits, future priorities and breeding for organic farming. As in all these topics plant traits played a central role, this allowed for cross checking the provided information. In addition, the companies' seed catalogues and websites were studied. Furthermore, a list of the mentioned selection criteria was sent back to the breeders for comments. At the same time they were asked to give a priority score (between 1 and 5) for the various traits. Finally, the breeders were invited to comment on an early draft of the paper.

2.3. Context of the research

2.3.1. **Dutch organic onion production**

In the Netherlands organic onions are mainly grown by large scale field crop farmers. In this paper we only deal with direct-seeded onions, as this is the main way of establishing the crop. With an acreage of about 600 hectares in 2004 (Table 1.1, page 11) direct-seeded onions are the third most sown organic crop after cereals and potato. Most onions are stored to be able to supply the markets for the longest possible period of the year. About 85% of Dutch organic onion production is exported and major buyers are supermarkets in Germany and the UK (Lammerts van Bueren et al., 2006).

2.3.2. **Dutch onion breeding**

Dutch onion breeders operate internationally. Within the European Union (EU) the Netherlands belongs to the top 3 of onion producing countries with over 20,000 hectares (Eurostat, 2014). This makes the domestic seed market an important one for Dutch breeders.

At present four of the five main onion breeding companies only breed hybrid varieties for the Dutch market. The onion hybrid breeding system is based on cytoplasmic male sterility (CMS) in combination with fertility restorer genes. This system is present naturally in onion populations, albeit at low frequencies (Banga & Petiet, 1958; Havey, 2000; Kik et al., 1998). The smallest breeder continues to only breed open pollinated (OP) varieties.

Most current Dutch hybrid and OP varieties are derived from the Dutch landrace *Rijnsburger*. Many OP farmer selections of *Rijnsburger,* which differed in important traits like earliness, sprouting resistance, yield, or bulb shape, were grown in the Netherlands in the early 20th century. Each breeding company has gathered local selections and these form the basis of their hybrid breeding programmes. A few OP selections of the variety *Rijnsburger* are still marketed (e.g. *Balstora*, *Julia*). Dutch breeders prefer to use *Rijnsburger* populations for their breeding programme over foreign accessions, because of good storability, bulb shape and colour.

None of the Dutch seed companies runs a breeding programme specifically for organic farming. They consider the current organic market too small to justify such an investment. Because of prospects of a growing market, two companies started to test their breeding material on organic farms. The prediction of an increase of the organic seed market was based on the expectation that the use of organic seeds would become obligatory after a planned revision of the EU regulation on organic farming EEC 2092/91 (Council, 1991). However, when the new regulation EC 1452/2003 (EC, 2003) proved to be less strict than expected, one of the companies abandoned its organic project. The other company continues to test its inbred lines and hybrids in an organic nursery.

2.3.3. **Onion breeding and the organic principles**

In the 1990s the organic sector started discussing the compatibility of techniques used in plant breeding with the organic principles (Lammerts van Bueren et al., 2003). While this debate has not been concluded yet, the International Federation of Organic Agriculture Movements (IFOAM), the world umbrella organization for organic farming, has elaborated draft standards (IFOAM, 2004). For onion breeding the discussion on the use of hybrid varieties is relevant. The IFOAM draft standards do allow the use of hybrids, but only when these produce fertile seeds. Non fertile hybrids are considered in conflict with the principles of organic farming. that were established in a participatory process by IFOAM members (Luttikholt, 2007). First of all, non-fertile hybrids prevent farmers from reproducing their own seeds and thus achieving a closed system on their farm. Furthermore, this type of hybrids leads to inequity in the breeding system because their breeders profit from free access to OP varieties while they shield off their own varieties for further use by others breeders (Lammerts van Bueren et al., 2003). In the long run preventing exchange of genetic resources among breeders will limit the genetic base of breeding programmes.

It must be noted that, although IFOAM represents the organic sector as a whole, within the EU its standards are not legally binding. In the EU the regulations for organic agriculture are given by the Directive 2092/91 and do not (yet) specify standards for plant breeding other than a ban on genetic engineering (Council, 1991). However, in the past the IFOAM standards have influenced the EU law and regulations on organic farming significantly.

Table 2.1. Organic farmers' variety profile for direct-seeded storage onion (elaboration of results that were published earlier by Lammerts van Bueren et al. (2005)).

Traits	Phenotype preferred by farmers	Priority[1]
In the Field		
Vigorous growth		
Leafiness	More leaf mass is better	3
Dead leaf tips	No dead leaf tips	2
Root development	Well developed root system	3
Mycorrhiza	Good host for mycorrhiza	3
Supporting disease and pest management		
Resistance to		
Downy mildew (*Peronospora destructor*)	Resistant	5
Leaf blight (*Botrytis squamosa*)	Resistant	4
Neck rot (*Botrytis aclada*)	Resistant	2
Fusarium (*Fusarium oxysporum* f.sp. *cepae*)	Resistant	2
Thrips (*Thrips tabaci*)	Resistant	2
Waxiness of leaves	Leaves covered with wax	4
Erectness of leaves	Erect position	4
Earliness		
Early bulb swelling	Early bulb formation	5
Earliness (Fall down)	As early as possible to escape downy mildew, but without compromising storability; maximum 127 growing days	5
During and after storage		
Storability	95% of onions storable until April	
Sprout dormancy	No visible sprouts	5
Firmness of bulbs	Firm bulbs	5
Thickness of neck	Thin enough to allow neck closure at ripening, but not so thin that it would reduce leaf mass	5
Skin retention	No naked bulbs	5
Number of skins	≥ 2 skins	5
Bulb appearance		
Uniformity	Uniform	4
Skin colour	Yellow, not weathered	3
Inner colour	Uniformly white/cream, without visible green veins	3
Net yield	≥ 35 tonnes/ha	5

[1] Scale 1 − 5, with 1 = no priority and 5 = highest priority.

2.4. Traits desired by organic farmers

Variety traits organic onion growers considered essential, the preferred phenotype and the priority ranking of these traits are summarized in a variety profile for direct-seeded organic storage onion (Table 2.1). Major problems in onion production are the plant disease downy mildew (causing agent *Peronospora destructor*) and storability. Both reduce the yield of marketable onion bulbs. Another major problem is the large amount of labour required for weeding. However, due to the open canopy structure of an organic onion crop, farmers do not expect that variety characteristics contribute to the suppression of weeds. To make mechanical weed control easier, they prefer plants with a more erect growth habit. Below the most important traits of the variety profile are elaborated in more detail.

Vigorous growth

Farmers assume that a good leaf mass correlates with a more vigorous growth and allows the crop to more easily cope with drought periods in summer. They also assume that appearance of dead leaf tips is associated with stress susceptibility of the variety.

Dutch organic onion farmers apply about 80 kg/ha of nitrogen to their crop (Osman et al., 2005), which is less than the 100 kg/ha of nitrogen that is considered optimal for a conventional onion crop (PPO, 2003). Early in the growing season, mineralization of organic fertilizers is slow, which delays the availability of nitrogen. Onion is especially sensitive to nutrient shortage, because it has a rather poor root system (Brewster, 1994). Differences in root system size amongst varieties – although small - have been reported and a large root system enhances nutrient uptake (De Melo, 2003). An increased colonization of the roots by Arbuscular Mycorrhizal Fungi (AMF) enhances phosphorous uptake and reduces the susceptibility to water stress (Harrier & Watson, 2003; Sharma & Adoleya, 2000).

Supporting disease and pest management

Downy mildew is the main problem in organic onion production. This foliar disease usually appears approximately one month before harvesting (July/August). If weather conditions are conducive to the disease, it may rapidly destroy the entire canopy. During the study period none of the commercially available varieties was resistant. Farmers prefer early bulbing varieties to enhance the chance of harvesting onions of a marketable size (> 50 − 60 mm) when the disease appears early. This has become even more important since the Dutch Product Board for Arable Crop Production (HPA) issued a regulation in 2004 that obliges all farmers to destroy the onion canopy when either at least 3000 leaves in an area of 20 m^2 are infected with downy mildew or at least 8000 infected leaves are scattered over an area of 100 m^2. Furthermore, farmers think that varieties with a more waxy leaf are less susceptible to downy mildew.

During storage, neck rot (causing agent *Botrytis aclada*), among other diseases, affects the bulbs. A thin neck (lower part of the stem, which remains on the bulb after harvest) contributes to a healthier bulb during storage. The thinner the neck, the better it cures and the more difficult it is for the pathogens to penetrate the bulb. However, this trait conflicts with productivity, because plants with a neck that is too thin produce a smaller leaf apparatus and smaller bulbs. Therefore, farmers look for a balance between neck size and bulb size.

Storability

The last onions of the season should be storable until April. Important quality traits affected by storage duration are dormancy, bulb firmness and retention of the outer skins. These quality requirements are set by traders and do not differ from what is demanded by the conventional market. However, organic farmers do not use sprouting inhibitors. Besides that, the time from packing to purchase by consumers takes on average three weeks, which is considerably longer than for conventional onions. Therefore organic farmers rely more on the variety's ability to store well than conventional farmers.

Currently, organic onions are often stored at lower temperatures (0.5 - 1°C) than at conventional farms (3 - 4°C) to delay sprouting. The lower storage temperature increases energy use and financial costs. Bos et al. (2014) estimated that drying and storage of vegetable crops are responsible for 40% of the energy consumption of a Dutch organic arable farm. So, both for economical and ecological reasons varieties with better storability are needed.

Recent organic variety tests have shown that current varieties differ in dormancy (Osman et al., 2005) and indeed Dutch organic farmers shifted their choice to the variety *Wellington*, that showed the best performance for this trait: in 2005 *Wellington* was the most sown onion variety in organic fields (Lammerts van Bueren et al., 2006). However, due to problems with watery scales, the second year farmers reduced the acreage of *Wellington*, but it remained the second most sown variety. In conventional onion production *Wellington* does not rank so high (R. van den Broek, pers. comm.).

2.5. Priorities in Dutch onion breeding

The interviewed breeders estimate that 90% of the time they invest in selection is spent in the warehouse to assess quality of the harvested bulbs at the end of the storage period (early spring). Relatively little time is dedicated to selection in the field. One of the main reasons for selection in the field would be to improve resistance against the major foliar diseases: downy mildew and leaf blight (causing agent *Botrytis squamosa*). However, Dutch breeders agree that the *Rijnsburger* populations they select from do not contain the required absolute resistance against these leaf diseases. Furthermore, they share the opinion that incomplete forms of resistance are not interesting for the conventional market.

High levels of resistance against both diseases have been found in *Allium* species that are related to onion (*Allium cepa)*: leaf blight resistance in *Allium fistulosum* (Currah & Maude, 1984*)* and downy mildew resistance in *Allium roylei* (Kofoet et al., 1990; Van der Meer & de Vries, 1990; Scholten et al., 2007). Crosses between A. cepa and A. roylei only yield few fertile seeds, but the success rate is still higher than of crosses between *A. cepa* and *A. fistulosum* (Kik, 2002). About 20 years ago seed companies started selection in progenies of interspecific crosses with *A. roylei*, but due to the complexity of this approach these resistance breeding programmes are not part of the regular breeding programme, but executed as special projects. For the screening of downy mildew resistance, molecular marker technology is applied (Scholten et al., 2007). The availability of this technology makes it possible to replace screening in the field in the early stages of the special resistance breeding projects by laboratory analysis. The latter is also preferred because the preparation of inoculum for artificial infection in the field is difficult.

Although all breeders give low priority to selection in the field, there are clear differences in the way they take plant traits into consideration. The four breeders can be divided into two pairs. The first pair gives no or very little attention to field observations: one breeder states that he does not take any plant characteristics into account at all and the other explains that he merely takes rough field notes, but that these have very low priority in his final decision making. For both breeders, a good performance in the field will ultimately result in high yield and high quality bulbs and as they already select for bulb quality, selection in the field becomes redundant. The other pair of breeders indicates that they make frequent field observations, but also state that if they find highly productive onions with good quality traits they will select these anyway, regardless of other plant traits. When using a plant with good bulb traits, but unfavourable leaf traits, in a hybrid cross they try to compensate for this by choosing an inbred line with favourable plant leaf traits as the other parent.

2.5.1. **Comparison of breeders' priorities and the organic variety profile**

Table 2.2 lists the traits breeders select for and the importance of each trait.

Bulb quality traits and net yield

As mentioned in the previous section, all breeders consider the traits they observe in the warehouse more important than field traits. Breeders mention the same traits – high net yield, skin retention, bulb firmness, bulb shape, uniformity, sprouting resistance - and priorities are similar. The reason for this is that breeders follow the demands of onion traders because these usually buy specific varieties from farmers. Hence fulfilling traders' preferences is crucial for seed sales.

A strong focus on some of the traders' quality requirements has trade-offs. Breeders agree that strong selection for bulb firmness goes at the expense of yield. Some also attribute the problem of watery skins, which appears in some years, to a strong emphasis on breeding for skin retention. Finally, a high level of resistance to sprouting conflicts with their own interest to produce sufficient amounts of seeds for a competitive price. Therefore they are continuously looking for the most optimal balance between the traits that are required by the different stakeholders.

Table 2.2. Onion traits breeder select for and their priorities within two selection phases: in the field and after storage in the warehouse. All breeders give higher priority to selection in the latter phase.

Traits	**Priority[1] for conventional market**				**Change in priority if breeder would also select for organic[2]**			
	Breeders							
	A	B	C	D[3]	A	B	C	D[3]
In the field:					**>**	**>**	**>**	**=**
***Vigorous Growth*:**								
Seed emergence	4	1	4	5	<	>	=	=
Plant vigour	5	4	1	5	=	=	>	=
Leafiness	3	3	4	4	>	=	=	=
Leaf colour	2	3	2	3	>	=	>	=
Dead leaf tips	3	4	1	4	>	=	>	=
Root development	4	2	1	5	>	>	=	=
Supporting Disease and Pest Management								
Resistance to								
Downy mildew (*P. destructor*)	5	3	5	1	=	>	=	=
Leaf blight (*Botrytis squamosa*)	5	3	5	1	=	>	=	=
Fusarium (*F. oxysporum* f.sp. *cepae*)	1	3	1	1	=	>	=	=
Leaf health	5	3	5	5	=	=	=	=
Waxiness of leaves	3	3	1	5	>	>	>	=
Erectness leaves	3	3	5	3	>	>	=	=
Leaf bending	2	3	1	3	>	=	=	=
Earliness:								
Early bulb swelling	5	3	1	3	=	>	>	>
Earliness (Fall down)	5	4	5	3	=	=	=	>
During and after storage:					**=**	**=**	**=**	**=**
Storability:								
Sprout dormancy	5	4	5	5	=	>	=	=
Firmness of bulbs	5	4	5	5	=	=	=	=
Thickness of neck	5	3−4	5	3	<	=	=	=
Skin retention	5	5	5	4	=	=	=	=
Number of skins	4	4	1	4	=	=	=	=
Thickness of skins	4	3	1	4	=	=	=	=
% Rot	5	2	4	5	=	=	=	=
***Bulb appearance*:**								
Shape	5	5	5	4	<	=	=	=
Red discoloration	5	5	5	4	=	=	=	=
Uniformity	5	5	4	4	<	=	=	=
Doubling of bulbs	5	3	5	5	=	=	=	=
Bulb size	5	3	4	3	=	=	=	>
Single centre	3	3	3	5	=	=	=	=
Skin colour (yellow)	3	3	3	4	=	=	=	=
Net yield	5	5	5	4	=	=	=	=

[1] Scale 1 − 5, with 1 = no priority and 5 = highest priority

[2] At present none of the breeders runs a separate selection programme for organic production.
>, priority increases; =, priority stays the same; <, priority decreases

[3] The priority score for field traits of breeder D applies to selection among advanced populations and varieties. In the initial phases of his breeding programme he only selects among harvested bulbs after storage..

The traits mentioned above are also top priority for organic farmers. This is because the bulk (85%) of Dutch organic onions is exported to conventional supermarkets. For both organic and conventional onions Germany and UK are main export markets within the EU (Baas & Pals, 2006; Lammerts van Bueren et al., 2006). As traders apply the same standards for both organic and conventional products, here priorities of breeders and organic farmers overlap.

Only breeders' efforts to improve dormancy cannot be explained by a similarity in current market demands. This trait has low priority for conventional farmers, because they use the chemical sprout inhibitor maleic hydrazide (MH). Nevertheless, breeders have selected for this trait, because they received signals that supermarkets would ban the use of chemical MH in due time. Whether they will continue to give priority to this trait remains doubtful, because the discussions on MH did not result in a prohibition. Therefore, at this moment, varieties with a longer dormancy do not have a comparative advantage on the conventional market.

Like organic farmers, breeders also look for a thin neck to prevent storage diseases. As a thinner neck results in a smaller leaf apparatus and hence lower yields, they look for a balance. According to one breeder, a too thin neck also makes the onion more susceptible to stress.

Earliness

The most important selection trait in the field is earliness. Dutch breeders distinguish three maturity classes (early, intermediate and late) and within each class they look for the earliest lines. They assess this trait by recording the date of 50% of leaf fall down. For conventional agriculture earliness is important because it increases the chance of dry and warm days during harvesting and during the period the bulbs are left on the field for curing (end of August or beginning of September). Although organic farmers also give priority to earliness, they have an important additional reason: to escape an attack by downy mildew. Therefore besides an early fall down, also early bulb formation is important. Two breeders also take early bulb formation into account. The reason for this is not because they are interested in an escape from leaf diseases, but because they expect that early bulbing types cope better with drought.

Earliness is negatively correlated with storability, so breeders look for a balance between these traits.

Erect plant type

Three of the four breeders prefer plants with erect leaves. Breeders consider this trait important to avoid lodging of the massive crop canopy in a conventional field. Due to the lower nitrogen availability the vegetative development of an organic crop is less abundant and therefore lodging is not a problem in organic fields. Nevertheless, organic farmers also give this trait a high priority. This is because a crop with erect leaves makes mechanical weeding easier. So, although for this trait the organic and conventional objectives do not match, the end result satisfies both markets.

Disease resistance

Breeders aim at absolute resistance against the most important diseases: downy mildew and leaf blight. Only one breeder indicates that besides aiming at a high level of resistance against downy mildew by selecting in populations of interspecific crosses, he also screens for general plant health, i.e. plants with healthy green leaves, in his *Rijnsburger* populations. A breeder from another company grows his onions in a “stress” nursery, without fertilizers and fungicides, every second year. He observes that the advances in plant health he obtained are not because of selecting part of the generations in this nursery, but due to the fact that he selects for specific plant traits: waxiness and erect leaves. The relation between more wax and a lower susceptibility to downy mildew was confirmed by the other breeders. Also organic farmers point to the importance of these traits to reduce disease pressure.

Especially for organic farmers the broader way of looking at plant health, like by the two breeders mentioned above, is valuable. This is true for the current situation in which selection in the interspecific crosses has not resulted in resistant varieties yet. For downy mildew the situation may change in the near future, as in 2006 two seed companies distributed seeds for experimental use of the first resistant varieties. Results of independent variety tests were not available at the moment of writing. But also when the resistance genes from other species have been successfully crossed into commercial varieties, including general plant health remains necessary, because farmers have to deal with multiple diseases and want to diminish the reliance on purely monogenetic resistances. Therefore it is unfortunate that even the breeders, who take these traits into account, indicate that these have lower priority.

Increased root system and more vigorous growth

The same breeders, who look for early bulbing, also pay attention to drought resistance. They find that more leafy plants are less susceptible to drought stress and also relate stress resistance to a better rooting system. One of them systematically screened his plant material for the amount of roots. He attributes gains in selection for a better rooting system to his selection environment: once in every two generations of the breeding cycle he grows his onions in the earlier mentioned “stress nursery”. The influence of the environment on rooting ability is also mentioned by one of the breeders who pays less attention to selection in the field. He claims that some of his varieties are better rooting, because his main breeding nursery is situated in the south-west of the country, which is more prone to drought stress than the north-west where most of his competitors are based. Breeders argue that better rooting varieties tend to mature later, so also for this trait a balance should be sought.

2.5.2. **Would breeders use other criteria if they would select for organic farming?**

During the study breeders were also asked what they would do differently if they would select specifically for the organic market. All breeders indicate that they expect that their conventional breeding programme also yields varieties suitable for organic farming. Their argument is that the main selection criteria, storage and bulb quality traits, are determined by trader demands and these overlap. Nevertheless, Table 2.2 shows that three out of four breeders would give higher priority to screening traits in the field such as leafiness, waxiness, erectness of leaves and root development, while the storage and bulb quality traits and yield would receive the same high priority. One breeder would lower the priority for bulb shape and uniformity.

2.6. Hybrid breeding

The case of onion is illustrative for the objections of the organic sector against non-fertile hybrids. The CMS used by Dutch breeders is derived from the *Rijnsburger* populations and prevents seed setting for almost 100%. Although in theory skilled breeders can try to produce seeds from these hybrids by pollinating these with their own set of lines with different restorer genes, two of the three hybrid breeders found that in practice chances to successfully obtain fertile inbred lines in this way were so small that they did not even bother to attempt this. As a result, the CMS-system slows down genetic development, as advances made by one company for a certain plant trait (e.g. storability) are not rapidly combined with advances of another breeder on another trait (e.g. mildew resistance). This favours the breeding company with the leading varieties, but not (organic) farmers who need varieties, which perform well for all priority traits.

Another disadvantage of onion hybrids is the multiplication costs, because seed yields of hybrid onions are generally lower than seed yields of OPs. The difference in seed price between hybrids and OPs becomes even larger when seeds are multiplied organically. Seed company Hoza sells its organic seed of OPs at twice the price of conventional seed of the same variety (Hoza, 2007), while seed company Bejo calculates that organically multiplied hybrid seeds cost three times more than conventionally multiplied hybrid seeds (Van der Zeijden, 2003). Farmers consider the high costs of organically multiplied hybrid seeds a problem. The price difference also motivated a small group of organic farmers to get involved in organic multiplication of OP varieties. However, variety choice within the group of OPs is limited, because most breeding companies focus on hybrids.

2.7. Conclusions and perspectives

2.7.1. Do breeders’ selection traits match organic farmers’ priorities?

Although breeders develop varieties for the conventional market, the bulb and storage traits they select for coincide with organic farmers’ priority traits. This is because traders mainly export organic onions to conventional supermarkets and their quality standards for organic onions are similar to their conventional standards. Due to the strong influence of traders there are also only minor differences between breeders in priorities for bulb and storage traits.

Besides the importance of bulb quality, organic farmers also need a good field performance under organic growing conditions. However, for all breeders selection in the field has a low priority. Yet, breeders differ in their approach in the field: two of the interviewed breeders make very few or no field observations, while the other two screened their plants under a conventional cropping regime, as well as under sub-optimal growing conditions (one with less fungicides, the other with no fungicides and fertilizers at all).

Despite the limited attention to the field not all farmers' priority field traits are neglected by breeders. Most breeders and organic farmers share a preference for an erect plant type, but for different reasons. For organic farmers this plant type makes mechanical weeding easier, while breeders want to prevent lodging of the crop. So, remarkably, a similar plant type is required to address two different problems that both are unique to either only the organic or only the conventional cropping system.

Also breeders aim at downy mildew and leaf blight resistance that are among the top priorities of organic farmers. The breeders' approach is strongly focused on resistance genes of related *Allium* species, because only these have been reported to confer the high level of resistance that is required by the conventional market. Field resistance, that is present in *Rijnsburger* populations, and other traits such as more wax and early bulbing that may help to diminish problems with diseases, do not receive priority. This is because they expect that the effect will be too limited to allow for a significant reduction of fungicide use. Organic farmers also prefer a high level of resistance, but they do not want to rely solely on monogenic resistances to single diseases. To avoid the risk of a break-down of such resistance genes, other traits that contribute to general plant health remain important. But even the two breeders who claim to pay more attention to observations in the field, state that field results receive low priority in decision making.

Finally, farmers wish to have varieties that show a good vegetative development. They think that better rooting varieties with an enhanced symbiosis with AMF may contribute to this. Breeders do not observe AMF. Two breeders did evaluate the rooting systems, but again they gave this trait a low priority in their selection.

2.7.2. **The selection environment**

The selection environment may also influence the results of a breeding programme. Empirical evidence of the Dutch breeders shows that selection progress towards an improved root system is better in a drought or nitrogen stress environment. A larger root system is also thought to be an advantage for an organic crop, because nitrogen is scarce early in the season. As the breeders' experience implicates that material selected in stress environments may already be an improvement for organic farmers, selecting in an organic environment may even enhance the chance to find better adapted varieties. A shift in selection environment, during a part of the breeding programme, seems more feasible for breeding companies than a shift in priority traits. This is because conventional companies are not interested in varieties with traits that are only interesting for a specific niche market.

2.7.3. **Perspectives of obtaining varieties for the organic sector through conventional breeding programmes**

From the above it becomes clear that for bulb quality traits the conventional seed sector can supply organic farmers with varieties that fulfil their requirements. The reason for this is that the Dutch organic sector mainly supplies a market that employs conventional quality standards. However, for a targeted improvement of the required field traits a shift in priority traits is required. Breeders themselves also indicate that they would dedicate more time in the field, if they would aim at breeding for the organic sector. However, as long as the organic seed market remains limited, private breeding companies will not make this shift.

The majority of conventional breeding companies have decided to abandon OP onion breeding for the Dutch market and since a decade new varieties are mainly hybrids. To produce these hybrids, breeders use cytoplasmic male sterility. As the fertility restorer genes are not publicly available, this breeding methodology conflicts with the organic principles of the world umbrella organization for organic farming IFOAM.

If in the future the organic seed market will grow, conventional breeders might consider taking organic preferences for key traits into account. However, it is less likely that seed companies that currently use CMS-hybridisation methodology will be prepared to adapt this methodology to the organic principles, by e.g. making restorer genes publicly available. The latter would require a change in company policy, while adapting to the needs of new promising markets is part of the existing policies.

At present conventional breeders can provide varieties that comply with organic farmers' demands for storability and quality traits, but are not giving priority to the required field traits. If in the future the organic seed market will grow, breeders may also pay more attention to field selection. However, if the organic sector wants both varieties that perform well in their production system as well as varieties that are developed according to their principles, it should either set up its own onion breeding programme or seek alliances with breeding companies that are prepared to harmonize their breeding methodology with the organic principles.

Chapter 3:

Are specific testing protocols required for organic onion varieties?

Analysis of onion variety testing under conventional and organic growing conditions

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Abstract

Organic growers need information on variety performance under their growing conditions. A four-year onion variety research project was carried out to investigate whether setting up a variety testing system combining conventional and organic variety trials is feasible and efficient rather than organizing separate variety trials under the two management systems. During four years commercial onion cultivars were tested at a certified organic and a non-organic location. Both systems were managed without chemical pest, disease and sprouting control, but differed in fertility management (organic manure in autumn versus synthetic fertilizer), soil cultivation and weed management (mechanical weeding versus application of herbicide). Management system significantly affected plant density, thickness of neck, proportion of small bulbs, and proportion of multi-centred bulbs. Variety × management system interactions were significant for bulb uniformity, earliness, proportion of large bulbs, dormancy and relative storage success but did not change the ranking of the varieties. We conclude that organic growers can profit from a more conscious variety choice when conventionally fertilised trials would refrain from using pesticides, fungicides, herbicides and sprout inhibitors. However, this would require an adaptation of the management protocol in such a way that trials might no longer represent conditions of conventional farmers. Furthermore, assessments of leaf erectness, disease resistance to downy mildew and leaf blight should be included in the protocols for organic use. We advocate better communication between breeders and growers on specific variety characteristics contributing to improving yield stability under low-input, organic growing conditions.

Keywords:

onion; organic agriculture; variety testing

3.1. Introduction

In organic farming in the Netherlands, onion (*Allium cepa*) is one of the most important vegetable crops. The total area of organic onion production expanded from 294 ha in 1999 to 680 ha in 2010 (Table 1.1, page 11). More than 80% of the produce is exported. Yields of onion production can differ substantially between conventional and organic farming systems in the Netherlands. They range from 50 - 100 tonnes/ha for conventional conditions to 25 - 60 tonnes/ha for organic conditions. In years with severe infestation of downy mildew (*Peronospora destructor*) yields can even be lower under organic conditions as there are no appropriate means to protect the crop other than growing resistant cultivars. In 2007, the first two resistant varieties resulting from conventional breeding programmes were released and grown by organic growers (Scholten et al., 2007). Lower onion yields in organic farming systems are also caused by lower levels of nitrogen input (approx. 40 - 50%) in organic than in conventional farming. Moreover, organic fertilizers are known for their slow release of nitrogen early in the growing season. Some organic growers are inclined to sow later (beginning of April instead of March) than their conventional colleagues to allow the soil temperature to rise resulting in a higher and more uniform germination and better nitrogen availability. Many research projects in the Netherlands have focussed on optimising organic onion production in terms of yield and bulb size distribution to better cope with mechanical weed management and to reduce disease pressure from downy mildew (Van den Broek, 2004; 2005; 2008).

To avoid crop failure, growers also have to be very demanding regarding the varieties they select to grow. Desired traits for organic production in general and more specifically for onion cultivation, such as leaf erectness for less damage during mechanical weed control, have been identified (Chapter 2). Organic growers need relevant information on variety performance under low-input, organic growing conditions as sometimes the performance of varieties under organic management differs from that under conventional conditions as Murphy et al. (2007) showed for cereals. In some countries, such as Austria, the government financially supports an organic testing protocol for assessing the Value for Cultivation and Use for cereals in addition to the conventionally managed trials (Löschenberger et al., 2008; Rey et al., 2008). Most official variety trials in the Netherlands, including those for onion, are no longer financed by the government but by a consortium of growers, breeders and seed traders. As onion is an important export crop, the conventional sector organises regular variety trials.

However, the Dutch organic sector is too small to finance separate organic variety trials and is searching for cheaper options, e.g. by modifying the conventional onion testing protocol in ways that would give better information for both management systems. Therefore, the Dutch government financed a research programme from 2001 - 2004, aiming to compare onion variety trials carried out under conventional and organic growing conditions to provide answers to the following three questions:

1. Which traits are relevant to include in protocols of conventional onion variety trials to assess the suitability of varieties for cultivation under organic growing conditions?
2. To what extent can conventionally managed trials without pest and disease control, including traits relevant for organic farming systems, provide good information for the performance of varieties under organic growing conditions?
3. For which traits relevant for organic agriculture is the performance of the existing varieties inadequate to contribute to yield stability, and is there a need for variety improvement in that respect?

3.2. Materials and methods

3.2.1. **General methodology**

Each year 14 - 20 modern onion varieties were tested under conventional and organic growing conditions, from 2001 to 2004. In contrast to the current practice, for this project the conventional trials were managed without chemical pest, disease and sprouting control (hereafter named ‘non-organic’) to assess varietal differences in disease resistances and to analyse whether ’non-organic’ variety trials can provide useful information for organic growers. For more details of the crop management in the trials see Table 3.1.

The field experiments were established in two of the most important areas for onion production in the Netherlands: Flevoland (situated in the centre) and Zeeland (located in the southwest). Only in 2001, the organically managed trial was located in Flevoland (Nagele) on an organic certified experimental farm. The “non-organic” trial was located at the experimental station of Wageningen University and Research Centre (Lelystad), at 30 km distance from each other.

Table 3.1. Soil characteristics and crop management of the non-organic and organic trials, 2001 - 2004.

	Non-organic	**Organic**
Soil texture	Clay	Clay
Silt fraction (%)		
2001	21	30
2002	20	33
2003	33	36
2004	18	33
pH soil		
2001	7.6	7.5
2002	7.4	7.6
2003	7.4	7.4
2004	7.5	7.7
Soil organic matter (%)	1.8	2.4
2001	1.9	2.1
2002	1.9	2.5
2003	1.8	2.4
2004		
P_2O_5 (mg/100 g)		
2001	30	15
2002	34	26
2003	39	36
2004	25	39
K_2O (mg/100 g)		
2001	20	19
2002	31	26
2003	26	29
2004	20	26
Preceding crop		
2001	Spring barley	Grass / clover
2002	Spring wheat	Spring wheat with clover
2003	Sugar beet	Spring wheat
2004	Spring barley	Sugar beet
Fertilisation Trial	Mineral fertilisers	Organic fertilisers
2001	370 kg KAS (100 kg N/ha)	20 tonnes goat manure (65 kg available N/ha)
2002	410 kg KAS (110 kg N/ha)	24 tonnes goat manure (65 kg available N/ha)
2003	410 kg KAS (110 kg N/ha)	24 tonnes goat manure (65 kg available N/ha)
2004	440 kg KAS (120 kg N/ha)	24 tonnes goat manure (60 kg available N/ha) + 1.5 tonnes vinasse potassium (60 kg available N/ha) in spring
Time of fertilisation	Before seed bed preparation in spring	In autumn before ploughing (goat manure)
Weed management	Chemical After sowing before emergence 1.5 l/ha Stomp; after first real leaf appearance 0,25 basagran+0.25 actril	Mechanical (1-5×)
Pest and disease management	None	None

In the subsequent years, experiments were carried out in Zeeland, with the non-organic trials conducted on the experimental station Rusthoeve (Colijnsplaat), and the organic trials on a certified organic farm in IJzendijke, again at about 30 km from each other.

From 2002 to 2004 the onion varieties were directly sown in April. Only in 2001 sowing had to be postponed until early May due to extreme rainfall in April. All cultivars were harvested at the same date, early September. For each variety, seeds for the two management systems came from the same source and were conventionally produced without chemical post harvest seed treatments. When organically produced seed was available, organic seed was used for both management systems (Table 3.2). In 2001, seed of one variety was only available after a priming treatment. Seed priming to stimulate rapid and even germination is permitted in organic agriculture when only a clay mixture without addition of chemical seed treatment with fungicides is applied. For all seed lots the germination rate was obtained from the seed companies and these data were used to correct, if necessary, the standard sowing rate of 100 seeds/m^2.

For all trials the net plot size was 1.5 m × 8 m, with a row distance of 0.27 m (5 rows per 1.5 m bed). To evaluate storability the onions were stored by ambient air ventilation until approximately mid February/beginning of March at a temperature of 3 - 4°C.

3.2.2. **Variety choice**

The choice of varieties was determined yearly together with the stakeholders involved: organic growers, seed companies and researchers. The budget of the project allowed 14 - 20 varieties per year to serve on the one hand the wish of the organic growers and seed companies to observe the performance of the latest, most promising varieties suitable for the Dutch organic, low-input conditions and on the other hand to guarantee some level of scientific rigour of the research programme by including a core group of varieties for at least all four years (Table 3.2).

Table 3.2. Overview of the 16 onion varieties evaluated for at least two years in the variety trials between 2001 - 2004.

Variety	Variety type[a]	2001	2002	2003	2004	# of years in trials	Origin
Yellow onion							
Canto	F1			X	X	2	Nickerson-Zwaan
Hytech	F1		X	X	-	2	Bejo Seeds/De Groot & Slot
Napoleon	F1		X		X	2	S&G Seeds/Syngenta
Wellington	F1		X		X	2	S&G Seeds/Syngenta
Arenal	F1		X	X	X[b]	3	Advanta Seeds
Hystar	F1	X[b]	X[b]	X[b]	-	3	Bejo Seeds/De Groot & Slot
Baldito	F1	X	X	X	X	4	Seminis/Monsanto
Drago	F1	X	X	X	X	4	Nickerson-Zwaan
Hyfort	F1	X[c]	X	X	X[b]	4	Bejo Seeds/De Groot & Slot
Hyskin	F1	X	X	X	X	4	Bejo Seeds/De Groot & Slot
Profit	F1	X	X[b]	X[b]	X[b]	4	Advanta Seeds
Sunskin	F1	X	X	X	X	4	S&G Seeds/Syngenta
Balstora	OP	X	X	X	X	4	Bejo Seeds/De Groot & Slot
Red onion							
Red Kite	F1	X	X	-	-	2	Seminis/Monsanto
Redspark	F1		X	X	X	3	Bejo Seeds/De Groot & Slot
Red Baron	OP	X	-	X	X	3	Bejo Seeds/De Groot & Slot
Total # of varieties/year		10	14	13	13		

a F1 = hybrid variety; OP = open pollinated variety
b Organically produced seed
c Primed seed

3.2.3. **Criteria for evaluation**

The criteria to evaluate the suitability of varieties to be grown under organic conditions were identified in a participatory process with a group of 30 organic onion growers (Chapter 2). Specific criteria for field evaluation during the growing season were added to the criteria regularly applied in current conventional onion variety trials (Table 3.3).

Table 3.3. Evaluation characteristics and methods applied in the variety trials.

	Evaluation methods
In the field	
Plant density	Number of plants/ m^2
Earliness	Days from sowing to 50% of leaf fall down
Uniformity crop stand[a]	1 - 9 (1 = very low, 9 = very high)
Leaf erectness [a]	1 - 4 (1 = planophile, 2 = intermediate, 3 = erect, 4 = very erect)
Leafiness[a]	1 - 9 (1 = very few, 9 = large amount of leaves)
Dead leaf tips[a]	1 - 9 (1 = large number and large proportions, 9 = very few and little)
Leaf colour[a]	1 - 3 (1 = green, 2 = bluish-green, 3 = blue)
Downy mildew[a] (*Peronospora destructor*)	1 - 9 (1 = all leaves severely infested, 9 = no infestation)
Leaf blight[a] (*Botrytis squamosa*)	1 - 9 (1 = all leaves severely infested, 9 = no infestation)
At harvest	
Gross yield	Yield of net plot area (8 m × 1.5 m)
Uniformity bulb	1 - 9 (1 = very low, 9 = very high)
Thickness of neck	1 - 9 (1 = very thick, 9 = very fine)
Bulb shape	1 - 9 (1 = very flat, 6 = round, 9 = rhombic)
After storage	
Good bulbs	% unaffected bulbs of total weight including bulbs with no or too few skins, but excluding rotten and sprouted bulbs
Bulb size distribution	% bulbs of good bulbs in the classes: < 40 mm, 40 – 50 mm, 50 – 70 mm, > 70mm
Portion marketable	% weight of good onions bulbs > 40 mm of total weight after storage,
Firmness of bulbs (1)	As measured by penetrometer (30 onion bulbs in the class 40-60 mm)
Firmness of bulbs (2)	Based on rating; score of 100 is average
Relative storage success	% good bulbs of a specific variety divided by the average % good bulbs across all tested varieties. A higher figure meant a better output.
Dormancy	Day numberon which 50% has sprouted, starting from 1 January

[a] Upon request of organic farmers these traits were added to the protocol for non-organic onion variety trials

3.2.4. **Statistical analysis**

The experimental design consisted of four years with two locations per year of which one location was treated as non-organic and the other as organic. Within each location a completely randomised block design was performed with three replicates and a variable number of varieties. The analysis for this paper was based on the results of those 16 varieties that had been included in the trial for at least two years (Table 3.2).

To take into account that the management system (non-organic versus organic) was only replicated at location level an analysis was performed with year and location within year as random terms and management system, variety and their interaction as fixed terms in the model. Restricted maximum likelihood (REML) method was used to estimate the fixed and random effects.

All results and conclusions presented in this paper are based on the Wald test. All analyses were performed in the statistical package GenStat. The REML analysis also resulted in (predicted) means for each variety-management system combination that were comparable and corrected for differences due to year and location. These means were used to calculate the Spearman rank correlation to test whether the ranking of the varieties was different between the two management systems.

3.3. Results

3.3.1. **Field traits**

In all four experimental years the non-organic fields showed on average a statistically lower number of plants (78 plants/m^2) than the organic fields (91 plants/m^2). As seed from the same seed lot was used for both non-organic and organic trials, and as the sowing dates did not differ substantially, the lower densities under non-organic management were most likely associated with seedling damage caused by the application of herbicides. However, also other differences in soil cultivation and growing conditions could have influenced plant density. As plant density often affects earliness of bulb development, bulb-size distribution and, therefore, marketable yield, plant density should always be

Table 3.4. Mean values and analysis of variance on the performance per trait (P values) in the variety trials under non-organic and organic conditions across the four years (2001 - 2004), and the Spearman rank correlation (r_s) with probability between the two management systems (non-organic and organic), based on the average per variety.

Traits	**Mean values (min.-max.)**		**Differences organic and non-organic**	**Variety**	**Interaction**	**Spearman rank correlation**
In the field	**Non-organic**	**Organic**	**P-value**	**P-value**	**P-value**	**r_s value**
Plant density	77.7 (69.9-84.6)	90.7 (85.3-97.0)	0.025	< 0.001	0.093	0.324
Earliness	6.0 (5.1-6.6)	6.6 (5.7-7.1)	0.160	< 0.001	0.050	0.632**
Uniformity crop stand	6.7 (6.2-7.4)	6.8 (6.4-7.3)	0.467	< 0.001	0.518	0.576**
Leaf erectness	6.4 (5.1-7.7)	6.5 (5.1-7.5)	0.696	< 0.001	0.804	0.929***
Leafiness	7.2 (6.8-7.5)	7.3 (6.8-7.9)	0.658	< 0.001	0.206	0.129
Dead leaf tips	5.9 (5.1-6.3)	6.1 (5.5-6.6)	0.446	< 0.001	0.243	0.400*
Leaf colour	7.1 (6.1-7.8)	7.0 (6.0-7.7)	0.344	< 0.001	0.832	0.879***
Downy mildew	5.4 (4.0-6.0)	5.8 (4.8-6.4)	0.688	< 0.001	0.671	0.698***
At harvest						
Gross yield (tonne/ha)	53.9 (46.6-57.3)	44.7 (38.2-49.9)	0.192	< 0.001	0.808	0.732***
Uniformity bulb	6.1 (5.7-6.5)	6.4 (5.5-7.0)	0.082	< 0.001	0.017	0.482*
Thickness of neck	6.1 (5.7-6.4)	6.6 (6.2-7.1)	0.031	< 0.001	0.579	0.837***
Bulb shape	6.3 (6.0-6.8)	6.5 (6.0-7.1)	0.358	< 0.001	0.092	0.632**
After storage						
Proportion bulbs < 40 mm	7.8 (5.3-12.2)	16.5 (11.1-23.5)	0.054	< 0.001	0.147	0.565**
Proportion bulbs 40-50 mm	21.7 (17.6-31.3)	35.9 (27.0-42.9)	0.005	< 0.001	0.317	0.774***
Proportion bulbs 50-70 mm	50.1 (35.7-57.3)	34.6 (19.6-41.8)	0.302	< 0.001	0.811	0.774***
Proportion bulbs > 70 mm	10.7 (2.5-15.5)	1.0 (0.5-2.2)	0.343	< 0.001	<0.001	0.671**
Portion marketable	83.5 (63.5-89.8)	71.4 (45.9-78.8)	0.161	< 0.001	0.469	0.747***
Firmness of bulbs (1)	199.5 (176.1-335.4)	191.3 (170.4-290.2)	0.318	< 0.001	0.353	0.694***
Firmness of bulbs (2)	101.0 (74.5-111.4)	101.5 (79.0-111.9)	0.746	< 0.001	0.746	0.938***
Relative storage success	99.7 (93.5-102.6)	98.7 (80.1-106.3)	0.557	< 0.001	0.006	0.582**
Dormancy	28.4 (-8.9-112.3)	18.7 (-8.7-62.8)	0.326	< 0.001	0.013	0.768***

*=P< 0.05 ;**=P< 0.01;***=P< 0.001

assessed in onion variety trials, whether they are non-organic or organic. Correcting for variation in plant density might be possible for some variables (e.g. yield) but is complicated for other ones (e.g. bulb size distribution). The low values for the rank correlation coefficients between non-organic and organic trials for plant density suggest that in non-organic trials the application of herbicides influenced the plant density differently per variety and this complicates any extrapolation to performance under organic conditions (Table 3.4 and Figure 3.1a). So the non-organic trial gave a poor prediction of the ranking of varieties for plant density in the organic trials. This has also consequences for the prediction of yield, bulb size distribution and earliness.

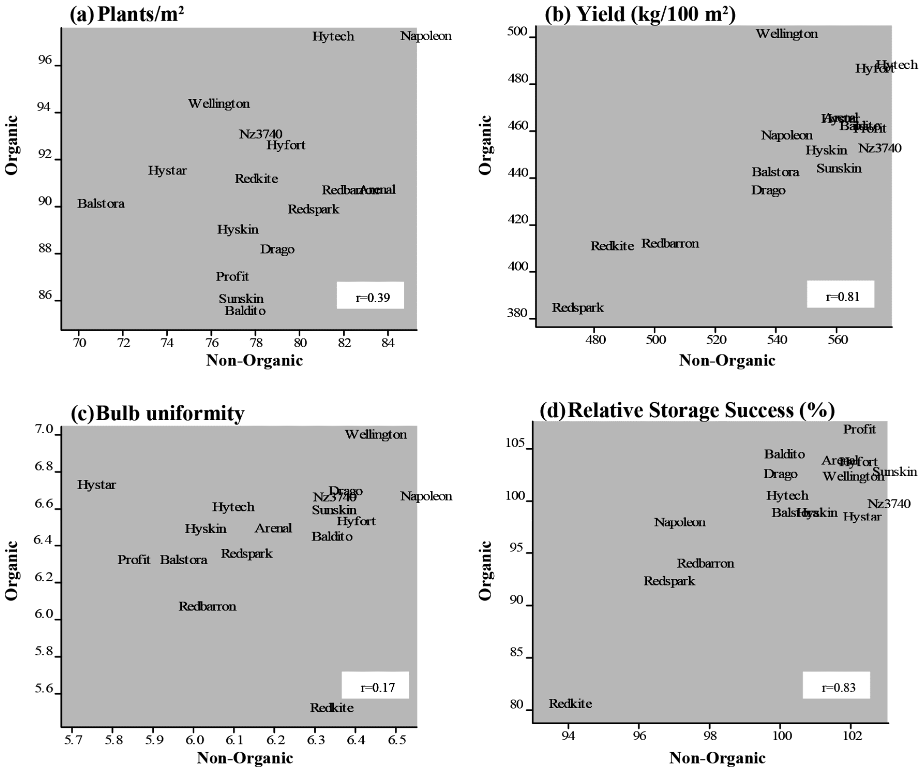

Figure 3.1. Correlation (r) between results in the organic and non-organic trials, with 16 onion varieties, over the period 2001-2004 for (a) plants/m^2, (b) gross yield (kg/100 m^2), (c) bulb uniformity and (d) relative storage success (%).

Table 3.5. Comparison of the average yields (tonnes/ha) of 16 onion varieties grown under non-organic and organic conditions in trials carried out in the period 2001 - 2004.

	2001	2002	2003	2004	Mean over 4 years
Non-organic Lelystad/Colijnsplaat	77.6	41.6	27.8	68.9	53.9
Organic Nagele/IJzendijke	53.6	38.6	28.9	58.0	44.7
Yield reduction under organic (%)	30.9	7.2	-4.0	15.8	17.0
P value	< 0.001	< 0.001	0.200	< 0.001	
S.e.d.[a]	0.83	0.83	0.86	1.29	

[a] Standard error of difference of means

The gross yield assessed at harvest time showed genetic variation, and especially the red varieties yielded on average lower than the yellow onions. We also assessed a large variation among years due to different weather conditions and downy mildew infestations. On average, the gross yield was lower under organic growing conditions (44.7 tonnes/ha) than under non-organic conditions (53.9 tonnes/ha) (Table 3.4 and Figure 3.1b). Although in three of the four years the yield differences between organic and the non-organic fields were statistically significant, the overall difference was not significant (Table 3.5). The average reduction in yield was 17.0%. Given the chemical crop protection in the common conventional practice, the differences in yield between the two farming systems will be larger in practice. The non-organic and organic trials suffered from a severe downy mildew incidence in 2002 (Table 3.6) and from a mid- and late season drought in 2003. The average yields in the three years with moderate to low downy mildew incidence (2001, 2003 and 2004) gave an indication for an average yield difference between organic and non-organic conditions, which in our trials showed a maximum of 30.9% (Table 3.5). The overall comparison showed that there were significant differences amongst varieties but not between the management systems; moreover no significant interaction was observed. The Spearman correlation showed a good rank correlation between the results from the non-organic and organic trials (Table 3.4 and Figure 3.1b). This means that in this data set the non-organic trials provided a good prediction of the ranking of organically grown varieties with respect to their yielding capacity.

Organic growers prefer varieties with an erect leaf attitude to avoid leaf damage during mechanical weed control. Varieties with more leaf mass are considered more stress resistant in dry periods and more productive. Absence of dead leaf tips during early crop growth might indicate more regular growth and less sensitivity to stress. For these three leaf characteristics we observed significant variety differences ($P < 0.001$), but no effects of farming system or significant Variety × Management interactions (Table 3.4).

The main disease that occurred during these trials was downy mildew. Especially in 2002 yields in both non-organic and organic experiments were severely affected by this disease (Table 3.6). In most trial years downy mildew started late and was slightly less severe under organic conditions than under non-organic conditions (without disease treatment) (Table 3.6), but eventually hit the yield in a dramatic way under both management regimes. There were significant variety effects ($P < 0.001$). There were no significant management system effects nor was the Variety × Management interaction statistically significant (Table 3.4). There was a good rank correlation between the (not treated) non-organic and organic trials ($r_s = 0.70$), so that the results of non-organically managed trials without fungicides may be used to predict differences in susceptibility of varieties for downy mildew under organic conditions.

Organic growers aim at a crop that can escape disease through earliness, has a high yield and a well storable product without using chemical sprouting inhibitors; therefore they require, like their conventional counterparts, a mid-early variety that matures in less than 127 growing days. There were significant varietal differences in earliness ($P < 0.001$), both under organic and non-organic conditions. We found a positive rank correlation ($r_s = 0.63$) between organic and non-organic trials (Table 3.4). However, we also found a significant interaction effect ($P = 0.05$), suggesting that results of conventional trials cannot be used to predict earliness under organic conditions. Earliness may be associated with higher plant density which stimulates early maturing. As the higher plant density in the organic trials may have confounded our results, further research would be required to confirm our findings.

We also included the characteristics leaf blight, leaf colour and crop stand uniformity in the evaluation. Leaf blight did not occur in the years of the trials, so we cannot conclude whether results of non-organic, non-treated variety trials will give a good prediction for this trait under organic conditions. Farmers expected that leaf colour would differ under low fertilizing conditions and could be an indicator of not being able to cope with low nitrogen availability. For both leaf colour and crop uniformity variety differences were significant ($P < 0.001$), but there were no significant treatment effects or Variety × Management interactions, nor any correlations with other traits (Table 3.4). The non-organic trials gave a good prediction of performance of leaf colour and crop uniformity under organic conditions.

Table 3.6. Comparison of the mean score[a] for downy mildew tolerance of 16 onion varieties tested under non-organic (non org) and organic (org) conditions between 2001 - 2004.

Variety	2001		2002		2003		2004		Mean over 4 years [b]	
	non-org	org	non-org	org	non-org	org	non-org	org	Non-org	org
Arenal			3.7	5.7	9.0	7.7	6.3	5.3	5.8	6.3
Baldito	5.0	6.7	3.7	5.3	9.0	6.7	6.0	5.2	5.9	6.0
Balstora	4.5	6.5	4.5	5.3	8.7	6.7	6.3	7.0	6.0	6.4
Canto					9.0	6.3	5.2	4.7	5.4	5.1
Drago	4.0	5.7	3.0	5.2	9.0	7.3	6.3	6.0	5.6	6.0
Hyfort	3.7	6.2	3.7	4.7	9.0	7.3	6.3	5.3	5.7	5.9
Hyskin	5.0	6.2	3.7	4.2	9.0	7.3	6.0	4.5	5.9	5.5
Hystar	4.3	6.5	3.7	4.8	9.0	7.0			5.7	5.9
Hytech			4.2	6.2	9.0	7.0			5.9	6.4
Napoleon			2.7	4.0			5.3	5.0	5.2	5.3
Profit	4.7	6.7	4.2	4.8	9.0	8.3	4.7	5.5	5.6	6.3
Redbarron	3.0	5.8			9.0	7.0	4.0	4.0	4.7	5.3
Redkite	2.3	5.7	2.3	4.7					4.0	5.5
Redspark			3.0	4.5	8.0	6.7	3.7	3.2	4.4	5.9
Sunskin	3.5	5.8	3.8	4.8	9.0	9.0	6.3	6.0	5.6	6.4
Wellington			2.7	4.5			5.0	4.0	5.0	5.1
Mean	4.0	6.2	3.5	4.9	8.9	7.3	5.5	5.1	5.5	5.9
P value	< 0.001		< 0.001		< 0.001		0.043		0.688	

[a] 1 = all leaves severely infested, 9 = no infestation

[b] average over 4 years is based on the REML-model, i.e. averages corrected for missing years.

3.3.2. **Harvest traits**

The bulb-size distribution can be influenced by variety and by management (e.g. sowing date, plant density, fertilisation, control of weeds, pests and diseases). The markets for both organic and conventional onions prefer the bulb size class 50 - 70 mm. Varieties differ significantly in their bulb-size distribution. Bulbs smaller than 40 mm cannot be sold. Especially organic growers want to avoid the risk of a too high rate of bulbs smaller than 40 mm, which is more likely under organic conditions as the fraction of large bulbs is closely correlated to total bulb yield and thus to nitrogen availability. As expected, under organic conditions a significantly larger proportion of bulbs were smaller than 40 mm (16%) than under non-organic conditions (8%). The organic trials also had a significantly larger proportion of bulbs in the size class 40 - 50 mm than the non-organic trials. These differences were most likely associated with differences in plant density (Table 3.4) and/or fertilisation level. The non-organic and organic trials showed a good rank correlation for bulb sizes, (Table 3.4). For the largest class (> 70 mm) we found a significant Variety x Management interaction (P < 0.001).

Bulb uniformity is demanded by the market. Average uniformity in bulb size was not significantly ($P = 0.08$) higher under organic (6.4) than under non-organic conditions (6.1). However, varieties differed significantly ($P = 0.01$) for this trait under organic conditions, but under non-organic conditions there were no significant differences ($P = 0.08$) among the tested varieties. The trials showed an interaction effect ($P = 0.02$), and a low rank correlation ($r_s = 0.48$) between the results of the organic and non-organic trials (Figure 3.1c). This means that non-organically managed trials including the use of herbicides cannot give reliable information on bulb uniformity for organic growers.

A finer neck is needed to allow the foliage to fall down easier at maturation time and the neck will dry easier thus preventing moulding during storage. Onions harvested from the organic fields showed a significantly larger proportion of smaller sized bulbs and therefore probably also finer necks than the non-organically grown ones ($P = 0.031$) (Table 3.4). Varieties differed significantly in producing thick necks. The trials showed a good ranking correlation ($r_s = 0.84$) between the results under organic and non-organic trials. So the non-organic trials can be used to predict the thickness of necks of the varieties grown under organic circumstances.

3.3.3. **Storage quality traits**

The decisive traits for both conventional and organic growers are the traits related to the quality and thus the marketability of the bulbs after storage, such as loss in bulb weight, skin retention, healthy (unaffected) bulbs, % marketable bulbs, % waste, firmness of bulbs, relative storage success and dormancy. For organic growers dormancy is more important than for conventional growers as the last group can compensate lack of dormancy with chemical sprouting inhibitors. For all these traits the differences between the varieties were small, although significant. Nevertheless the trials showed an interaction effect on the dormancy ($P = 0.01$), mostly due to one variety (*Wellington*) which had by far the best dormancy especially under non-organic conditions. Also for the relative storage success there was a significant interaction ($P = 0.006$). Under organic conditions there was more variation among the varieties than under non-organic conditions. Some varieties (mostly the red types) showed a lower relative storage success under organic conditions than under non-organic conditions (Figure 3.1d).

On the one hand one could conclude that the trials with this set of varieties show a good correlation between the results of the organic and non-organic trials for all storage quality traits (Table 3.4), suggesting that organic growers can rely on the variety differences and ranking resulting from conventional trials. However, as the trials also showed significant Variety × Management interaction but no ranking differences, trials with another set of varieties could possibly result in a change in ranking.

3.4. Discussion

3.4.1. **Which traits are relevant to include in the protocol of onion variety trials to evaluate the suitability of varieties for organic growing conditions?**

Besides the traits that are normally evaluated in conventionally managed onion variety trials, organic farmers have requested to investigate some extra criteria concerning the field performance of onion varieties: crop canopy uniformity, leaf erectness, leafiness, dead leaf tips, leaf colour, resistance to downy mildew and resistance to leaf blight (*Botrytis squamosa*) (Table 3.3). For all these traits we found varietal differences in our trials (except leaf blight that did not occur). For crop canopy uniformity, leafiness, and leaf colour we did not find clear evidence for correlations with other traits such as yield. Therefore, in our opinion, these traits are not relevant to include as predictors for stress resistance, yield and/or the other tested traits. For dead leaf tips the varieties showed significant differences. However, more research would be needed to show that dead leaf tips are an indicator for low stress resistance and would therefore be a useful trait to add in variety testing. Leaf erectness is important to avoid damage by mechanical weeding; this research showed significant genotypic differences. Also for resistance to downy mildew organic growers made clear that this is an important trait for their variety choice. The differences in field tolerance between (non-resistant) varieties found in our trials were not large enough to be effective in practice during severe incidences, although in years with less severe disease pressure less susceptible varieties can keep up longer and can provide an economically acceptable yield. Resistance or tolerance to downy mildew of a variety (in combination with earliness) does add important information for the growers to make better informed decisions concerning variety choice. At the time of the trials resistant varieties were not yet on the market, but when in 2007 two resistant varieties entered the market seed demand of these varieties by organic growers was higher than seed availability in the following years (pers. comm. F. Van de Crommert, 2010). An effect of including additional traits such as downy mildew resistance in variety testing protocols might be that breeders would pay more attention to resistance during selection, which could be beneficial both to conventional and organic varieties in the future.

Although differences in susceptibility in leaf blight are also relevant to growers, in the years of this research we could not assess this trait and cannot confirm significant varietal differences for this trait.

In conclusion, leaf erectness, resistance to downy mildew and leaf blight are important additional traits to be added to the protocol of variety testing.

3.4.2. **To what extent can conventionally managed trials without disease control provide good information on the performance of varieties under organic growing conditions?**

We first have to stress that the results described above are influenced by the assortment of 16 varieties selected for the tests of which most were *Rijnsburger* types, the main genetic background of the current varieties on the Dutch market (Chapter 2). We also stress that the fertility level of the Dutch clay soils is relatively high compared with the soil fertility level in other countries. This means that the results can differ when other varieties are included and tested under lower levels of fertility.

Literature on comparing results of variety testing under organic and conventional conditions of other crops than onions show in some cases that the ranking of varieties is the same and sometimes can differ between both growing conditions depending on the evaluated trait, the included variety assortment and fertility level of the test locations (Chapter 6) (Murphy et al., 2007; Lorenzana & Bernardo, 2008; Vlachostergios & Roupakias, 2008). No relevant references were found on onion. Our trials, comparing the performance of onion varieties under organic and non-organic growing conditions, showed system effects for plant density, thickness of neck, and small bulb size proportions. Interaction effects for important traits such as bulb uniformity, earliness, proportion of large bulbs, dormancy and relative storage success were found. However, for most traits this did not lead to differences in ranking of the varieties. The trials showed a good correlation between the results under organic and non-organic conditions except for plant density and leafiness. A moderately significant correlation occurred for dead leaf tips and bulb uniformity.

A number of important traits showed interaction (earliness, bulb uniformity, proportion of bulbs > 70 mm, relative storage success and dormancy). From literature it is known that the number of plants emerging after sowing is strongly influenced by the (early) sowing date, sowing density, seed germination rate, management and weather conditions (Brewster, 1994). It is also known that herbicides can reduce crop establishment in onions and herbicide effects can differ per variety (Brewster, 1994; Hoek & Van den Broek, 2002). As the application of herbicides in the non-organic trials influences the plant density differently per variety it complicates the extrapolation from a non-organic trial with use of herbicide to the performance under organic conditions. In conventional onion variety trials differences in plant densities between varieties do occur regularly. In that case yield may be corrected for number of plants/m^2; however normalizing traits like bulb-size distribution and earliness is not possible in this way.

The criteria leaf erectness and susceptibility to downy mildew are important for organic growers and for these traits the conventional trials without disease control showed a good correlation with organic trials. If organic growers want to assess the differences in susceptibility to diseases such as downy mildew they have to urge for a ‘non-treated’ trial in regions with high natural disease pressure.

The high input conditions of non-organic trials gives a shift in bulb-size distribution to larger sizes compared to organic trials. Although organic growers want to avoid thick necks correlated with large bulb sizes as this affects the storability, they are even more concerned about the risk of too large proportions of unmarketable bulbs smaller than 40 mm. Although there was an interaction effect, it did not lead to different ranking of the varieties for this trait. The conclusion is that non-organically managed trials provide sufficient information to organic growers when leaf erectness and susceptibility to downy mildew and leaf blight are included.

3.4.3. **For which traits of importance for organic agriculture is the level of performance among the current varieties not high enough to contribute to yield stability and is there a need for variety improvement for organic agriculture?**

Our research showed that in a year with downy mildew infestation yields can be reduced dramatically. The organic sector is already very positive about the recent availability of downy mildew resistant varieties. However, this resistance is a monogenetic trait based on the only available resistance gene (Scholten et al., 2007). To reduce the risk of break down during too long exposure of downy mildew and to support the escape management, organic growers would benefit from the combination of earliness and resistance to downy mildew. Chapter 2 shows that some breeders pay attention to leaf erectness as they assume that such leaf attitude can show better drainage and might support field tolerance to leaf diseases. However, this supposed effect could not be confirmed by our trial results, nor by Van den Broek (2004; 2005). Nevertheless leaf erectness remains important for reasons to avoid damage during mechanical weeding. Our research shows that the highest yielding varieties are not very erect and early. From personal communication of onion breeding companies (F. Van de Crommert, 2010) we can expect at least progress on the combination of downy mildew resistance and earliness in the near future.

The trials also showed that onion was susceptible to drought stress and suffered severely from yield loss, especially in 2003. De Melo (2003) showed that there is genetic variability in root traits and that modern onion varieties have a more shallow rooting system than older varieties. Both conventional and organic onion production would benefit from varieties with an improved root system to overcome abiotic stress.

Although storability has reached a certain level through breeding, for organic growers this level is not high enough for long term storage.

Our conclusion is that for organic farming systems traits such as storability, dormancy, earliness in combination with resistance to downy mildew and leaf blight, erectness and improved root system or improved association with mycorrhizas (Galvan et al., 2011) would need to be improved by breeding. Such traits can in principle be added to a conventional breeding programme. It seems logic that soil related traits such as association with mycorrhizas or improved root system can better be selected in the target environment. However research is needed to give evidence for this suggestion.

3.5. Conclusions

Our research results lead to the overall conclusion that to obtain information on many important traits, organic growers would not need separate organically managed variety trials when conventionally fertilised trials would refrain not only from pesticide, fungicide and sprout inhibitor use, but also from herbicide use. However, this would require an adaptation of the management protocol in such a way that trials might no longer be representative for conventional farmers. In that case an additional low-external input trial or an organically managed trial would have to be added and this would increase costs, the main reason why there are no organic trials in the first place. Designing a non-organic trial without pest treatments and four replications, of which two are treated with herbicides and two are mechanically weeded, would be a possibility, but chances are too high that such a trial will be associated with a large interaction between variety effect and replication effect, thus reducing the statistical power of the trial. In addition to changes in the protocol for management, there is also a need to include leaf erectness and disease resistance to downy mildew and leaf blight in the testing protocol. We found differences between systems for important traits like plant earliness and bulb uniformity, but results might have been influenced by differences in plant density between systems. For the short term, the organic sector should be able to profit from a more conscious selection among existing or new varieties. In the long run, there is a need for more communication with breeders on specific variety characteristics such as storability, dormancy, earliness in combination with resistance to downy mildew and leaf blight, erectness and improved root system or association with mycorrhizas that can contribute to yield stability under low-input, organic growing conditions.

Spring wheat section

Chapter 4:

Adapting spring wheat breeding to the needs of the organic sector

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Submitted

Abstract

Organic farmers and food processors need plant varieties that are adapted to their crop husbandry and processing practices. Such varieties are scarce as the mainstream breeding sector focuses on developing varieties for the conventional product chain that has different goals and practices. In this paper we study the case of the Dutch bread production chain to assess options that might enhance the availability of varieties suitable for the organic sector. The research involves an analysis of organic crop management and food processing practices and associated variety requirements. The research shows that several variety traits prioritized by the organic sector are not adequately addressed by conventional plant breeders: high baking quality, weed suppressiveness and tolerance to harrowing. Some of the interviewed conventional breeders are willing to consider technical adjustments to their breeding programmes. However, seed legislation and company economics limit the space to implement such modifications. We conclude that developing spring wheat varieties for the organic bread production chain requires breeders to prioritize selection for high baking quality genotypes that tolerate an organic weed management regime. This would require a concerted initiative of all actors in the organic bread production chain that includes establishing new socio-economic partnerships to overcome current economic and legal barriers.

Keywords:

spring wheat; technology system, organic breeding; variety development; baking quality, the Netherlands

4.1. Introduction

Organic farmers need varieties that grow well without synthetic inputs and possess traits that complement organic crop management practices (Lammerts van Bueren et al., 2002; Wolfe et al., 2007; Lammerts van Bueren et al., 2011). In addition, such varieties have to provide products that are adapted to handling and processing conditions further down the organic production chain. European organic farmers encounter difficulties to find varieties that suit their needs, because most crop breeding efforts are oriented towards developing varieties for conventional cropping systems that use synthetic inputs to manage the crop growing environment. Varieties selected for the conventional market are not always the best suited for use in organic cropping, due to the differences in management practices between both production chains.

The purpose of this paper is to identify options to transform the breeding of varieties in such a way that breeders are able to address the needs of the organic sector. A plant variety of a certain crop can be considered as part of an agricultural technology. Technology and innovation systems literature teaches us that technology development is embedded in an institutional environment (e.g. legislation, financing system, values) that influences the final outcome of the technology development process (see e.g. Carlsson & Stankiewicz, 1991; Rip & Kemp, 1998; Berkhout, 2008). Thus varieties are developed within a specific technology system, the breeding system, that can be envisaged as a configuration of actors in its particular economic, institutional and physical crop growing environment (Figure 1.1, page 10). With the design of their breeding programme, breeders take into account the different components of the crop production system, such as the physical growing environment, crop husbandry and processing practices of the actors of the production chain they are selecting for. Furthermore, breeders´ decision making is influenced by the institutional environment (norms, legislation, financing system, etc.). Hence transforming the breeding system in such a way that it is able to address new needs, is not just a matter of prioritizing other plant traits or adjusting the selection environment, but also involves dealing with (different) institutional constraints (see e.g. McGuire, 2008). Correspondingly, assessing options to adapt conventional breeding to the needs of the organic sector, requires a study on these changes in the context of the broader system. In this paper we apply such a systems approach to the case of spring wheat in the Netherlands.

The case of spring wheat breeding for the Dutch organic bread production chain was chosen for this study, because actors of this chain are actively searching for new varieties. Currently, Dutch organic farmers rely on a single spring wheat variety, released more than 15 years ago. Although farmers appreciate this variety, they consider reliance on just one, relatively old variety as risky. They fear that sooner or later the genetic disease resistance in this variety will break down. However, screening and testing efforts for more than a decade have shown that modern conventional varieties do not have satisfactory baking quality when grown under low-input, organic conditions. This inability to find suitable varieties through the existing breeding system prompted the authors to study the reasons for this failure and possibilities to revert this situation. More specifically we explored:

- how and why required variety traits and priorities differ between organic and conventional bread production chains;
- breeders´ selection practices and choices and how these are influenced by the different components of the breeding system (Figure 1.1, page 10);
- options to improve spring wheat for the organic sector through conventional breeding programmes.

The paper first describes the general characteristics of the organic bread production chain and its actors. Thereafter we analyse the management of spring wheat under organic growing conditions and the organic bread making process in more detail to analyse the interaction between these two parts of the chain and to assess how variety requirements for the organic chain differ from those for the conventional chain. In addition, we explore to what extent current spring wheat breeding aims enable meeting the variety demands of the organic sector. Next to possibilities to directly or indirectly select for the desired characteristics, we discuss the factors that are essential to produce an environment conducive for creating more effective spring wheat breeding programmes that can supply such varieties for organic agriculture.

4.2. Research approach and methods

Information on the characteristics of the organic bread production chain were collected in the course of several projects on spring wheat variety testing and breeding with involvement of breeders, farmers, traders, millers and bakers conducted by the first author from 1999 to 2010. Data from an earlier study (Osman & Lammerts van Bueren, 2003) were used to compile criteria set by farmers, traders and millers from the organic sector and to develop a user-defined profile of organic spring wheat variety (Table 4.1).

We approached the five most important North-Western European spring wheat breeders for interviews on breeding approach, selection criteria and priorities. Four breeders agreed to participate in the study: three German and one Dutch breeder. Interviews were held both in the breeding nursery as well as in the office, and telephone communication was used for follow-up questions. Prior to the interviews, the companies' seed catalogues and websites were studied. This allowed to cross-check the consistency of the breeders' information on variety traits and selection criteria. From these discussions we composed a list of variety traits considered important by organic farmers or listed as essential by one or more of the breeders (Table 4.2). The four breeders then received the compiled list to score the criteria for importance (0 = not considered, 1 = lowest priority, 5 = highest priority). Breeders were also asked how they would change their selection if they would be developing varieties for the organic spring wheat production.

Table 4.1. Variety profile of a Dutch organic spring wheat variety. The variety *Lavett* which is appreciated and widely grown by organic farmers was taken as point of reference (adapted from Osman & Lammerts van Bueren, 2003).

Traits	Preferred phenotype	Priority
Supporting weed management		
Tolerance to harrowing	Firmly rooted and able to recover rapidly from burial	+
Tillering capacity	Able to compensate for a poor stand with extra tillers	++
Vigorous early growth	Able to emerge and cover soil rapidly	++
Canopy density	Dense	++
Plant length (also to reduce ear diseases)	± 100 cm (= standard variety *Lavett*)	+
Reducing risk of diseases		
Plant length (also because of weed suppression)	± 100 cm (= standard variety *Lavett*)	+
Peduncle length	± 20 cm	++
Ear density	Lax	+
Resistance against:		
Yellow rust (*Puccinia striiformis*)	Resistant	++
Brown rust (*Puccinia triticina*)	Resistant	++
Septoria tritici blotch (*Mycosphaerella graminicola*)	Resistant	++
Fusarium head blight (*Fusarium spp.*)	Resistant	++
Powdery mildew (*Blumeria graminis*)	Resistant	+
Reducing risks at harvest		
Lodging resistance	Resistant	++
Ripening	Early (harvestable first week of August)	++
Pre-harvest sprouting	Resistant	++
Productivity		
Manure use efficiency	Ability to achieve desired production and quality with as low manuring level as possible	++
Stay-green of leaves	Upper leaves healthy as long as possible	++
Grain yield	Like the variety *Lavett* (± 6 tonnes/ha)	++
Milling and Baking quality		
Specific weight	≥ 76 kg/hl	++
Hagberg falling number	≥ 260 s	++
Protein content	≥ 11.5 %	++
Zeleny sedimentation value	≥ 35 ml	++
Marketable loaf of wholemeal bread	Loaf volume like variety *Lavett*	++

Table 4.2. Breeders' selection criteria and priorities.

Traits	Priority[1] for conventional market				Change in priority if breeder would also select for organic[2,3]			
	Breeder							
	A	B	C	D	A	B	C	D
Supporting weed management								
Tolerance to harrowing	0	0	0	0	0	>	0	>
Tillering capacity	0	0	0	3	0	>	>	>
Vigorous early growth	0	0	2	4	0	>	>	0
Canopy density at flowering	0	0	0	0	0	>	>	>
Plant length	2	4	4	4	=	<	<	0
Reducing risks of diseases								
Peduncle length	0	2	0	0	0	>	>	0
Ear density	0	3	0	0	0	=	0	0
Resistance against								
Eyespot (*Oculimacula spp* .)	0	1	1	0	0	=	<	0
Take-all (*Gaeumannomyces graminis*)	0	1	0	0	0	=	0	0
Yellow rust *(Puccinia striiformis)*	4	2	4	4	=	>	<	0
Brown rust *(Puccinia triticina)*	5	4	4	5	=	=	<	=
Septoria tritici blotch (*Mycosphaerella graminicola)*	3	4	3	5	=	=	<	=
Stagnospora nodorum blotch (*Phaeosphaeria nodorum*)	1	1	2	0	=	=	=	0
Tan spot (*Pyrenophora tritici-repentis)*	1	2	3	4	=	=	0	0
Fusarium head blight (*Fusarium* spp.)	5	4	4	5	=	=	<	0
Powdery mildew (*Blumeria graminis*)	5	2	3	4	=	>	<	>
Common Bunt (*Tilletia tritici*)	0	0	0	0	0	>	>	>
Loose smut (*Ustilago tritici*)	0	0	0	0	0	>	>	>
Reducing risks at harvest								
Early ripening	3	4	2	4	=	=	0	0
Lodging resistance	4	4	4	5	=	=	<	0
Productivity								
Nitrogen use efficiency	0	0	0	3	>	>	>	>
plant density	0	0	0	3	0	0	>	0
# kernels/ear and ears/plant	2	0	0	0	=	0	0	0
Early flowering	4	4	4	4	=	=	<	0
Stay-green of leaves	0	2	3	3	0	=	<	0
Duration of grain filling period	0	1	0	4	0	=	>	0
1000 kernel weight	3	3	3	3	=	=	=	0
Grain yield	5	5	5	5	=	=	<	0
Milling and Baking quality								
Specific weight	3	4	2	0	0	=	=	0
Flour yield	0	0	2	0	0	0	=	0
Grain hardness	0	0	0	5	0	0	0	0
Hagberg falling number	3	2	4	5	=	=	=	0
Protein content	4	3	4	4	>	>	>	0
Zeleny sedimentation value	4	4	4	5	>	=	=	0
Wet gluten content	4	0	0	0	>		>	>
Gluten index	0	0	0	0	0		>	0
HMW-glutenin subunit composition	0	4	3	0	0		=	0
Stickiness of dough	0	0	2	0	0	0	>	0
Water absorption	0	2	2	0	0	=	>	0
Dough rheological properties	4	4	2	0	>	=	>	>
Loaf Volume in baking test	0	0	3	4	0	0	>	0

[1] Scale 0 − 5, with 5 = highest priority and 0 = not a selection trait

[2] one of the breeders was running a separate selection programme for organic production.

[3] >, priority increases; =, priority stays the same; <, priority decreases; 0 = not a selection trait.

4.3. Particularities of Dutch organic wheat production and processing

4.3.1. Preference for spring wheat over winter wheat

Cereals play important roles in an organic crop rotation, namely restoring soil quality and balancing labour demand. For these reasons farmers maintain cereals in their rotation, despite a relatively low economic return. Bread wheat is the most profitable cereal because Dutch organic traders pay a premium for baking quality. As spring wheat usually produces a better baking quality grain than winter wheat, organic farmers producing for the milling industry prefer to sow spring wheat (Table 4.3).

In conventional farming, spring wheat is only a small crop. In the Netherlands about 15% of the conventional wheat acreage consists of spring wheat (CBS, 2013). Conventional farmers mainly grow high-yielding winter wheat for the feed industry. They aim at maximizing grain yield, because the conventional baking industry pays a lower premium than its organic counterpart.

Spring wheat offers two more advantages over winter wheat in organic farming systems in regions with a temperate humid climate like The Netherlands. Firstly, weed control – a major problem in organic cropping systems – is more effective in a spring wheat crop. In late winter and early spring the fields are often too wet to enter with heavy equipment. The weeds developing in that period can, however, still easily be eradicated mechanically shortly before sowing the spring wheat crop in March. Secondly, spring wheat based cropping systems allow for a catch crop in winter that more effectively reduces nitrogen leaching during wet winters than winter wheat does (Thorup-Kristensen et al., 2009).

4.3.2. Bread production chain actors

The Dutch conventional bread market is dominated by supermarkets and their suppliers: large scale bakeries who obtain their flour from industrial mills (Table 4.3). Organic branches of actors in the conventional bread production chain also produce the organic bread for the supermarkets. However, only 30% of organic bread is sold through the supermarket channel (LEI Wageningen UR, 2012). Most organic consumers buy their bread in specialised organic shops. This bread is prepared by specialised organic bakers. Part of the specialised organic bakeries prefer wholemeal from traditional mills with millstones over roller milled wholemeal produced by a flour plant. They argue that stone milled flour has a better flavour and higher nutritional value because it contains all the original parts of the grain kernel. In contrast, wholemeal from a roller mill is product of a reconstitution process, in which the nutritious germ and outer layer fractions are usually left out, because these shorten flour shelf life and may reduce baking quality.

Specialised organic bakeries and traditional millers prefer to purchase domestic organic wheat because of its traceability and reduction of "food miles". Other millers also import organic wheat from warmer and drier climates that has a better price-quality relation.

Table 4.3. Key features of Dutch organic and conventional wheat production and bread distribution.

	Conventional	Organic	Source[1]
Acreage in hectares and % per crop type (average between 2009 – 2012)			
Winter wheat	128360 (84.4%)	687 (35.4%)	c: CBS (2014)
Spring wheat	23675 (15.6%)	1252 (64.6%)	o: CBS (not published)
Spring wheat production			
Nitrogen application (recommended rate in kg/ha)	150	100	c: Timmer et al. (2009) o: Sukkel et al. (2004)
Spring wheat yield (tonnes/ha)	7.1	5.3	c: CBS (2014) o: CBS (not published)
Bread distribution: market share /channel (2010 – 2011)			
Supermarkets	65.0%	30.2%	c: HBD (2012)
Bakeries	28.5%		o: LEI Wageningen UR
Specialised organic shops		45.7%	(2012)
Out of home		20.1%	

[1] c = conventional; o = organic

4.4. Influence of crop husbandry on required variety characteristics

Organic crop husbandry principles aim at sustaining health of the whole ecosystem, including soils, plants and people (IFOAM, 2005). According to organic thinking fostering biodiversity, ecological processes and cycles enhances and sustains system health. On the other hand synthetic inputs are rejected, because these compromise system health. Major differences between organic and conventional crop husbandry practices involve the use of untreated seeds, management of weeds, diseases and soil fertility (Table 4.1). Below we elaborate on the consequences for variety requirements.

4.4.1. **Seed quality**

In the Netherlands, seed quality of organic spring wheat is mainly compromised by Fusarium head blight (Osman et al., 2004). Farmers and the main organic cereal trader, who also is the main multiplier of organic wheat seeds, prefer resistant varieties. Non-chemical seed treatments with warm water or steam, that are allowed under organic regulation, are effective against Fusarium. However, these treatments increase seed costs and are therefore only applied in years with severe infestations of the seed crops. In conventional agricultural, impaired seed quality due to diseases is not considered a problem because seeds are commonly treated with a fungicide. Breeders do select for Fusarium head blight resistance, though, because this disease also reduces yield and product quality (see below).

In literature, resistance against seed-borne diseases, like common bunt (*Tilletia tritici*), is commonly mentioned as breeding priority for organic winter wheat (Löschenberger et al., 2008; Lammerts van Bueren et al., 2011). However, Dutch organic farmers do not experience problems with common bunt. This is probably due to the fact that spring wheat is less affected by common bunt than winter wheat. In addition, farmers also reduce the risk of building up seed-borne diseases by frequently refreshing their wheat seed stock with purchased certified seeds.

4.4.2. **Weed management**

Most farmers consider successful weed management the major challenge of organic crop production. Variety choice is an important component of organic weed management that should complement other practices such as adjusting the sequence of crops in the rotation, growing cover crops during the winter fallow and mechanical weeding (Barberi, 2002).

Table 4.1 shows that organic farmers value traits that contribute to weed suppression, such as vigorous early growth, tillering capacity, canopy density and plant length. In addition to the traits mentioned by farmers, in literature also leaf angle has been associated with weed suppressiveness (Eisele & Köpke, 1997; Drews et al., 2009; Hoad et al., 2012). Important for Dutch organic farmers as well are varieties that tolerate intensive harrowing (Table 4.1).

In conventional farming weeds are controlled with synthetic herbicides. Therefore, wheat breeders do not consider the above mentioned weed suppressing traits and tolerance to harrowing in their selection programme. Moreover, part of the interviewed breeders strongly selected for a shorter plant length than the length preferred by organic farmers, because they associate shorter stems with a higher harvest index which leads to a higher grain yield. Furthermore, these breeders assume that shorter plants are more resistant to lodging.

4.4.3. **Disease management**

Organic farmers generally do not consider diseases as an important constraint in wheat production. This is in line with the first author's observations that in organic conditions spring wheat diseases appear later in the season than in conventionally managed crops. This can be partly explained by the high level of resistance in modern varieties whereby the disease pressure remains usually low throughout the season. In addition, lower amounts of nitrogen fertilizer than in conventional fields and the absence of growth regulators in organic fields have also been associated with a reduced severity of powdery mildew (*Blumeria graminis*), brown rust (*Puccinia triticina*), Septoria tritici blotch (*Mycosphaerella graminicola*) and Fusarium head blight (*Fusarium spp*.) (Van Bruggen, 1995; Walters & Bingham, 2007; Van der Burgt et al., 2011; Gosme et al., 2012).

Nevertheless there are occasionally disease outbreaks in organic fields and in such an event organic farmers are left with limited management options. Their most effective strategy is to grow resistant varieties (Vereijken, 1989). Dutch organic farmers prioritized resistance to yellow rust (*Puccinia striiformis*), brown rust and Fusarium head blight, followed by powdery mildew and Septoria tritici blotch (Table 4.1). Conventional farmers are also interested in resistant varieties, but only when these allow them to replace or considerably reduce fungicide treatments. This means that most conventional farmers only grow resistant varieties when these carry high levels resistances against all diseases that they normally treat with fungicides at the same spraying moment (Vanloqueren & Baret, 2008). Organic farmers favour a high level of resistance, but in the absence of such a possibility partial resistance will also improve their results. Furthermore, due to the risk of a breakdown of a resistance gene, they are also interested in morphological plant traits that hamper the establishment and spread of diseases, such as taller plant types with more open ears that extend high above the canopy. The drier micro-climate around the ears of such plant types is unfavourable for most fungal diseases, while the larger distance between leaves and ear retards vertical disease spread (Arraiano et al., 2009; Yan et al., 2011).

All four breeders give high priority to resistance for brown rust and Fusarium head blight despite the availability of fungicides (Table 4.2). Yellow rust is prioritized by three of the four breeders. Only one of the four interviewed breeders considers morphological plant traits in his strategy to improve disease resistance. He selects for taller plants to prevent ear diseases. The other plant morphological traits mentioned by farmers are not considered by breeders or receive low priority.

4.4.4. **Soil fertility management**

In organic cropping systems nitrogen is usually limiting productivity (Berry et al., 2002) and baking quality. Organic farmers' nitrogen application is 33% less (50 kg/ha) than the recommended rate for conventional spring wheat production (Table 4.3). Furthermore, as mineralisation of organically bound nitrogen depends on temperature and water availability, nitrogen availability is not evenly distributed over the season. Nitrogen scarcity during flowering, which may be a problem in organic systems (Van Delden, 2001; Baresel et al., 2008), reduces grain protein content and baking quality. Conventional farmers improve baking quality of moderate baking quality varieties by increasing grain protein content through additional (late) nitrogen applications. Similarly, traders advice organic farmers since 2005 to increase the amount and improve timing of nitrogen application, i.e. apply organic amendments with highly soluble nitrogen at tillering and flowering. However, such amendments are scarce and costly within organic cropping systems. Farmers who follow the traders´ advice usually apply waste products (e.g. molasses, feather meal) from conventional agriculture. The importation of products from outside the organic system conflicts with organic principles and consumer expectations. Therefore the Dutch organic certification scheme foresees in a gradual reduction of the use of nitrogen sources from the conventional sector and a total ban from 2020 onwards (Maan, 2009). The tightening of the rules on nitrogen provenance will further reduce availability of this nutrient and thus increase the need for varieties that produce high baking quality, under an organic - low nitrogen input - fertility management regime.

Breeders select in nurseries that are fertilised with synthetic fertiliser, but the amount of applied nitrogen is moderate compared with conventional farmers´ practices and more similar to the amount applied by organic farmers. Due to the difference in nature of the fertilizer (synthetic vs. organic) distribution of nitrogen availability over time differs. Conventional spring wheat breeders have proven to be able to select varieties that are both high yielding under Dutch conventional and organic conditions (Chapter 6). However, conventional breeding nurseries are not the best environment to select for varieties that produce high baking quality in organic fields. The expression of baking quality interacts with growing environment and therefore selecting for high baking quality would require low-nitrogen conditions (Chapter 5). In addition, breeders should also raise the desired quality level they select for. Interviewed breeders do not select for the high quality level required by organic farmers anymore, as quality is negatively correlated with yield (see next section).

4.5. Influence of processing practices on baking quality and required variety characteristics

Most of organic baking quality wheat is used to produce wholemeal bread. To satisfy the needs of organic bakers, wheat varieties should provide flour that is suitable for baking voluminous loaves of wholemeal bread. Bakers value loaf volume because they have the experience that this trait goes together with positive bread properties such as an improved bread crumb structure. In addition, they claim that their consumers demand a high loaf volume. Traditional organic consumers may prefer more firm, solid breads, but according to specialised organic bakers, nowadays the majority of organic consumers tend to prefer more voluminous softer loaves, but not as fluffy as the ones preferred by supermarkets. The latter want organic breads to be similar in appearance to conventional breads. Besides a high loaf volume, organic bakers appreciate a high water absorption capacity of the flour, because this delays drying-out of the bread.

In contrast to their colleagues from mainstream bakeries, specialised organic bakers prefer restraining the use of food additives and processing aids. The mainstream baking industry boosts baking quality of flour by adding bread improvers like ascorbic acid, gluten powder, enzymes, etc. Although organic variants of these products are available, most specialised organic bakers want to limit the use of these additives and processing aids whenever possible. This restraint to improve baking quality of the flour artificially is in the first place driven by their organic principles. Secondly, according to bakers, they also want to restrict the use of gluten and enzymes because these negatively influence the sensory qualities of the bread. Finally, organically certified additives, like gluten powder, are relatively expensive. Therefore, economic considerations also play a role in the desire to restrict the use of bread improvers. As a consequence, the organic baking industry looks for varieties that produce high quality flour that requires as little manipulation to improve quality as possible. This implies that the required quality level for the organic sector is higher than the quality level that satisfies the needs of their conventional counterparts. The quality level is even more important for those bakers that use stone milled wholemeal instead of wholemeal from a roller mill, as the latter process usually grinds the kernels in finer particles which positively affects loaf volume.

As baking trials to assess true baking quality are time consuming and expensive, the milling industry also uses indirect baking quality parameters that can be assessed through relatively fast and cheap tests: protein content, Zeleny-sedimentation value (a measure for protein quality), Hagberg falling number (a measure for seed dormancy) and specific weight. These indirect baking quality parameters are however only crude proxies for bread quality aspects like flour yield and loaf volume. Therefore millers only use these parameters to make a pre-selection, but eventually purchase a grain lot after satisfactory results in a real baking test. Like bakers, also millers consider loaf volume the most important evaluation criterion in the baking test. For farmers the indirect baking quality parameters are important traits when considering variety choice. Traders only pay farmers a premium price when their harvested grain reaches at least the minimum levels for the four indirect baking quality parameters (Table 4.1) and the premium increases with the values of these parameters.

The above mentioned baking quality traits are also important for conventional bakers and thus also considered by breeders in their selection programmes. The interviewed German breeders claimed that for spring wheat they aim at only releasing varieties that fit the two highest classes of baking quality of the German variety list. In their country, spring wheat is mainly grown for the baking industry, whereas winter wheat is mainly grown for animal feed. Their breeding goals thus follow the criteria of the German variety list, namely: protein content, sedimentation value, Hagberg falling number, flour yield, loaf volume, water absorption, elasticity and stickiness of dough (Steinberger, 1995; Zeller et al., 2007). Breeders make different choices in the way they evaluate baking quality (Table 4.2), because they have only small amounts of grain early in the breeding process and costs of bread baking test are relatively high. Breeder C is the only breeder who conducts baking tests in the F8 generation (the 8th cycle of selection after crossing), prior to submission to the official Value for Cultivation and Use

(VCU) testing. The other breeders rely on the baking trials that are carried out by the variety testing authority. The baking test used by Breeder C and variety testing authorities is the so-called Rapid Mix Test (AGF, 2007), which evaluates loaves of white bread baked from flour, produced with a laboratory mill, with added ascorbic acid. However, detecting the best varieties to produce wholemeal bread would require a baking test with wholemeal instead of flour (Doblado-Maldonado et al., 2012). Variety performance and ranking for loaf volume and sensory quality, among others, has proven to be effected by flour type (e.g. white versus wholemeal), baking process and baking recipe (Magnus et al., 1997; Kihlberg et al., 2004; Gélinas & MacKinnon, 2011, Steinfurth et al., 2012). Therefore tests used by the organic millers always involve wholemeal and most prefer not to use any bread improvers.

Selection for baking quality is further complicated by the fact that the main baking quality parameters (e.g. protein content, dough strength, loaf volume) are directly or indirectly correlated with grain nitrogen content, which in turn is negatively correlated with yield (Chapter 5). Conventional farmers look for higher yielding varieties. Therefore breeders aim at increasing yield while maintaining the level of baking quality traits similar to their standard variety. In addition, all four breeders only make crosses between a high baking quality parent and a high yielding variety; crosses between two high baking quality parents would compromise too much on the yield.

4.6. Influence of the institutional environment on breeding

4.6.1. **Regulatory environment: variety registration procedure**

At the end of the breeding process, breeders need to submit candidate varieties for official registration. In the European Union (EU), variety tests, so called Value for Cultivation and Use (VCU) tests, are part of this procedure. These tests favour the selection of certain types of varieties through the choice of testing environment and evaluation criteria (Louwaars, 2007). Although procedures and criteria differ between EU countries, usually candidate varieties have to reach a minimum yield level to pass. The German VCU procedure includes extensive evaluation of baking quality. In contrast, in the Netherlands, since 2006 baking quality tests are no longer part of conventional spring wheat VCU.

Failing VCU test prevents market release and thus meeting the criteria of the testing authorities has also become a breeding goal (Wiskerke, 1997; Wiskerke

2003). Indeed, one of the interviewed breeders explained that he had changed his spring wheat breeding approach for the conventional market, because he experienced difficulties to reach the yield level required to pass the first year of the German VCU. This minimum yield level is gradually increasing, because it is related to the average yield level of a set of popular varieties that is regularly updated. Recent releases of one of his competitors had raised the minimum required yield to a level that he was no longer able to match. To increase his chance of selecting varieties with higher grain yields, he therefore adapted his selection strategy in the opposite direction of what would be required for the organic sector: he lowered his standard for baking quality level and started to select shorter plant types.

4.6.2. **Economic environment**

The disappearance and mergers of seed companies show that European cereal breeders operate in a highly competitive environment and many struggle for survival. In the Netherlands, this concentration process reduced the number of wheat breeding programmes from five to only two during the last 15 years. Only one of these two remaining Dutch wheat breeding companies develops spring wheat varieties. For Dutch spring wheat farmers this means that they have become more dependent on results of breeding programmes in neighbouring countries, that were not specifically developed for their conditions. On the other hand, historical accounts of Dutch wheat farmers´ variety choice suggest that varieties of foreign breeding programmes are often well adapted to Dutch growing conditions (De Haan, 1957; Zeven, 1990).

Wheat breeding is only economically sustainable when breeders sell sufficient amounts of seeds of their registered varieties, because their investments are financed through a small levy on the seed price. A company needs a market of at least 50,000 ha to be able to maintain a cereal breeding programme. As it only occupies a small portion of the acreage of conventionally managed wheat (Table 4.3), breeders consider spring wheat a marginal crop. German wheat breeders estimate that they spend 10% of their efforts on spring wheat and 90% on winter wheat. To reduce costs, the interviewed breeders limit the number of varieties they bring on the market and aim at developing wheat varieties that grow well in several countries in North Western Europe. So, private sector breeders only select for markets of a substantial size and cannot serve small (organic) sectors and diversity in end-uses with specialty varieties.

4.7. Discussion and conclusion: perspectives to improve organic spring wheat

The distinct approach to crop production and food processing of the organic sector leads to the following variety requirements that are not adequately covered in conventional wheat breeding programmes:

- Enhanced weed suppressiveness through traits like vigorous early growth, dense crop canopy and plant length;
- Capacity to recover from harrowing;
- Morphological traits that make the crop environment less conducive to the development of diseases like peduncle length, plant length, less compact ear;
- High baking quality level to allow the production of wholemeal bread with restricted use of bread improvers.

The variety profile, that describes the set of traits prioritized by actors of the Dutch organic bread production chain, is shaped by both organic values as well as economic motives. The need for taller plants and higher baking quality is the consequence of rejecting synthetic inputs like herbicides, fungicides and fertilizers in crop production and bread improvers during processing. Organic farmers, millers and bakers reject the use of synthetic inputs as these are thought to compromise health of the ecosystem. Both organic farmers and millers have alternative options to increase baking quality (e.g. applying organic amendments with highly soluble nitrogen at flowering, adding organic gluten powder to the recipe), but these alternatives conflict with other organic values (closing cycles in the case of fertilizers and providing authentic and tasty food in the case of food additives) and increase production costs. The lack of satisfactory and cost effective organic crop management and processing options, increases the importance of variety choice and breeding for the organic sector.

Part of the specific organic variety requirements, mentioned above, could be addressed by conventional breeders without the need to introduce major modifications to their on-going breeding procedures. However, breeding for higher baking quality and longer plants conflicts with conventional breeding goals, namely high yield and resistance to lodging. These conflicting goals explain why conventional breeders are currently not able to provide spring wheat varieties that match the organic variety profile.

Most conventional breeders followed our research activities with interest and were open to participate by e.g. providing breeding material for testing under organic conditions. Results of these tests increased their awareness of the necessary modifications to their breeding programme to attend the needs of the organic sector. Although part of the conventional breeders proved to be receptive to consider modifications in their programme, their room to implement such modifications is restricted by the regulatory and economic environment. The regulatory framework in the form of the variety registration procedures function as a selection mechanism that also steers the direction of variety development towards a variety profile for conventional production systems, i.e. varieties with high yields and, consequently, with lower baking quality. Variety testing authorities in various EU countries have recognized that regular VCU procedures prevent the release of variety types required by the organic sector and have started to adopt specific organic VCU procedures that include testing under organic growing conditions and evaluation for traits prioritized by the organic sector (Löschenberger et al., 2008; Rey et al., 2008). However, breeders consider costs of these mandatory procedures too high to submit specific varieties for relatively small market segments like the organic sector. Facilitating the release of specific varieties for the organic, would therefore also require lowering costs of mandatory variety release procedures (Chapter 7).

Breeders are steered in their decisions and selections by company economics. The disappearance and mergers of companies show that cereal breeders operate in a highly competitive environment and many struggle for survival. Wheat breeding is only economically sustainable when breeders sell sufficient amounts of seeds of their registered varieties, because their investments are financed through a small levy on the seed price. Therefore private sector breeders only select for markets of a substantial size and cannot serve small (organic) sectors and diversity in end-uses with specialty varieties.

To address the economic issue, winter wheat breeders have developed combined conventional and organic breeding programmes (Birschitzky, 2007; Löschenberger et al., 2008; Baenziger et al., 2011). In such mixed programmes the first generations of breeding usually overlap, while in the final years the programme is split-up into an organic and conventional part. Programmes should be split up as soon as selection pressure for one market leads to a considerable reduction of desired genotypes for the other market. In the specific case of spring wheat, programmes should be split up from the fourth (F4) generation onwards when breeders start to select strongly for shorter plant types. In the case of spring wheat, breeders also should pay specific attention to improving baking quality to the required level. This implies conducting baking trials as early as possible, i.e. as soon as seeds are available in sufficient quantities. For such baking trials, breeding material should be grown under organic or low-input growing conditions, because growing environment influences variety ranking (Chapter 5). For the same reason baking trials should mimic conditions of the organic millers and bakers (see above). At present experience lacks to judge whether this would be sufficient or that improving baking quality also require specific crosses between high baking quality parents.

The above mentioned mixed breeding programmes, have the potential to deliver spring wheat varieties that meet minimum bio-physical conditions and baking quality at a lower cost than a completely separate organic breeding programme. However, only reducing breeding costs will not be sufficient to enhance the variety assortment for the organic sector. In addition, another socio-economic relationship needs to be developed between the different players in the bread production chain, given that breeding investments need to be recovered from the selling of relative small volumes of seed. There are various examples of initiatives that have been successful in breaking away from the prevailing regime and made food chain technology and organization more sustainable (Klerkx et al., 2010; Roep & Wiskerke, 2012). In these cases, agreement and concerted action of farmers, processors, technology developers (researchers) and consumers played an important role. Exploring such un-orthodox social relations around variety development seem highly relevant for the organic sector as well (Osman et al., 2007b).

Chapter 5:

Perspectives to breed for improved baking quality wheat varieties adapted to organic growing conditions

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Abstract

North-Western European consumers like their bread to be voluminous and easy to chew. These attributes require a raw material which is rich in protein with – among other characteristics – a suitable ratio between gliadins and glutenins. Achieving that is a challenge for organic growers, because they lack cultivars that can realize high protein concentrations under the relatively low and variable availability of nitrogen during the grain filling phase common in organic farming. Relatively low protein content in wheat grains thus needs to be compensated by a high proportion of high-quality protein. Organic farming therefore needs cultivars with genes encoding for optimal levels of glutenins, gliadins and a maximum ability for nitrogen uptake, a large storage capacity of nitrogen in the biomass, an adequate balance between vegetative and reproductive growth, a high nitrogen translocation efficiency for the vegetative parts into the grains during grain filling and an efficient conversion of nitrogen into high quality proteins. In this perspective paper we discuss the options to breed and grow such varieties.

Keywords:

baking quality; bread; low input; organic farming; proteins; quality; *Triticum aestivum*; wheat

5.1. Introduction

Most North-Western European consumers, including the ones preferring organic food, like their daily bread to be voluminous and easy to chew. Loaf volume is mainly determined by total protein content and the composition of the protein fraction (Finney & Barmore, 1948; Weegels et al., 1996; Wrigley et al., 2006). Good dough for making the desired soft bread with a large loaf volume should have a balance between extensibility and elasticity: in order to gain volume during the rising process, enabled by the gas production from the yeast, the dough should be able to extend without rupturing. Dough that is too strong will not be extensible, while too weakly extensible dough will lose shape. Although the relation between protein composition and dough properties is complex and not yet fully understood, it is generally accepted that a protein fraction called gliadins confers extensibility and that the protein fraction of glutenins is responsible for elasticity (see Box 5.1) (Khatkar & Schofield, 1997; Wrigley et al., 2006).

Box 5.1. Wheat proteins and their relevance for baking quality.

Dough and baking quality is determined by the gluten fraction. This gluten fraction consists of glutenins and gliadins. From the plant point of view, glutenins and gliadins are considered storage proteins.

Glutenins form polymeric polypeptides that are joined by di-sulphide bonds. Based on size, glutenins are further subdivided into Low Molecular Weight Glutenins (LMWGs) and High Molecular Weight Glutenins (HMWGs). The fraction of HMWGs can be further subdivided into fractions of different sizes. The size distribution of the glutenin fraction plays an important role in baking quality: dough strength and loaf volume increase with an increasing ratio of HMWGs over LMWGs and larger proportions of non-extractable protein (Gupta et al., 1992; Weegels et al., 1996; Wrigley et al., 2006).

Gliadins have smaller molecular weights than HMWGs, but weights overlap with LMWGs. Gliadins are found as monomeric polypeptides in flour extracts. Based on mobility on an acid-polyacramidegel (A-PAGE) gliadins are further subdivided into sulphur-rich α-, β- and γ-gliadins and sulphur-poor ω-gliadins. The latter have been related to a reduced loaf volume (Van Lonkhuijsen et al., 1992; Uthayakumaran, 2001; Branlard & Metakovski, 2006). However, the effect of individual gliadins on baking quality properties remains a matter of debate, because separating individual gliadin groups from wheat gluten is difficult and the diversity within individual groups is enormous (Metakovski et al., 2006).

In addition to the gluten proteins, wheat protein consists of two other classes of structural proteins: albumins and globulins. However, these two classes are not believed to influence baking properties.

An optimal balance between extensibility and elasticity requires an optimal balance between the different protein fractions. Such a balance is known to be influenced by genotype (G), environment (E), management (M) and G × E × M interactions, both in a direct way and in an indirect way (Figure 5.1). Environmental factors that play an important role are temperature and water availability during flowering and grain filling. Grain protein content increases with drought and with increases in temperature as well as in soil nitrogen availability (Altenbach et al., 2003; Gooding et al., 2003; Dupont et al., 2006; Triboï et al., 2006). Management factors affecting baking quality include plant density and (mainly) nitrogen husbandry.

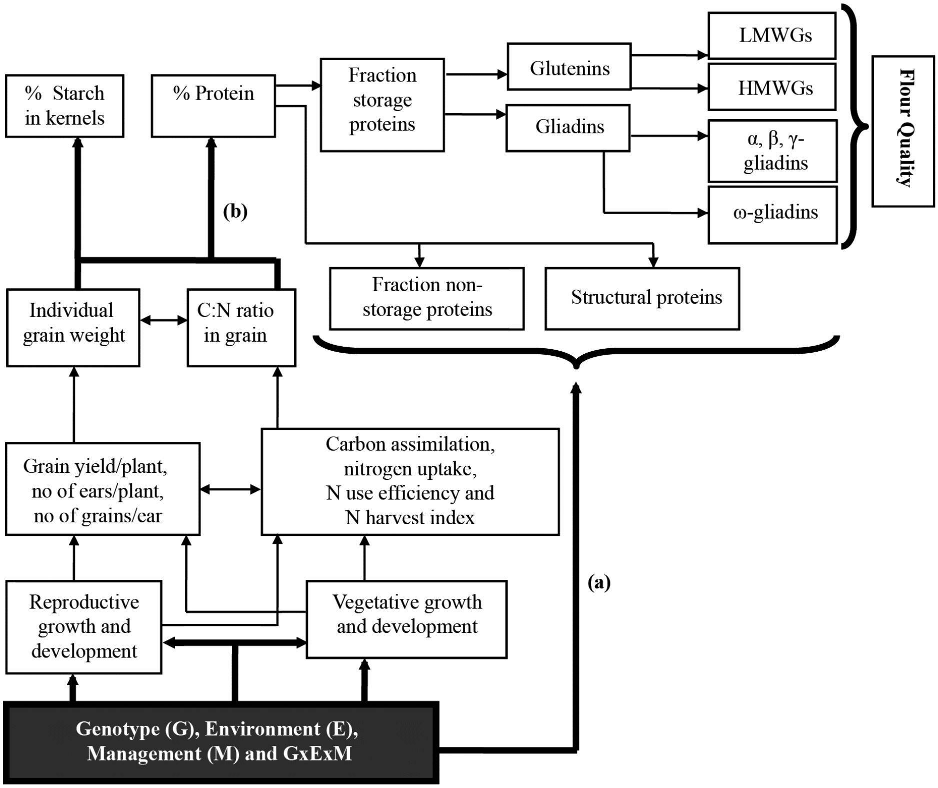

Figure 5.1. The influence of genotype, environment, management and their interaction on flour quality through two different pathways: a. direct pathway mainly involving the biochemistry of protein production and b. the indirect influence via growth and development as affected by agronomic factors, processes and feedback mechanisms.

Protein content of North-Western European organic wheat is 10-25% lower and organic fields yield 20-50% less compared to a conventional crop because of lower inputs of nitrogen fertilisation and irregular availability of nitrogen due to factors influencing mineralisation in the soil (Chapter 6) (Hanell et al., 2004; L-Baeckström et al., 2004; Hildermann et al., 2009; Jones et al., 2010). The reduced protein content results in lower water absorption capacity, less extensible and more tenacious dough and lower loaf volumes when wheat of organic origin (Haglund et al., 1998; Műnzing et al., 2004; Carcea et al., 2006; Steinberger et al., 2007) is compared with conventional wheat. Lower protein content in samples of winter wheat variety Hereward of British organic farms also decreased gliadin/glutenin ratio, compared to samples of the same variety from conventional farms (Godfrey et al., 2010). This change in protein composition, may also explain the change in dough properties observed in the other studies.

Organic management options to enhance nitrogen availability include incorporating legumes and nutrient catch crops in the rotation and choice and timing of organic fertilizers (see Dawson et al., 2008, for a review). However, increasing nitrogen availability to levels that are common in North-Western European conventional wheat production by crop management practices alone is costly. Therefore organic growers rely on complementing nitrogen management with variety choice.

Most current North-Western European wheat varieties were bred for use in conventional farming conditions (thus with availability of large quantities of inputs of crop protectants and inorganic fertilizers) and do not reach the baking quality level required by the organic baking industry when grown under organic conditions. The selection of varieties that combine high yield and baking quality in organic and low nitrogen input cropping systems requires a different breeding approach. As illustrated in Figure 5.1, a breeding strategy for increased baking quality under organic farming conditions in North-Western Europe should take into account that baking quality is largely influenced by two types of pathways, both affected by genotype, environment and management as well as their interactions:

1) Direct pathways mainly involving the biochemistry of protein production by
   a) the direct effect of the genotype of a variety on the size and composition of the fraction of storage proteins, i.e. the proportions of glutenins and gliadins, size distribution of polymeric protein, etc., and
   b) the interaction between this direct genotypic effect on protein quantity and quality and the environmental and management conditions.
2) Indirect influence via growth and development by
   a) the indirect effect of the genotype of a variety on protein content of the grains and its protein quality through the interplay between vegetative and reproductive growth as mediated by the environment and crop husbandry, and
   b) the interaction among genotype, environment and management regarding this indirect effect.

In this paper we elaborate on breeding perspectives within this framework by first discussing the options of improving variety characteristics influenced by the first type of pathways such as protein quality and the influence of soil nitrogen levels on protein composition and its implications for breeding for protein quality under organic conditions. We then discuss the options for improving variety characteristics influenced by the second type of pathways by discussing the options for breeding for protein content, the amount of nitrogen stored in biomass, the total plant biomass, the nitrogen uptake and improving nitrogen translocation efficiency.

Although other grain components, such as starch and fatty acids, also have some influence on baking quality, in this perspective paper we focus on proteins, as this fraction is the most influenced by organic crop husbandry.

5.2. Assessing baking quality

All actors in the chain indicated in Table 5.1 assess the quality of the (intermediate) product they use and they produce. Bakers and millers require a very direct quality assessment of the final raw material. According to these actors loaf volume is the most reliable and direct characteristic describing and predicting baking quality. A good loaf volume is usually associated with other highly desired baking quality properties such as good crumb properties (Sluimer, 2005). Assessing loaf volume requires a time consuming baking test.

For breeders, on the contrary, a quality trait should be easy to assess on large numbers of small samples. They will often have to rely on an indirect chemical or physical parameter. Furthermore breeders are interested in detecting differences in quality that are under genetic control. As baking tests require relatively large amounts of seeds and are laborious, in practice breeders select for (a combination of) indirect parameters for loaf volume that are easy to measure, such as:

1. Protein content.
2. Sedimentation volumes of flour suspended in lactic acid containing either isopropyl alcohol (Zeleny-sedimentation test) or Sodium-Dodecyl-Sulphate (SDS-sedimentation test); a large part of the sediment formed in both tests consists of glutenins.
3. Presence of certain protein groups, the so-called High Molecular Weight Glutenin subunits (HMWGs) (Payne et al., 1987; Weegels et al., 1996; Shewry et al., 2006) (Box 5.1).

If the selection procedure includes baking tests, these are postponed to the final stages of the breeding programme, as at that stage the number of remaining breeding lines is reduced and availability of sample material is less limiting.

Table 5.1. Actors, processes and (intermediate) products in bread making.

Actor	Process	Product	Remarks
Breeder	Crossing, selection	Variety	Breeders need genetic variation, heritable traits, adequate selection criteria and knowledge on G×E×M.
Farmer	Grain filling through carbon and nitrogen accumulation	Grain	G×E×M influences grain size and quality, and suitability for grinding.
Miller	Milling	Flour	Influences quality by milling technique (e.g. starch damage) and blending of different fractions and batches.
Baker	Mixing	Dough	Process influenced by physico-chemical characteristics of different components of flour in interaction with (partly biological) additives, mixer (speed, time) and proofing time.
Baker	Baking	Bread	Quality is a resultant of interaction between dough quality and conditions during baking.

5.3. Improving protein quality

Across varieties, there is a negative genetic correlation between grain protein content and grain yield (Simmonds, 1996; Triboï & Triboï-Blondel, 2002). This negative correlation is often observed both under conventional and under organic conditions and is difficult to correct by agronomic measures. Improving protein quality - by breeding specific varieties that provide the highest loaf volume per unit of protein (loaf volume index) – has been proposed to overcome the trade-off between quality and yield (Finney & Barmore, 1948; Spanakakis, 1995).

The largest measurable effects on loaf volume have since long been related to the presence of a subclass of glutenins: the High Molecular Weight Glutenin subunits (HMWGs). In the 1980s Payne and others identified the location of the genes on the wheat genome that code for the synthesis of these HMWGs (Moonen et al., 1982; Payne et al., 1984; Payne et al., 1987) and these findings have had a major impact on bread wheat breeding. Three tightly linked pairs of loci on three homologous chromosomes have been identified and different alleles of each gene code for distinct HMWGs (see Shewry et al., 2006, for a review). The size of the positive effect on baking quality properties differs for every type of HMWGs. According to Payne and co-workers the effects (in their case) on SDS-sedimentation volume were additive and based on this premise they developed the "*Glu-1* quality score" that attached different weights to each pair of subunits (Table 5.2). The *Glu-1* quality score of a variety is calculated by adding up the score of each HMWGs present in that variety. Payne et al. (1987) claimed that about 50% of the variation for baking quality could be explained by this scoring system. Subsequent studies of different groups showed that not all gene effects were additive, also epistatic effects occurred and that the amount of variation explained by the HMWGs depends on the genetic background of the material tested (e.g. Kolster et al., 1991). Kolster et al. (1991), for example, estimated that only 20% of the variation for loaf volume could be explained in a set of winter wheat lines of a Dutch breeding programme. Despite these and other critics (see Weegels et al., 1996 for a review) there is more or less consensus on the fact that stacking the alleles that code for the HMWGs that give the largest effects at the three paired loci, e.g. a combination of 2^*, 7+9 and 5+10 (Table 5.2), will improve baking quality through its direct effects on protein quality.

Despite the fact that the importance of gliadins and LMWG glutenins on baking quality has long been known, research has strongly focused on HMWG glutenins. This should probably partly be attributed to the fact that the presence of the

HMWGs can easily and reliably be detected with sodium-dodecyl-sulphate polyacramylgel electrophoresis (SDS-PAGE). This laboratory technique delivers a gel, in which the different HMWGs are precipitated in different bands. In contrast, separation and correct identification of LMWGs and gliadins has proven to be difficult due to similarities in molecular weight and mobility during gel electrophoresis between different LMWGs and also between LMWGs and gliadins (Juhasz & Giannibelli, 2006; Ikeda et al., 2008; Liu et al., 2010). Also genetics of HMWGs is simpler than of e.g. gliadins. Only three paired loci code for HMWGs, while six loci are involved in gliadin synthesis and these gliadin-loci are highly polymorphic: at least 174 gliadin alleles have been identified (Metakovsky et al., 2006). Finally, effects of individual gliadins and LMWGs are small compared to the effects of HMWGs. Oury et al. (2010) included both the HMWGs and LMWGs composition in a multivariate analysis on a large dataset of French variety trials, but adding information on LMWGs only slightly improved the prediction of French bread making quality.

Table 5.2. *Glu-1* scores assigned to individual or pairs of High Molecular Weight Glutenin subunits (HMWGs) located on different chromosomes. The total quality score for a genotype is calculated by adding up the values of each HMWGs present in the genotype.

HMWGs at each of three chromosomes with *Glu*-loci			Score
Chromosome 1A	Chromosome 1B	Chromosome 1D	
-	-	5+10	4
1; 2^{*}	17+18; 7+8; 7+9; 13+16; 14+15	-	3
-		2+12; 3+12	2
Null	7; 6+8; 20	4+12; 2.2+12	1

Source: Cornish et al. (2006).

5.3.1. Influence of soil nitrogen levels on protein composition

An increased availability of soil mineral nitrogen increases the total levels of especially storage proteins (glutenins and gliadins), resulting in a higher total protein content of the grains (see e.g. Triboï et al., 2003). The amount of structural proteins (globulins and albumins) is not influenced by nitrogen applications or only slightly increases. The rate of increase differs for each group of storage proteins and this results in a change in the relative proportions of each fraction in the total amount of proteins. According to a number of authors the proportion of the glutenin fraction remains more or less stable, while the proportion of the gliadin fraction increases with increasing N fertilization (Gupta et al., 1992; Jia et al., 1996; Wieser & Seilmeier, 1998; Triboï et al., 2003, Kindred et al., 2008; Godfrey et al., 2010). According to these studies the gliadin/glutenin ratio increases with increasing protein content. Wieser & Seilmeier (1998) found that for all 13 German winter wheat varieties they studied the gliadin/glutenin ratio changed in the same direction, but the degree to which the ratio changed was variety specific. Johansson et al. (2001; 2004) and Pechanek et al. (1997) report inconsistent results for the change in gliadin/glutenin ratio when different varieties are compared. Besides to methodological difficulties in accurately separating protein fractions, these different findings can probably also be attributed to the fact that sets of varieties differed between studies and that in all studies only a relatively small number of varieties was tested. This is an indication that the changes in gliadin/glutenin ratio are not only the result of changes in nitrogen supply, but may also be partly genetically controlled. Studies with larger sets of varieties would be required to confirm this. If the rate of change in gliadin/glutenin ratio is also influenced genetically, it will be possible to select specific genotypes with an improved protein composition under growing conditions with lower nitrogen availability.

Relative changes within the gliadin fraction also have been reported, but different studies give different results. Wieser & Seilmeier (1998) report that ω-gliadin increased more with an increase in nitrogen rate than the α- and γ-gliadin fraction did, while in the study of Daniel & Triboï (2006) both ω- and γ-gliadins increased and α- and β-gliadins decreased with an increase in fertilizer rate. Both research groups mention methodological difficulties of separating the different gliadin fractions as a possible explanation for conflicting results with other studies. As the distinct gliadin groups differ in sulphur content, a shift in gliadin composition may also occur when sulphur is deficient. The latter is more likely under high nitrogen input conditions. Godfrey et al. (2010) showed that the proportion of sulphur poor ω-gliadins and nitrogen/sulphur ratio increased while protein content decreased when they compared a treatment without sulphur fertilization, but with 192 kg of N/ha, with a treatment with 53 kg S/ha and the same amount of N-fertilization. In the same study a treatment with only farm yard manure, showed a nitrogen/sulphur ratio and ω-gliadin content that were similar to treatments that received the same amount of nitrogen in the form of ammonium-nitrate and 53 kg of S/ha. This indicates that sulphur-deficiency is less likely to become a problem in an organic cropping system that uses manure.

Especially for organic conditions timing of the fertilizer application may greatly affect the composition of the protein fraction. Daniel & Triboï (2000) pointed to the fact that in treatments where N was limiting at anthesis, a fertilizer application at flowering resulted in a significant increase of the gliadin fraction in the flour. Higher gliadin content in the treatment that received 70 kg N/ha at sowing and 70 kg N/ha before heading compared to a treatment with 140 kg N/ha at sowing was also reported in a study with four spring wheat varieties in Sweden (Johansson et al., 2004). The late application also reduced dough strength (dough deformation time measured with a Brabender glutograph). The early (not split) 140 kg N/ha application showed a larger fraction of total (sodium dodecyl sulphate) unextractable polymers and a larger fraction of large unextractable polymers. The not split 140 kg N/ha treatment also resulted in weaker dough compared to the treatments with lower amounts of N-fertilizer.

Protein composition (gliadin/glutenin ratio, polymer size distribution) is not only influenced by soil nitrogen availability, but also changes over time during the grain filling phase. This change is influenced by genotype, temperature, drought, length of vegetative cycle and grain filling period (Gupta et al., 1996; Panozzo et al, 2001; Triboï et al., 2003; Naeem & MacRitchie; 2005; Martre et al., 2006; Malik et al., 2011). Therefore Malik et al. (2011) concluded that baking quality should be optimised by selecting the proper combination of the factors cultivar (duration of vegetative cycle, grain-filling duration, HMWGs composition), nitrogen application regime and temperature conditions during grain filling. Due to the large influence of nitrogen availability on protein composition, selection for improved protein quality for organic conditions should take place in nurseries with low nitrogen input conditions.

5.4. Increasing protein content

Protein composition affects baking quality, but an increase in protein content *per se* also increases loaf volume: with increasing protein content the total amount of glutenin - when measured as percentage of flour instead of percentage of total protein – increases. The total percentage of glutenin in flour correlates better with loaf volume than the percentage of glutenin of total protein (Gupta et al., 1992) or the presence of specific HMWGs (Weegels et al., 1996). This may especially be true for flour with relatively low protein content (Wieser & Kiefer, 2001).

However, selection for high protein content would require a different breeding approach than is currently practised, because modern wheat breeding has resulted in varieties that are higher in yield but usually lower in protein content than older varieties (Triboï & Triboï-Blondel, 2002; Jones et al., 2010). The reason for the decrease in protein content is that breeders have mainly increased yield by prolonging the grain filling period and increasing harvest index - by reducing plant height and increasing number of grains per plant (Austin et al., 1989; Richards, 2000; Brancourt-Hulmel et al., 2003), thus changing the balance within a crop between vegetative growth and reproductive growth in a manner which is likely to affect the C/N ratio and thus protein content through complex mechanisms (Figure 5.1). According to Sinclair (1998) breeders did not deliberately select for a higher harvest index, but its increase was a consequence of selecting for high yield under increasing nitrogen input conditions. Sinclair's review paper shows that efforts that pursued direct selection on harvest index always failed in improving grain yield. Breeding progress also shifted variety-specific optimum nitrogen supply towards higher levels (Austin, 1999; Sylvester-Bradley & Kindred, 2009).

Plant biomass is the main source of nitrogen and hence protein accumulation in grain. Under non nitrogen limiting growing conditions about eighty percent of the nitrogen in the kernel at harvest originates from the senesced leaves, stems and roots, while uptake from the soil during the grain filling period is responsible for the remaining twenty percent (see e.g. Austin et al., 1977; Spiertz & Van de Haar, 1978). In organic cropping systems nitrogen accumulated in the plant biomass before anthesis may often be the only source of nitrogen for the kernel, because during the grain filling period usually little or no mineral nitrogen is left in the soil for direct uptake unless there is abundant mineralization going on during the end of the growing period of wheat. Baresel et al. (2008) studied six winter wheat varieties at three organic locations in Germany during three years and found that nitrogen uptake from the soil during grain filling varied from 0 to 15% of the total uptake during the whole growing period, with the highest amount at the more fertile locations.

To increase grain protein content, without compromising on yield, one could consider the following strategies:

1. Increasing the amount of nitrogen stored in the biomass in a form which makes the nitrogen re-usable for accumulation in the grain.
2. Simultaneously increasing the amount of plant biomass and decreasing harvest index.
3. Improving the efficiency of nitrogen translocation to the kernel.

The first two strategies would require an increased nitrogen uptake from the soil.

5.4.1. **Increasing nitrogen uptake**

Many studies on nitrogen uptake by wheat apply the concept of Nitrogen Use Efficiency (NUE), defined by Moll et al. (1982) as the amount of grain dry matter per unit of available nitrogen in the soil. They further distinguished the components Uptake Efficiency – the total amount of nitrogen in above ground biomass per unit of available soil nitrogen – and Utilization Efficiency – the amount of grain dry matter per unit of nitrogen in the above ground biomass. NUE is the product of Uptake Efficiency × Utilization Efficiency. Following this concept an increase in grain nitrogen content should be achieved by an increase in Uptake Efficiency, because increasing Utilization Efficiency, i.e. increasing grain yield per unit of absorbed nitrogen, would decrease grain protein content. Furthermore it must be noted that to analyse differences between genotypes in nitrogen uptake efficiency, dividing the total nitrogen uptake by the available amount of nitrogen is not strictly necessary as values for all genotypes are divided by the same amount of available nitrogen. Hence, evaluating genotypic differences in nitrogen uptake (= total amount of nitrogen in above ground biomass) or nitrogen uptake efficiency gives the same results. European varieties differ for total nitrogen uptake (Austin et al., 1977; Le Gouis et al., 2000; Kichey et al., 2007; Baresel et al., 2008). Furthermore, variety ranking for nitrogen uptake differs between levels of soil nitrogen supply (Le Gouis et al., 2000; Kichey et al., 2007) and plant growth stages (Baresel et al., 2008). The latter finding is especially relevant for organic cropping systems, since nitrogen availability is not evenly distributed over the cropping season due to its dependence on (factors influencing) soil mineralization processes. In organic cropping systems often little nitrogen is left in the soil during the grain filling period. Baresel et al. (2008) concluded that in environments with low nitrogen availability varieties with an increased nitrogen uptake in the early growth stages would be more adapted and that varieties with a higher nitrogen uptake during flowering are only useful in environments that still have sufficient nitrogen available at that stage.

Nitrogen uptake obviously depends on properties of the plants' root system such as total size of the root system, root architecture, length and distribution through the soil profile, age and formation of root hairs, production of exudates, and genetic variation for such root traits has been reported in wheat (e.g. Siddique et al., 1990; Andersson & Johansson, 2006; Ford et al., 2006; Waines & Ehdaie, 2007; Manschadi et al., 2008; Wojciechowski et al., 2009). Experiments of Liao et al. (2004; 2006) and Ehdaie et al. (2010) give evidence that genotypes with a larger root system also have a higher nitrogen uptake. These studies involved a limited number of selected genotypes (4 - 5). Research on larger sets of randomly chosen genotypes would be required to confirm these results. However, evaluating root traits is difficult, time-consuming and hence expensive. This probably explains why research efforts are limited and only few breeding programmes do select for improved root traits. In the future marker assisted selection may offer a solution, but wheat root traits are believed to be controlled by many minor genes that interact with environments. Only recently first QTLs for root traits have been reported and located on the 1BL.RS rye-wheat translocation segment (Sharma et al., 2011).

In the absence of reliable high-throughput screening techniques for root traits, direct selection within breeding populations is not feasible for commercial breeders. There is some circumstantial evidence that selection under drought stress conditions may increase the root system (Chapter 2) (Baresel, 2006; Manschadi et al., 2008). Therefore introducing parents with a larger root system in the crossing scheme, followed by an selection scheme that alternates between a non-drought and a drought stress environment, such as the scheme proposed by CIMMYT (Van Ginkel et al., 2001; Kirgiwi et al., 2004) may be a fruitful approach that merits further research. However it should be noted that the demands on a root system to cope with water shortage are not necessarily the same as the demands on a root system to cope with nitrogen shortage. Novel approaches for breeding for rhizosphere-related traits have been proposed (Wissuwa et al., 2009) but might be rather crop- and situation specific.

5.4.2. **Increasing total plant biomass**

Especially older studies show that, while breeding has increased total grain yields, the total crop biomass of European winter wheat varieties has remained the same over time (Austin et al., 1989; Brancourt-Hulmel et al., 2003) or even decreased as in German spring wheat (Feil & Geisler, 1988; Feil, 1992). However, Austin and co-workers (1989) already reported that UK varieties developed in the 1980s showed a higher biomass than older varieties during the most favourable year of the three years of their research. More recently these findings were confirmed by Shearman et al. (2005) who concluded that in the UK between 1972 and 1980 yield increases were mainly the result of an increased harvest index, while from 1983 onwards an increase in pre-anthesis above ground dry matter production improved grain yield. The increase in above ground dry matter was positively correlated with a higher radiation use efficiency and specific dry leaf weight. Shearman et al. (2005) suggested that the 1BL.1RS wheat-rye translocation might explain the increase in above ground dry matter. As this study only involved a limited number of varieties (8 varieties over a 23 year period) from one country, more research would be required to confirm that modern European wheat breeding is increasing total plant biomass.

According to Australian studies differences between wheat genotypes in total above ground dry matter at anthesis and maturity were caused by early vigorous growth (Regan et al., 1992; Richards, 1992b). Furthermore, below a plant length of 100 cm, total above ground dry matter was positively correlated with plant length, with an increase of 4% per 10 cm increase in height (Richards, 1992a). Beyond a plant length above 100 cm total above ground biomass did not increase further with an increase in plant height.

Shoot biomass and leaf area at early growth stages are subject to G ×E interaction and assessments are time consuming and destructive (Rebetzke & Richards, 1999; Liao et al., 2004). A number of traits like long coleoptile tillers, broad and long seedling leaves, large seeds and embryo’s show good correlations with early vigorous growth and show a more stable performance over environments (Rebetzke & Richards, 1999; Richards & Lukacs, 2002). The height reducing genes Rht-B1b and Rht-D1b, that confer gibberellin insensitivity and have been widely used in European wheat breeding, have been associated with reduced early vigour and coleoptile tiller size (Rebetzke & Richards, 1999; Ellis et al., 2004). However, literature provides contradictory results as the negative effects of these height reducing genes seem to depend on genetic background and environmental factors (Addissu et al., 2009; Wojciechowski et al., 2009).

Australian research also showed that increased early vigour might result in increased nitrogen uptake. A line developed from a cross between a parent with high specific leaf area and a large embryo parent, showed considerably higher shoot and root mass and nitrogen uptake in a sandy soils under greenhouse and field conditions (Liao et al., 2004; 2006).

5.4.3. **Increasing the amount of nitrogen stored in biomass**

To enhance yield some molecular biologists propose to manipulate the expression of the genes that code for enzymes involved in photosynthesis and nitrogen assimilation, e.g. nitrogen reductase and glutamine synthetase (see e.g. Harrison et al., 2000; Masclaux et al., 2001). Such interventions may also increase the amount of nitrogen stored in the biomass. However, according to a number of plant physiologists perspectives on direct success are low due to many unknown feed back and feed forward processes that buffer against changes in the plants' metabolic system (see e.g. Lawlor, 2002; Sinclair et al., 2004; Yin & Struik, 2008; Yin & Struik, 2010).

Hilderman et al. (2010) gave empirical evidence of differences between genotypes in nitrogen content of shoots at tillering and flowering. Austin et al. (1977) found that leaves contain higher amounts of nitrogen than stems. Moreover, it is likely that a larger fraction of the nitrogen stored in the leaves can be re-translocated to the growing grains than is true for the nitrogen stored in the stem, of which a larger proportion is locked in cell walls. Therefore selection for varieties with a higher leaf/stem ratio may also increase the amount of nitrogen available for translocation to the kernel.

5.4.4. **Improving nitrogen translocation efficiency**

Protein content of the grain may also increase if a larger portion of the total nitrogen taken up by the plant ends up in the kernel. Studies distinguish between remobilisation efficiency – nitrogen in the kernel that was taken up until anthesis divided by nitrogen present in plant biomass at anthesis - and translocation efficiency - nitrogen in grains absorbed after anthesis divided by total nitrogen absorbed after anthesis. Differences between European winter wheat varieties for remobilisation efficiency seem to be small (Barbottin et al., 2005; Baresel et al., 2008; Bogard et al., 2010). In the study of Baresel et al. (2008), for example, remobilisation efficiency varied between 73% and 79%. It must be noted, however, that these studies did not measure nitrogen remobilisation and translocation independently, but estimated values using data from nitrogen analyses of different plant parts at anthesis and harvest. Kichey et al. (2007), who used labelled ^{15}N to study translocation efficiency and remobilisation efficiency separately, report a larger variation in remobilisation efficiency: between 69.8 and 88.8%. Variation in translocation efficiency in this research was also small: between 89.7% and 93.4%.

The studies treated above did not include root tissue in their calculations. In hydroponics experiments with six spring wheat varieties, Andersson & Johansson (2006) found differences between varieties for nitrogen concentration in the roots at maturity. They calculated that at maturity the root system still may contain 10-20% of the total nitrogen present in the plant. Therefore these authors proposed that breeders should select varieties with low root nitrogen concentration at harvest as in such varieties a larger proportion of total plant nitrogen should have ended up in the grain. In our opinion, however, these results should be confirmed under field conditions first. Various authors found inconsistencies when they compared trials in controlled environments with field trials (see e.g. van Sanford & MacKown, 1987; Waines & Ehdaie, 2007; Wojciechowski et al., 2009).

5.5. Outlook: Implications for breeding

In this paper we reviewed the possibilities to improve baking quality through improving protein quality and through increasing protein content.

Improving protein quality

From a theoretical point of view, improving protein quality seems especially attractive for organic farming, because varieties with a better protein quality would require less nitrogen to obtain a similar baking quality as varieties with an inferior protein quality. Protein quality is determined by the proportion and composition of the gliadin and glutenin fractions and the size distribution of protein aggregates. However, as there are many different proteins involved, and as these also interact with other components in dough, knowledge on the optimal protein composition is lacking. Under nitrogen scarcity the gliadin/glutenin ratio decreases and this may result in stronger dough and depressed loaf volume. The relative proportion of the gliadin fraction is more affected by nitrogen supply than the glutenin fraction. The fact that gliadin accumulation is highly influenced by available soil nitrogen, is probably the major explanation for the high variability between results of baking tests of samples of different locations and years. In literature indications can be found that the change in gliadin/glutenin ratio differs for genotypes and thus may be a selectable trait. More extensive research would be required to confirm this. In the absence of knowledge on optimal protein composition, loaf volume is the most reliable indirect parameter for protein quality. Due to the influence of nitrogen availability on protein quality, selection for loaf volume should be done under organic conditions or at least low nitrogen input conditions.

Increasing protein content

The other strategy would be to breed for varieties that give relatively high protein content under low nitrogen fertility conditions. Plant biomass is the most important, and under organic and low nitrogen input conditions, often the only source of grain nitrogen. Theoretically, increasing protein content without compromising on yield would require simultaneously increasing total plant biomass and decreasing harvest index. Literature provides evidence that an increase in plant biomass is associated with root mass and nitrogen uptake. Unfortunately, studies that include data on plant biomass up to anthesis, usually do not consider grain quality traits. Hence, further research would be required to study whether an increase in plant biomass also results in an increase in grain protein content, or under which ranges of nitrogen supply and timing of nitrogen availability it would be possible that an increase in biomass would result in an increase in grain protein content and not, for example, in a higher yield of lower quality. Plant traits like seed and embryo size, seedling leaf size and plant length, show good correlation with plant biomass, are easy to screen for and stable over environments.

Plant biomass production is related to the plants capacity of nitrogen uptake. In environments with low nitrogen availability uptake may be increased with a larger root system that is able to feed on a larger soil volume. In a practical breeding programme it is not possible to screen large amounts of plants for root size. Including root size as a criterion for selecting parents for crossings and screening the offspring under drought conditions may be a way forward to enhance root size.

This combination of characteristics (e.g. early vigour, higher above and below ground biomass) in a wheat cultivar would also provide other traits desirable in organic farming such as weed suppression and production of stable soil organic matter. This illustrates that achieving high baking quality is not necessarily associated with a trade-off for other, agronomically relevant, characteristics.

With the increasing pressure on reducing inputs in sustainable food production requirements described here for bread wheat varieties adapted to organic growing conditions might also become relevant for conventional wheat production in the foreseeable future.

Chapter 6:

Comparing the performance of cereal varieties in organic and non-organic cropping systems in different European countries

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Abstract

Top ranking varieties are tested in multiple environments before and after registration in order to assess their value for cultivation and use (VCU testing). Recently, interest has increased in obtaining varieties specifically adapted to organic farming conditions. This raised the question if an independent system of trials may be required for this purpose. To help answering this question, through the exchange network of European cereal researchers SUSVAR (www.cost860.dk), a number of data sets of agronomic traits from barley, wheat and winter triticale, from trials performed in Denmark, Sweden, The Netherlands, France, Switzerland, UK and Germany, were made available and analysed using an approach based on mixed models involving parameters describing genetic correlation between the two types of experiments, i.e., organic and non-organic (high or low input). Estimated variance components and correlations were used to evaluate response to selection and index selection. The response to index selection was analysed as a function of the fraction of available trials assigned to the organic system. The genetic correlations were interpreted in terms of ranking agreement. We found high genetic correlations between both systems for most traits in all countries. Despite high genetic correlations, the chances of very good agreement in observed rankings were moderate. Combining information from both organic and non-organic systems is shown to be beneficial. Further, ignoring information from non-organic trials when making decisions regarding performance under organic conditions, is a sub-optimal strategy.

Keywords:

genetic correlation; organic field trials; non-organic field trials; response to selection; variance components

6.1. Introduction

In Europe varieties of arable crops are tested in multiple environments to assess their value for cultivation and use for a certain cropping system or region both before and after inscription in a National or the European Common Catalogue of varieties. Over the last decade the acreage dedicated to organic cropping systems has shown a continuous growth in a number of European countries (Eurostat, 2007). This can be attributed to a combination of public concern about human health and the environment and national policies to support more sustainable agricultural production systems. With this increased attention for organic farming, also the issue of how to identify varieties that are better adapted to organic farming conditions surged. In various European countries members of the organic sector have suggested that an independent system of organic variety trials may be required for this purpose. This is based on the assumption that the ranking of varieties for key plant traits differs between an organic and conventional cropping system. To study this assumption, research groups in Austria, Denmark, Germany, Netherlands and Switzerland almost simultaneously, but independently of each other, conducted trials to compare cereal varieties under organic and conventional or low input (in the Swiss case) cropping systems. The Danish research is still ongoing. The results from the other countries showed high phenotypic correlation coefficients (r) between the performance in organic and non-organic sites, ranging from 0.75 to 0.99 for most traits (Osman et al., 2005; Oberforster, 2006; Schwärzel et al., 2006; Kleijer & Schwärzel, 2006). In Switzerland earliness and a number of baking quality traits (protein content, Zeleny sedimentation, wet gluten content, dough stability and loaf volume) showed a significant genotype × system interaction. In Austria lower correlations were found for resistance to *Septoria tritici* and *Fusarium spp.* Also, in Austria phenotypic correlation for yield was considerably lower in the drought prone cropping region ($r = 0.59$) than in the humid region ($r = 0.83$) (Oberforster, 2006).

Recently, results of studies comparing the performance of wheat varieties and breeding lines from other continents have become available. In Canada, Mason et al. (2007) did not find a significant genotype × system interaction for yield and quality traits, except for dough mixing development time. Kitchen et al. (2003) concluded that the varieties they studied in Australia did not show a comparative advantage in either the organic or non-organic systems for grain yield and biomass production. These two studies compared modern cultivars and old varieties that were developed before agricultural intensification; but in both studies only a total of five varieties were included. So, the fact that they did not find differences between organic and non-organic systems may also be attributed to this limited number of varieties.

While all the studies mentioned above conclude that there are no or only minor differences between the results of testing varieties in organic and non-organic systems, also reports with opposing results have been published. Murphy et al. (2007) compared 35 soft winter wheat breeding lines at five pairs (organic, non-organic) of sites during two years in Washington State, USA. They found significant genotype × system interaction for yield and specific weight at four of the five sites. In Germany, Burger et al. (2008) compared testcrosses of doubled haploid lines with a tester line of maize and only report small to moderate phenotypic correlations for yield and highly variable genotypic correlations.

One of the factors influencing the outcome and interpretation of results is the statistical model used. Between 2004 and 2008 European cereal researchers and breeders with an interest in low input and organic agriculture regularly met through the exchange network SUSVAR (www.cost860.dk). This made it possible to collect data sets from organic and non-organic barley, wheat, and winter triticale trials, that were performed in Denmark, Sweden, The Netherlands, France, Switzerland, UK, and Germany for a joint analysis with the same statistical methods. The purpose of this work was to assess the need to set up a separate variety testing system of organic farming, by studying the following questions:

- how big is the genetic correlation between organic and non-organic trials?
- what is the relation between genetic correlation and the ranking order of the varieties in organic and non-organic trials?
- what are the gains or losses of selecting indirectly - based on results of non-organic trials only - and by using an index based on results of both organic and non-organic trials?

We tackled these questions using the mixed model methodology in a way similar to an approach, which has been proposed to decide if it is worthwhile to subdivide a target region into subregions for local recommendation (Piepho & Möhring, 2005). The approach is based on the premise that a variety recommendation is essentially a selection problem, so well-known results on selection theory are relevant, i.e. it makes sense to consider a “response-to-recommendation” as a measure for the performance of a variety testing system. As advocated in that paper we used mixed models, which comprise a genetic correlation between organic and non-organic trials. Estimates of the genetic correlation were interpreted in terms of ranking agreement. An approach based on index selection (Falconer & Mackay, 1996; Bos & Caligari, 2007) was proposed to study the effect of the number of organic trials on the response to selection.

Table 6.1. Characteristics of the analysed series of experiments.

Dataset	Crop	No. of years	No. of sites[b)]	No. of replications	No. of analyzed traits	No. of genotypes
Danish	barley	2 (2002-2003)	2	2	6	188
Swedish	barley	11 (1994-2004)	4	2	2	56
Dutch I	spring wheat	4 (2001-2004)	1	3	5	24
Dutch II	spring wheat	3 (2001-2003)	1	2	5	36
French	winter wheat	3 (2004-2006)	3	3	8	30
Swiss[a)]	winter wheat	3 (2002-2004)	5	3	3	12
U.K.[a)]	winter wheat	3 (2004-2006)	1	3	6	20
German[c)]	winter triticale	2 (2004-2005)	1	2	1	64

[a)] Organic and conventional trials were performed at different locations which were paired for the purpose of this analysis and treated as one site

[b)] Sites: Danish – Flakebjerg, Foulum; Dutch – Nagele; French – Lusignan, Le Moulon, Rennes; German – Hohenheim; Swedish – Öjebyn, Röbäcksdalen, Ås, Offer; Swiss – Delley, Utzensdorf, Reckenholz, Moudon, Nyon; U.K. – Metfield

[c)] German trials comprised nitrogen level as an additional factor; the corresponding parameter estimates are not presented here.

6.2. Materials and methods

6.2.1. The experiments

Cropping systems

The data sets comprise results of field trials performed in two agricultural systems over several years and/or at a number of sites (Table 6.1). In all experiments an “organic” cropping system was compared with a cropping system that applied synthetic fertilizers, denoted here as “non-organic”. Between countries there were differences in both the organic and non-organic cropping systems (Table 6.2). While in most countries the organic system was certified by a national authority, in Denmark and Sweden this was not the case. In Sweden the fields in the

Table 6.2. Descriptors of the cropping systems used in the experiments.

Dataset	Comparison	Type of field	Crop	Seed treatment	Management of Diseases	Management of Weeds	Fertilitymanagement Nitrogen/ha[1]	Fertilitymanagement Type
Danish	Organic (not certified)	Research station	Spring barley	No	No	Harrowing	60 - 90 kg	Slurry
	Conventional	Research station		Fungicide	No	Herbicides	150 kg	Inorganic
Swedish	Organic (not certified, >5 years)	Research station	Spring barley	No	No	Harrowing	60 - 80 kg	Slurry
	Conventional	Research station		Fungicide	No	Herbicides	40 and 80 kg	Inorganic
Dutch	Organic (certified, >20 years)	Experimental farm	Spring wheat	No	No	Harrowing	100 kg	Manure + slurry
	Conventional	Experimental farm		Fungicide	No	Herbicides	140 - 200 kg	Inorganic
French	Organic (certified, > 5 years)	Commercial farm	Winter wheat	No	No	Harrowing (2 farms) no control (1 farm)	0 - 60 kg	Manure
	Low-input	Experimental farm		Fungicide	No	Herbicides	40 - 110 kg	Inorganic
Swiss	Organic (certified, >5 years)	Commercial farm	Winter wheat	No	No	Harrowing	Not quantified	Manure + slurry
	Low-input	Research station		Fungicide	No	Herbicides	140 kg	Inorganic
UK	Organic (certified, >10 years)	Experimental farm	Winter wheat	No	No	No direct control	Pre-crop	Legumes
	Conventional	Commercial farm		Fungicide	Fungicides	Herbicides	Min 160 kg	Inorganic
German	Organic (certified, 11 years)	Research station	Winter triticale	No	No	No	0 kg and 60 kg	Organic
	Conventional	Research station		Yes	Yes	Yes	0 kg and 110 kg	Inorganic

[1] Including mineral nitrogen available in soil

experimental farm had been managed without synthetic inputs for at least five years. In Denmark, this was the case for one of the locations whereas synthetic inputs were used up until three years before the “organic” trial at the other location. The amount of nitrogen fertilizer used varied between experiments (Table 6.2). Two fertilizer regimes (no fertilizer and 60 - 110 kg N/ha) were included in each system of the German trials.

Crops

In the different countries different cereal crops were selected for the study. In the Danish and Swedish research, spring barley was chosen as crop. Winter wheat was the crop in the British, French, and Swiss experiments, while the Dutch worked with spring wheat. In Germany the research was conducted with winter triticale.

The choice of genotypes

Table 6.3 provides an overview of the type of varieties included in the trials.

The Dutch, Swedish, and Swiss study followed a typical variety testing procedure: each year new advanced breeding lines and varieties were included and entries that were not resistant enough, lacked quality or showed poor yield were discarded. In the Dutch case, “new” entries (varieties that were not previously tested in the Netherlands) first passed a phase of pre-testing (Dutch II), and from this pre-testing the 2 to 3 best varieties entered the main trial each year (Dutch I). For this study seed companies sent in new varieties, that they were releasing for the conventional market, but also considered interesting for organic farming. As a consequence, in the Dutch II trials in each year different varieties were tested (together with four standard varieties that did not change over years), whereas the set of varieties of Dutch I only showed minor changes over years.

Varieties in the Swedish trials were chosen among those commonly used in conventional agriculture in the area. Additional varieties were included that had shown a better rooting ability in a hydroponic test.

In Switzerland the set of varieties also differed between systems. In the low input network a larger set of varieties were tested. Varieties that were not considered interesting for the organic system were first not included in the organic sites. Comparable sites were included in the analysis for this publication and varieties that were not tested in organic fields were not considered (see next subsection).

In the Danish case, all breeding lines and varieties from the official Danish variety testing system were included each year as well as a number of international varieties known to be specifically adapted to organic conditions; this implied that the entries changed to some extent between the two years.

Table 6.3. Type of genotypes used in the experiments.

Dataset	Type of genotypes
Danish	Lines and varieties included in VCU[1] testing, variety mixtures and selected ‘organic’ candidates
Swedish	Newly released varieties and selected organic candidates
Dutch	Lines and varieties included in VCU[1] testing
French	Lines and varieties included in VCU[1] testing, variety mixtures and selected ‘organic’ candidates
Swiss	Varieties included in VCU[1] testing, issued of conventional and organic breeding programmes
UK	Varieties from the period 1950-2000 with a proven record of good performance
German	Released varieties and current elite breeding materials

[1] VCU = Value for Cultivation and Use (official variety testing system for inclusion in the National variety list).

Locations, years and experimental design

In most cases, the two types of experiments were conducted at the same location. In Switzerland and UK this condition was not satisfied. Therefore, pairs of locations were identified on the basis of similar environmental conditions and treated as sites in the analysis. Trials were organized as complete or incomplete block designs. As the sets of varieties tested in two systems and in different years/locations were not always the same, the analysis was done only in the cases where the design of the experiment allowed for estimation of the covariance components of interest. Also, the observations of the traits were not always sufficiently complete for the estimation procedure to work. The traits which were used in the present analysis are summarized in Table 6.4.

Table 6.4. Traits analysed in experiments.

Trait	Symbol	Dataset Danish	Swedish	DutchI	DutchII	French	Swiss	UK	German
Yield (dt/ha)	YIELD	+	+	+	+	+	+	+	+
Height (cm)	HEIGHT	-	-	+	+	+	+	+	-
Thousand grain weight (g)	TGW	+	+	-	-	+	-	+	-
Hectoliter weight (kg/hectoliter)	HECTW	-	-	-	-	+	+	+	-
Protein content (%)	PROT	+	-	-	-	+	-	+	-
Soil coverage (1 - 9 scale, %)[ab]	SOIL	-	-	+	-	-	-	+	-
Lodging (1 - 9 scale)[b)]	LODG	+	-	-	+	+	-	-	-
Breaking of straw (0 -1 0 scale)[b]	STRAW	+	-	-	-	-	-	-	-
Brown rust (*P. triticina*) (1 - 9 scale, %)[c]	RUST	+	-	+	+	+	-	-	-
Septoria tritici blotch (*M. graminicola*) (1 - 9 scale)[b]	SEPT	-	-	+	+	+	-	-	-

[a)] Soil coverage measured in 1 - 9 scale in Dutch data set and in % in U.K. data set.

[b)] Lodging, breaking of straw, Septoria tritici blotch and brown rust measured in the scale in which 0 or 1 denotes the desired situation (no lodging, no infection, no straws broken).

[c)] Brown rust measured in 1 - 9 scale in Dutch data set and in % in Danish data set.

6.2.2. **Estimation**

The variances and covariances needed to estimate the genetic correlation and to study the response to selection can be obtained from each of the analysed data sets as follows. Let y_{gjkr} denote the observation of the trait for the g-th genotype (variety) ($g = 1,2,...,G$) in the j-th system ($j = 1,2$ for organic and non-organic systems, respectively) at the k-th environment (meaning location, year or combination of both, $k = 1,2,...,K$) in the r-th replicate ($r = 1,2,...,R$). For easier presentation, we describe the model as if all the trials were done in complete blocks, although some of the series were done in incomplete blocks and for these an appropriate model was used. Then, we assume for the observation the mixed model

$$y_{gjkr} = \mu + \alpha_j + \beta_k + \gamma_{jk} + u_{gj} + v_{gk} + w_{gjk} + z_{jkr} + e_{gjkr}, \qquad (1)$$

where μ denotes the general mean, and α_j, β_k , γ_{jk} denote the fixed system, environment and system × environment interaction effects, respectively. The genotype × system is assumed to be a random effect and is denoted in (1) by u_{gj}. We assume that $u_{gj} \sim N(0, A_{jj})$, $Cov(u_{g1}, u_{g2}) = A_{12}$, that is, the genotypic values in the two systems can have different variances, and they can be correlated. Further, v_{gk}, w_{gjk}, z_{jkr} , e_{gjkr} denote the random effects of genotype × environment interaction, of genotype × system × environment interaction, of blocks nested within system and environment, and of error, respectively. We assume that: $v_{gk} \sim N(0, \sigma_v^2)$, $w_{gjk} \sim N(0, \sigma_w^2)$, $z_{jkr} \sim N(0, \sigma_z^2)$, $e_{gjkr} \sim N(0, \sigma_{e(jk)}^2)$. In case of the German dataset the model was extended to account for the additional fertilizer treatment factor.

The variance components in model (1) are estimated using the REML algorithm (Searle et al. 1992, numerical implementation in Genstat 9, VSN International). The estimators are used to obtain the genetic correlation coefficient between organic and non-organic system

$$\hat{r}_G = \frac{\hat{A}_{12}}{\sqrt{\hat{A}_{11}\hat{A}_{22}}}$$

and a measure of environmental and error variance

$$\varphi = \hat{\sigma}_v^2 + \hat{\sigma}_w^2 + \frac{\overline{\sigma}_e^2}{R},$$

with σ_e^2 being the mean error variance from the series of experiments. This latter measure is needed to specify the phenotypic variances P_{ij} as functions of the number of trials, as detailed below.

6.2.3. **Index selection**

We here assume that optimal use is going to be made of information from both the organic and the non-organic trial system. The simplest way to combine information from two systems in an optimal way is to use index selection. Thus, the estimate of performance of a variety under organic conditions will be obtained as a weighted combination of means under both the organic and the non-organic system, with weights depending on genetic variances, covariances and the numbers of trials in both systems.

Using derivation of Falconer & Mackay (1996; p. 240) and adapting it to our problem, we define the selection index as

$$I = b_1 P_1 + b_2 P_2 ,$$

where P_1 and P_2 are the phenotypic values of the trait (e.g., yield) observed in organic and in non-organic trials, respectively, and b_1 and b_2 are the corresponding weights. The weights defining the index are to be chosen in such a way that the correlation between the index and the genotypic value of the genotypes in the organic conditions, *A*, is maximal. It can be shown that the optimal weights are obtained by solving the equation

$$\begin{pmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{pmatrix} \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} A_{11} \\ A_{21} \end{pmatrix},$$

where A_{mn} and P_{mn} are the genetic and phenotypic variances and covariances, respectively, of the trait measured in system *m* and *n*, *m,n* = 1,2 (the phenotypic variance refers to genotypic means). The solution is

$$b_1 = \frac{A_{11} P_{22} - A_{21} P_{12}}{P_{11} P_{22} - P_{21}^2} ,$$

$$b_2 = \frac{-A_{11} P_{21} + A_{21} P_{11}}{P_{11} P_{22} - P_{21}^2} .$$

On the other hand, it can be shown that the variance of *I* is given by

$$\sigma_I^2 = b_1^2 P_{11} + b_2^2 P_{22} + 2 b_1 b_2 P_{21} = b_1 A_{11} + b_2 A_{21} .$$

Now, according to Falconer & Mackay (1996, p. 328), the response to selection (the mean value of index *I* within the selected fraction of genotypes in relation to the population mean) is given by

$$R_A = i \sigma_I ,$$

where *i* is the intensity of selection, that is, R_A is proportional to σ_I (or equal to σ_I if we consider selection with unit intensity, equal to one standard deviation). Thus, we have

$$R_A \propto \sqrt{b_1 A_{11} + b_2 A_{21}} . \qquad (2)$$

For any series of experiments we can estimate the response to selection, R_A, by inserting into equation (2) the parameter estimates obtained in the analysis of model (1), that is, estimates of A_{11}, A_{22}, $A_{12} = A_{21}$, $P_{11} = A_{11} + \varphi/t_1$, $P_{22} = A_{22} + \varphi/t_2$, and $P_{12} = P_{21} = A_{12}$, where t_1 and t_2 are the numbers of trials in the organic and non-organic system, respectively.

For comparison, we also compute the response to direct selection R_1 (when only information from the organic system is used) and response to indirect selection R_2 (when only information from the non-organic system is used). Using standard results (Falconer & Mackay, 1996, p.189), the formulas for these responses are, respectively,

$$R_1 \propto \frac{A_{11}}{\sqrt{P_{11}}} \quad \text{and} \quad R_2 \propto \frac{A_{21}}{\sqrt{P_{22}}} \ .$$

6.2.4. **Studying the response to selection**

In addition to estimating the response to selection for each series of trials, we can also consider the following scenario to study the effect of the number of organic and non-organic experiments in the series. Assume that we currently have t_1 organic and t_2 non-organic experiments, and that we have to decide how to divide additional t experiments between the two systems. In this case, $P_{11}= A_{11} + \varphi/(t_1+t\pi)$ and $P_{22}= A_{22} + \varphi/[t_2+t(1-\pi)]$, where π is the proportion of experiments assigned to the organic system. In this way we express R_A in (2) as a function of A_{11}, A_{22}, r_G, φ, t_1, t_2, t and π, and study its properties. We impose the restriction t_1, $t_2 \geq 1$ to ensure that the ratios in P_{11} and P_{22} cannot have a zero denominator, as π is let to vary between 0 and 1. Specifically, in our calculations we take t_1=1 and t_2=10. The choice of these proportions between organic and non-organic trials reflects the current and prospected proportion between the organic and non-organic cereal acreages.

6.3. Results

6.3.1. **Parameter estimates**

For each series of experiments and each trait the analysis of model (1) provided several estimated parameters and statistics (Table 6.5 and Table 6.6). Table 6.5 shows mean values and genetic variances in the two considered cropping systems, as well as genetic correlation and predicted responses to selection; Table 6.6 shows Wald statistics for tests concerning fixed effects in model (1), environmental variance components, error variances and numbers of experiments.

Table 6.5. Mean values, genetic variance, genetic correlation and response to index, direct and indirect selection for all analysed datasets and traits.

Trait	Data set	Mean value		Genetic variance				Genetic correlation[a]	Environ-mental	Response to				
		organic	non-organic	organic A_{11}	s.e.	non-organic A_{22}	s.e.	r_G	variance φ	index seletion R_A	direct selection R_1	R_A-R_1	indirect selection R_2	R_A-R_2
YIELD	Danish	52.70	55.44	17.22	2.25	18.58	2.43	0.94	10.37	3.96	3.87	0.09	3.65	0.30
	Swedish	32.77	39.72	4.93	1.44	6.97	1.76	0.98	12.44	2.18	2.15	0.03	2.13	0.05
	Dutch_I	57.32	77.85	9.25	3.74	22.16	7.82	0.98	6.14	2.94	2.82	0.13	2.88	0.06
	Dutch_II	52.27	76.69	17.95	4.57	47.25	12.97	0.98	3.96	4.16	4.09	0.07	4.10	0.07
	French	60.81	75.90	18.73	5.12	43.52	11.00	0.98	21.16	4.18	3.97	0.21	4.10	0.08
	Swiss	46.90	75.85	12.64	7.30	24.77	13.18	0.95	14.49	3.36	3.21	0.16	3.20	0.17
	UK	52.15	98.20	30.60	15.99	187.60	67.00	0.85	32.66	4.96	4.52	0.44	4.54	0.41
	German	52.81	80.06	14.31	5.64	23.70	7.33	0.79	21.14	3.12	2.87	0.25	2.49	0.63
HEIGHT	Dutch_I	92.99	100.08	60.22	18.48	48.91	15.38	0.97	4.42	7.70	7.69	0.01	7.44	0.26
	Dutch_II	92.45	95.36	161.40	44.30	78.05	22.81	0.86	2.23	12.66	12.66	0.00	10.85	1.81
	French	95.02	97.90	121.60	23.10	135.00	25.60	1.00	9.83	11.00	10.97	0.03	10.98	0.02
	Swiss	93.43	104.43	78.27	33.88	131.40	56.50	0.99	10.13	8.81	8.80	0.02	8.73	0.08
	UK	81.55	76.86	153.60	52.40	73.76	25.55	0.98	9.70	12.29	12.27	0.02	11.89	0.40
TGW	Danish	42.99	43.15	11.31	1.39	11.33	1.39	1.00	2.12	3.32	3.29	0.04	3.29	0.04
	Swedish	43.63	45.04	13.10	4.95	15.97	6.11	1.00	6.91	3.55	3.47	0.08	3.50	0.05
	French	43.41	44.51	7.71	1.94	8.17	2.12	1.00	4.75	2.71	2.64	0.07	2.65	0.06
	UK	40.38	44.54	17.32	6.36	11.14	4.22	0.86	4.77	4.01	3.98	0.03	3.35	0.66
HECTW	French	74.34	75.89	4.80	1.14	4.65	1.11	1.00	4.05	2.12	2.06	0.06	2.06	0.06
	Swiss	81.47	81.62	4.90	2.18	2.13	1.00	1.00	1.44	2.19	2.17	0.01	2.13	0.06
	UK	69.87	75.57	2.28	1.05	2.15	0.91	0.88	2.33	1.36	1.30	0.05	1.14	0.22
PROT	Danish	10.16	10.78	0.91	0.17	1.50	0.26	0.95	0.26	0.93	0.92	0.01	0.89	0.04
	French	9.81	11.42	0.36	0.08	0.62	0.13	1.00	0.16	0.59	0.58	0.01	0.59	0.00
	UK	11.17	12.85	0.42	0.17	0.60	0.22	1.00	0.33	0.62	0.59	0.03	0.60	0.02
SOIL	Dutch_I	5.00	5.67	0.58	0.29	0.27	0.19	1.00	0.85	0.68	0.65	0.03	0.57	0.11
	UK	24.54	38.96	14.48	7.68	9.82	5.01	0.90	21.40	3.28	3.11	0.17	2.60	0.68
RUST	Danish	0.24	0.51	0.28	0.06	0.08	0.01	1.00	0.42	0.42	0.40	0.02	0.28	0.14
	Dutch_I	2.33	2.62	2.89	0.96	3.74	1.27	1.00	0.46	1.68	1.66	0.02	1.67	0.01
	Dutch_II	1.87	1.93	1.27	0.48	1.21	0.47	1.00	0.72	1.08	1.03	0.04	1.03	0.05
	French	2.24	3.39	0.87	0.30	1.31	0.44	1.00	1.18	0.91	0.87	0.04	0.89	0.02
SEPT	Dutch_I	3.12	4.06	1.39	0.60	1.61	0.67	0.89	0.47	1.11	1.09	0.02	0.98	0.13
	Dutch_II	4.36	3.94	2.20	0.98	2.97	1.14	0.86	0.61	1.41	1.39	0.02	1.21	0.19
	French	2.59	3.51	0.33	0.13	0.91	0.25	1.00	0.56	0.54	0.46	0.08	0.53	0.01
LODG	Danish	0.33	1.34	1.20	0.17	1.40	0.26	0.96	0.91	1.00	0.93	0.07	0.92	0.08
	Dutch_II	1.77	3.99	1.47	0.53	8.35	2.97	0.83	0.03	1.20	1.20	0.00	1.00	0.20
	French	1.41	1.70	0.34	0.14	0.92	0.27	1.00	1.11	0.53	0.44	0.09	0.51	0.02
STRAW	Danish	2.16	3.35	0.54	0.18	2.61	0.48	1.00	2.08	0.64	0.43	0.21	0.62	0.02

a) If the REML algorithm reported the variances and covariances giving the value of the genetic correlation greater than 1, the calculations were repeated with fixed correlation equal to 1, and such a value is put in the table.

Table 6.6. Additional results from analysis of data from organic and non-organic experiments.

Trait	Data set	Wald statistic for comparison of			Variance components[a)]				Mean error variance	No. of experiments[b]	
		systems (S)	environments (E)	interaction S x E	Variety x environment	s.e.	Variety x environment x system	s.e.		organic	non-organic
YIELD	Danish	10.61***	22.05***	25.37***	1.89	0.52	4.31	0.57	8.34	4	4
	Swedish	208.04***	27.97***	15.90***	1.97	0.74	3.68	0.74	13.58	37	44
	Dutch_I	601.64***	99.04***	26.08***	1.31	1.08	3.85	1.15	2.95	4	4
	Dutch_II	321.20***	112.08***	30.72***	-	-	0.17	0.58	11.38	3	3
	French	200.36***	48.70***	38.27***	6.06	1.71	7.73	1.63	22.11	6	6
	Swiss	972.17***	51.00***	145.67***	6.59	2.71	5.17	5.17	8.20	5	5
	UK	338.79***	99.73***	75.58***	7.18	8.02	24.01	9.09	43.41	3	3
	German	226.47***	86.03***	51.49***	5.07	-	6.88	-	18.38	2	2
HEIGHT	Dutch_I	216.65***	100.69***	80.03***	1.80	0.79	1.17	0.61	4.36	4	4
	Dutch_II	3.18	155.01***	227.66***	-	-	-	-	6.69	2	2
	French	16.56***	34.27***	22.64***	2.89	0.75	3.63	0.69	9.94	8	8
	Swiss	132.49***	54.62***	18.06***	1.54	0.92	3.61	1.06	14.93	11	11
	UK	13.67***	36.52***	10.80***	3.99	1.71	1.43	1.36	12.84	3	3
TGW	Danish	0.01	37.40***	15.30***	0.78	0.20	-	-	2.68	4	4
	Swedish	13.21***	14.21***	8.75***	4.98	1.16	0.66	0.35	2.55	6	6
	French	2.93	99.99***	7.20***	1.71	0.29	-	-	9.13	6	6
	UK	44.62***	11.06***	50.96***	1.29	0.83	1.63	0.85	5.76	3	3
HECTW	French	23.52***	53.85***	3.62**	0.31	0.23	1.67	0.26	6.81	7	7
	Swiss	0.49	15.81***	5.15***	0.68	0.20	0.64	0.13	0.34	8	8
	UK	225.26***	13.50***	1.72	0.17	0.35	0.89	0.45	3.81	3	3
PROT	Danish	107.91***	42.78***	15.14***	0.20	0.01	-	-	0.12	4	4
	French	74.94***	32.17***	12.55***	0.04	0.01	0.05	0.01	0.20	8	8
	UK	114.48***	104.72***	51.81***	0.11	0.04	-	-	0.52	3	3
SOIL	Dutch_I	82.46***	1.92	39.67***	0.64	0.17	-	-	0.64	4	4
	UK	258.52***	51.14***	67.23***	1.11	3.28	3.02	4.42	51.81	3	3
RUST	Danish	12.27***	8.17**	1.26	-	-	-	-	0.84	2	2
	Dutch_I	5.51*	15.43***	1.59	0.28	0.11	-	-	0.53	3	3
	Dutch_II	0.07	5.65**	3.10*	0.35	0.25	0.21	0.11	0.49	3	3
	French	84.46***	24.46***	41.38***	0.46	0.20	0.26	0.18	1.40	9	9
SEPT	Dutch_I	14.48***	7.21**	4.10*	0.19	0.17	0.11	0.13	0.51	2	2
	Dutch_II	3.06	4.91*	1.57	0.50	0.43	-	-	0.35	2	2
	French	33.73***	38.08***	0.96	0.06	0.09	0.31	0.08	0.58	3	3
LODG	Danish	156.16***	38.55***	61.02***	0.01	0.06	0.18	0	1.44	2	2
	Dutch_II	18.79***	-	-	-	-	-	-	0.08	1	1
	French	10.73**	12.74***	4.55***	0.55	0.09	0.30	0.05	0.78	4	4
STRAW	Danish	4.98*	215.43***	27.22***	-	-	-	-	4.16	2	2

* P < 0.05, ,
** P < 0.01,
*** P < 0.001

[a)] If an estimated environmental variance component was negative, model fitting was repeated with corresponding term removed; the situation is indicated by "-".

[b)] For some data sets traits were not observed in all experiments; in other cases, the REML algorithm was not convergent for all experiments due to the different sets of genotypes. The table shows the number of organic and non-organic experiments used in the calculations.

First we compare the mean values of the traits for two systems given in Table 6.5. It can be noticed that in most cases the mean value for the organic system was smaller than the mean for the non-organic system. Organic yield was always (eight times) significantly lower (see Wald statistics for "systems" in Table 6.6). Height in the organic system was smaller in four (significantly smaller in three) out of five cases. Thousand grain weight and hectoliter weight (analysed four and three times, respectively) were always smaller in organic conditions, although not always significantly so. Protein content and soil coverage (analysed three and two times, respectively) were always significantly smaller for the organic system. For lodging and breaking of straw, the organic means were significantly smaller. Infection by brown rust (*Puccinia triticina*) and Septoria tritici blotch (*Mycosphaerella graminicola*) was lower in the organic system except for Dutch II data, where there was no significant difference between the systems.

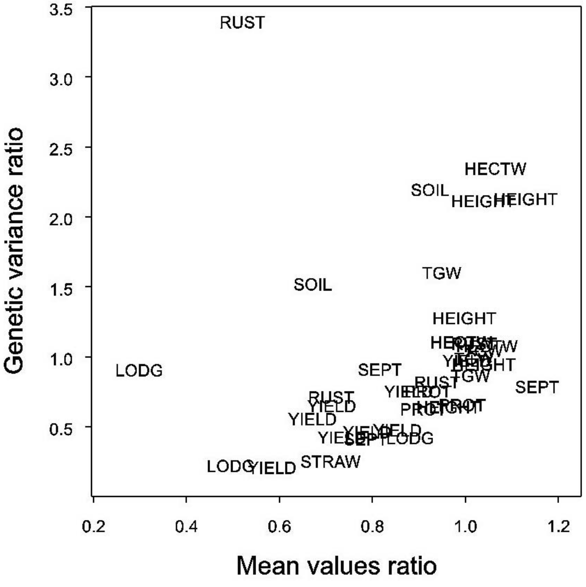

Figure 6.1. The ratio of organic genetic variance and conventional genetic variance versus corresponding ratio of mean values, for all analysed situations (for trait symbols see Table 6.4).

Secondly, we interpret in Table 6.5 the estimates of genetic variances characterising the variability of genotypic values within both agricultural systems. The genetic variance in organic conditions was always smaller than in non-organic conditions for yield, protein content, lodging and breaking of straw. The opposite relation was observed for hectoliter weight, soil coverage, brown rust and Septoria tritici blotch. The relation of genetic variances for organic and non-organic trials corresponds roughly to the relation of corresponding mean values (Figure 6.1).

Now we turn attention to the genetic correlations between the two systems (Table 6.5). The genetic correlations for yield are in the range from 0.79 to 1. For height, they varied from 0.97 to 1, with one exception of 0.86 for Dutch II data. Lower correlations were observed for thousand grain weight (TGW) and hectoliter weight in UK data. For other situations they were close to 1. Considering different data sets, the highest correlations were observed in the French data: the genetic correlation had to be set to 1 in seven out of eight cases in order to avoid a correlation estimate larger than 1. Three lower correlations were observed in Dutch II data: for height, lodging and Septoria tritici blotch.

The next column in Table 6.5 contains values of φ, the total variance incurred by the environment and its interaction with varieties and systems. In comparison to genetic variances, the value of φ was very low for lodging in Dutch II data, and for all cases of height. High values of φ were observed for soil coverage.

Finally, Table 6.5 shows predicted values of response to selection, expressed in the units of the trait measurement. According to the formulae given above, the values shown correspond to unit selection intensity, that is, to the situation where the mean value of genotypes selected from the parental population is bigger than the population mean by one standard deviation (for a normal distribution, this corresponds to selecting, about 35% of the population). In relation to the organic mean, the values of R_A were similar within traits (for yield from 5.14% to 9.51%). The largest values of the response to selection in relation to the organic mean were observed for the traits observed on the ordered categorical scale: lodging, brown rust and Septoria tritici blotch, intermediate for straw breaking, soil coverage and height, and the smallest for yield, protein, TGW and hectoliter weight. The difference between the response to index selection and the response to indirect selection for yield was from 5 to 63 kg/ha. It should also be emphasized, that direct selection is always outperformed by index selection. This stresses the, perhaps obvious, fact that results of non-organic trials provide valuable information on performance under organic conditions, and such information should not be discarded. Note that for each case in Table 6.5 the number of trials for organic and non-organic systems were equal. When in practice a combined organic/non-organic system will be set up, there will probably be more non-organic trials, which would increase the information to be gained from non-organic trials.

In Table 6.6 we see that the environments (years and/or locations) had significant influence on the level of the traits. Only once the difference between environments was not significant: for soil coverage in Dutch I. System × environment interaction effects were also highly significant in most cases. The least significant or a non-significant interaction was observed for both diseases (except for Septoria tritici blotch in French data) and for hectoliter weight in UK data set.

6.3.2. **Response to selection**

The response to selection was studied as a function of parameters described in Materials and Methods (Section 6.2.3) for different traits and data sets. Here, for illustration, we present such analysis for two selected situations:

yield in the French data set and

lodging in the Dutch II data set.

These were characterized by the following estimated parameters (Table 6.5):

i) $A_{11} = 18.73$, $A_{22} = 43.52$, $r_G = 0.98$, $\varphi = 21.16$,

ii) $A_{11} = 1.47$, $A_{22} = 8.35$, $r_G = 0.83$, $\varphi = 0.02$.

The two selected data sets differ in the value of the genetic correlation and in the relation between the genetic variances and the environmental variances. To calculate the response to selection it was assumed that t_1 and t_2 are equal to 1 and 10, respectively, and t, the number of additional experiments, is 5. Figure 6.2 shows results of the analysis of response to index selection R_A for situations (i) (plots a,c,e) and (ii) (plots b,d,f). Figures 6.2a and 6.2b show plots of R_A as a function of π and φ, for the values of A_{11}, A_{22} and r_G observed in the experiments; Figures 6.2c and 6.2d show R_A as a function of π and r_G, for the values of A_{11}, A_{22} and φ observed in the experiments. Figures 6.2e and 6.2f show the profiles obtained as intersection of surfaces shown above for values of φ and r_G obtained for the analyzed datasets.

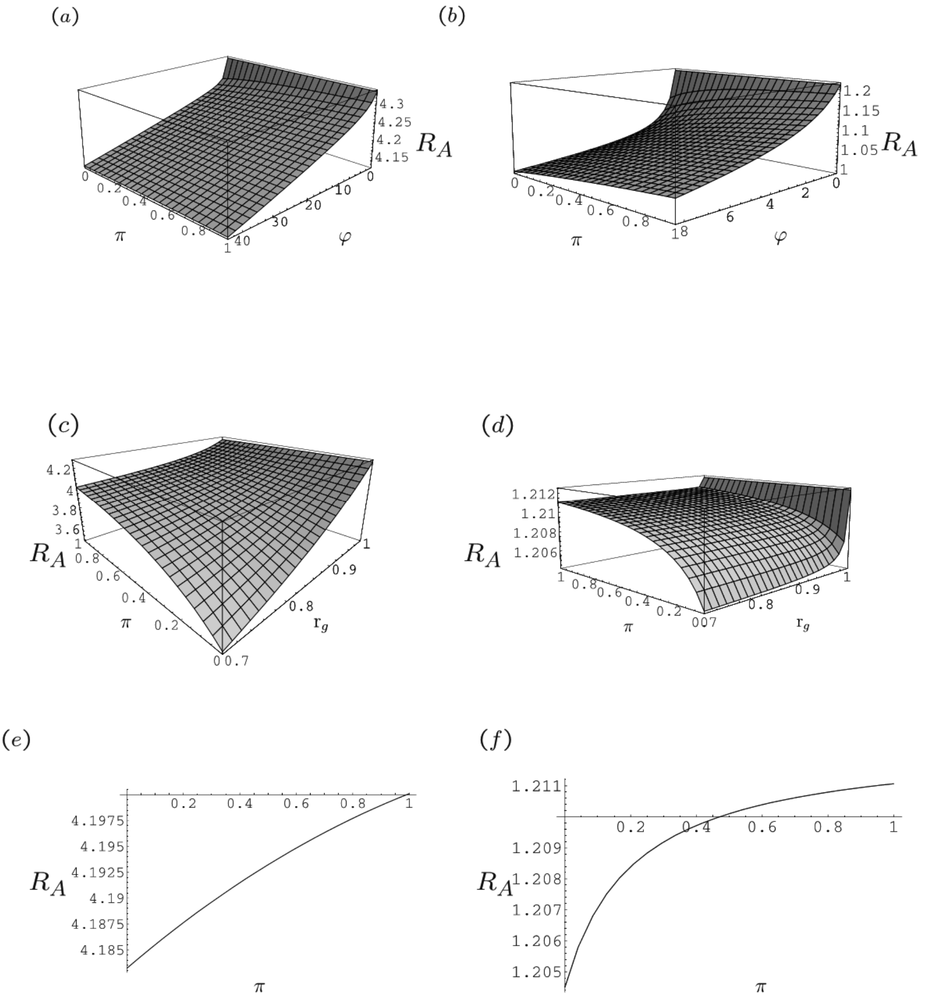

Figure 6.2. Functional dependence of index selection response on the number of added organic experiments, measure of the environmental variance and genetic correlation. Two columns of plots correspond to two analysed situations: Yield in French data set (a,c,e) and Lodging in Dutch II (b,d,f).

The observations from Figure 6.2 can be summarized as follows:

1) Figures 6.2a and 6.2b describe the effect of the proportion of additional organic experiments, π, and of the environmental variance, φ, on the response to selection, with a fixed genetic correlation of 0.98 and 0.83, respectively. In both figures the range of φ was chosen to be from 0 to max $\{A_{11}, A_{22}\}$. In both situations the advantage of adding organic trials decreased with an increase of the environmental variance. However, the surfaces (a) and (b) are different, and the difference is caused by the value of the genetic correlation. In (a), the increase of response to selection with increasing π is almost linear for all values of φ, whereas in (b) it is more curved.

2) In Figures 6.2c and 6.2d the effect of the genetic correlation, r_G, and of the proportion of added organic experiments, π, is shown for a fixed environmental variance of 21.16 and 0.02, respectively. The situations depicted in Figures 6.2c and 6.2d differ in the relation between φ and A_{11}, A_{22}. In Figure 6.2c, φ and genetic variances are of the same order; the dependence of selection response R_A on π is different for different values of r_G. In other words, the optimal choice of the number of organic experiments would depend on r_G. In Figure 6.2d, φ is much smaller than A_{11} and A_{22}, and the optimal choice of π practically does not depend on r_G, at least not in the range of r_G from 0.70 to 0.98.

3) In Figure 6.2e and Figure 6.2f we observe different optimizing situations. In Figure 6.2e the genetic correlation is high, but the environmental variance components are as big as the genetic variances. In consequence, the function is almost linear, and the increase of response to selection is comparable for all values of π, which means that replacing non-organic experiments by organic ones is always improving the selection for organic conditions by approximately the same value. In Figure 6.2f the genetic correlation is lower, but genetic variances are much bigger than the environmental variances. In consequence, the function is more curved, and after adding a number of organic experiments, say 3 ($\pi = 0.6$), the gain from further increase is getting smaller.

The fact that the functions in Figures 6.2e and 6.2f are both increasing functions means that allocating more organic experiments always gives more information. In particular, allocating all additional resources to organic experiments would give maximum selection gain. Generally, the effect of π on response to selection may seem surprisingly small. Note, however, that the small differences are mainly a result of the large genetic correlations, which mean that organic and non-organic trials provide very similar information. In the limit, when $r_G = 1$, both types of trial are, in fact, completely exchangeable.

In addition to the above interpretation, from the graphs (Figure 6.2e and 6.2f) we can deduce the gain in response to selection for each added organic experiment: about 0.4 kg/ha for yield in French data, and 0.005 units for lodging in Dutch II data.

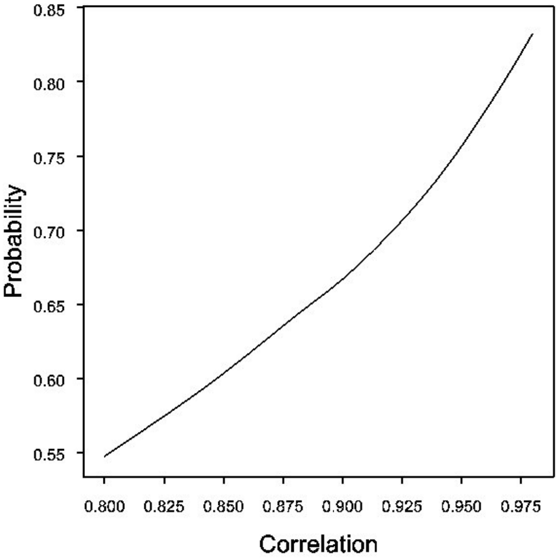

Figure 6.3. Probability that one variety, that belongs to the top 10% of varieties in an organic system, also is ranked in the top 10% of a non-organic system, for values of the genetic correlation from 0.80 to 0.98 (results based on simulations).

6.3.3. **Relation to ranking of varieties**

In addition to analysis described so far, a series of simulations was carried out to illustrate the effect of the genetic correlation on the agreement of rankings of genotypes in the two systems. Specifically, we generated bivariate random standard normal deviates with correlation r_G. As the measure of agreement we took the probability of a genotype being in the top 10% of the ranking in one system of trials, conditionally on it being ranked among the top 10% in the other. It was assumed that the number of genotypes is 50 and the simulations were done for r_G from 0.80 to 0.98, the range observed in the experiments. Figure 6.3 shows the mean probabilities obtained in 500 simulations. For example, for $r_G = 0.95$, it is expected that the probability that a variety ranked 1-5 in the non-organic system will be also ranked 1-5 in organic system is equal to about 0.75; for $r_G = 0.98$ the corresponding probability is about 0.85.

6.4. Discussion

6.4.1. Statistical approach

We have shown how to use a mixed model approach to estimate the parameters describing genetic and non-genetic variances in series of field trials conducted under two agronomical regimes: organic and non-organic. The genetic variance was allowed to be different in the two systems. The agreement of the genotypic means in the two systems was modelled by the genetic covariance. To make the model more realistic, the error variance was allowed to vary between experiments. To unify the model for all considered series of experiments, the years and locations have been combined to form “environments”; a separate representation of these factors in the model would be difficult due to generally small numbers of their levels. While we do not expect grossly different results when the environmental effects are partitioned into effects for years and locations, we could not substantiate this conjecture due to small sample sizes. It would be useful to investigate this by conducting experiments under both systems in many locations and many years in particular.

We have shown that selection can be useful concept in variety testing. In fact, the decision as to whether a candidate variety is to enter the national list is clearly a selection decision. Also, a recommendation of released varieties based on post-registration trials implies a selection among all listed varieties. Following, the work of Piepho & Möring (2005) we have shown how to use the estimated variances to obtain predicted responses to selection and to index selection. The response to selection was also expressed as a function of variable parameters to simulate different experimental situations.

The approach based on index selection is commonly used for situations in which correlated traits are observed in the same conditions (Falconer & Mackay, 1996; Piepho & Möhring, 2006). It has also been used for the problem of deciding if it is worthwhile to subdivide a target region into subregions for local recommendation (Piepho & Möhring, 2005). The present study provides another example that this approach is flexible enough to treat larger class of problems.

Common features of series of variety trials are missing data, as some traits are not observed in all experiments, and non-orthogonality, caused by the choice of genotypes. Although the REML algorithm used to estimate the variance components is numerically quite robust against missing data and some non-orthogonality (Piepho et al., 2008), we did not succeed to analyse all data (trials/traits) in the collected data sets. The main obstacle was the use of different sets of varieties in different trials, environments, or, particularly, systems. Not all of the experiments used in this study were initially designed to primarily compare systems. For future studies comparing organic and conventional trials, it is recommended to use the same sets of varieties and to use the same sites.

For some of the analysed data sets, the REML algorithm gave negative estimates of variance components. Also, in some cases, the genetic correlation calculated from estimated genetic variances and covariances was bigger than one. This can happen if the values of the parameters are close to or at the boundaries. As consistent estimates of the parameters were needed for further calculations, in such situations we applied procedures restricting the parameters, i.e., the negative variance components were set to zero, and the correlation was set to one.

It should be noticed that the approach used here to analyse response to selection considers only one trait at a time. Practical selection is never based just on one trait. The model of index selection has the potential to be extended to the multivariate case, but this was not done in this investigation. Also, the probabilities of ranking agreement could be calculated for simultaneous selection on several traits; but as probabilities of products of random events are involved, the probabilities of ranking agreement would probably be quite low.

The predicted response to selection for the traits measured on an ordinal scale was in some cases very high in relation to the mean value in organic conditions. This is probably a result of bias due to lack of normality, and it may be preferable to analyse these traits by generalized linear mixed models for ordered categorical data, though care needs to be exercised regarding asymptotic properties of these methods (Breslow & Clayton, 1993).

6.4.2. **Interpretation of the results**

As is commonly reported in comparisons between organic and conventional cropping systems in industrialized countries (Padel & Lampkin, 1994) we found that the mean values for the organic system were usually lower than for the conventional system. For yield this was accompanied by a specific relation between the corresponding genetic variances. It seems that the general statistical rule of some dependence between mean and variance is partly responsible for these observations. However, for soil coverage in the UK and Dutch studies, the genetic variance was higher in the organic system than in the conventional system, despite the lower mean value in the organic system. This was also true for plant height in the Dutch case. In the UK study plants were about 5% taller in the organic system, while the genetic variation for plant height was about two times higher compared to the conventional system. This agrees with one of the second author's field observations, that due to the usually abundant canopy development in a conventional trial, differences between varieties in vegetative traits (soil coverage, leafiness) are less easy to assess in the conventional trials than in organic trials. Remarkably, in the studies that compared organic and low input systems (French, Swiss), the genetic variation for plant height was lower in organic trials.

The genetic correlations observed in the experiments, ranging from 0.79 to 1, seem to be high. However, interpretation in terms of probability of ranking agreement shows that this does not correspond to error-free conclusions about one system on the basis of experiments in the other. Simulations showed that despite the high genetic correlation, the probability that a top 10% variety in one system, also would be top 10% in the other, could be moderate, e.g., about 0.85 for a genetic correlation of 0.98. It also should be noted that despite the high correlation, in most data sets the individual authors could identify specific varieties that deviate from the mean pattern by either performing better in the organic or non-organic system.

The estimated genetic variances, covariances and correlations were also used to calculate responses to index selection, which uses information from both organic and non-organic trials, and to both direct and indirect selection. By definition, the response to index selection is higher than to direct and indirect one. The difference between the response to index and indirect selection, which can be used as to measure of the necessity of running organic trials in addition to routinely used non-organic tests of varieties, was obviously higher in the situations where the genetic correlation was low. The maximum values of this difference observed in the analysed experiments, expressed in the units of the traits, were 63 kg/ha for yield and 0.66 g for TGW. For yield, this seems to be a value which can be practically significant. Obviously, this increase in selection efficiency is based on an increased number of trials. There was no consistent relation between the values of the response to direct and indirect selection. It should be noticed that the direct selection corresponds to the situation where only organic experiments are run as variety tests, or where information from existing non-organic trials would be completely ignored, which would not usually be a sensible decision-making strategy.

To illustrate the functional relation between the variance components and the selection response, an example of lodging in Dutch II data set was chosen. We made this choice because in this case genetic variances were much larger than the environmental variance, and genetic correlation was low. This allowed to show two contrasting situations. However, it should be noticed that the difference between variance components has a clear interpretation: lodging is not very common in organic trials, so genetic differences between varieties are not fully expressed (many 1s are observed), while in the conventional trials there is more differentiation between varieties. This also explains low genetic correlation for lodging.

We may also notice that, despite variety of crops and organizations doing experiments, the predicted response to selection was pretty similar in different series of experiments. So some consistency of parameters estimated on the basis of organic and non-organic trials can be expected across Europe.

6.4.3. **Factors influencing the results**

Exploration of the data prior to the final analysis showed the importance of the physical proximity of the organic and non-organic site. In two analysed series, from Switzerland and from U.K., the experiments in two compared systems were performed at different locations. For the purpose of the analysis, the experimenters decided how to pair the locations on the basis of similar environmental conditions to form "sites" subsequently considered as "environments". Experiments, which could not be paired, were removed. The effect was visible in the analysis. The Wald statistics for yield in Swiss data, for “systems” and for “system × environment” interaction, were larger than in other data sets. Moreover, both data sets, when analysed without this special treatment, gave quite low estimates of the genetic correlation. This was because the variability between two systems was “contaminated” with some variability between locations.

On the other hand, in practice organic and non-organic systems usually do not co-incide at the same farm. So, the requirement of proximity may lead to the choice to conduct the trials on research stations, that do not always fully represent the real practical situation, and therefore may bias the results. This risk is especially high when the organic system is represented by a "non certified" organic system, such as in the Scandinavian cases.

It is also important to note that, except for the German research, all conventional systems were not truly intensive, as no fungicides and growth regulator were used to control diseases and lodging. This was because the researchers also needed to score the resistance of the varieties for these traits under conventional growing conditions.

Difference in soil fertility between the two systems is expected to be one of the reasons for potential differences between ranking. The mean yields reflect the fertility level of the systems. The organic yields were considerably higher than in the studies in other continents (Murphy et al., 2007; Mason et al., 2007; Kitchen et al., 2003). Furthermore, from the tables one can calculate that the yield reduction in the organic system varied considerably between countries: from 5% in barley in Denmark to 47% for winter wheat in UK. However, the results do not show a clear influence of the difference in productivity between systems on the genetic correlation for yield.

Also the variety choice in the trials has an effect on the outcome. Except for the UK, in all experiments modern varieties and breeding lines, that were developed for non-organic cereal production, were chosen. One feature of modern cereal breeding is that varieties are selected for broad adaptability. In Denmark, France and Switzerland also small proportion of varieties, which were specially developed for the organic sector, were included. The UK data set consisted of selection of varieties from 1950 - 2000 from Western Europe, with a proven record of robust performance, by having occupied a larger acreage for a prolonged period of years. Hence, these also probably are varieties with a broad adaptability. One of the features of the recent studies that report genotype × system interaction (Murphy et al., 2007; Burger et al., 2008) is that these include early breeding material. A possible explanation for the high genetic correlations for yield that we found in this study may be the fact that Western European breeders strongly select for wide adaptation to cover all environments within a region. Therefore, results of this paper only apply to the variety testing system with the current range of varieties in Western Europe and cannot be extrapolated to comparisons between breeding under organic and non-organic growing conditions. For a prediction of the genetic correlations for the latter situation early breeding lines should be compared.

Finally, it should be noted that despite the many traits observed in the different studies, only yield could be analysed for all seven countries. For organic farmers, quality traits and traits that make the crop more competitive against weeds (e.g.

early soil coverage, plant length) and disease resistance are usually equally important. Unfortunately, data is lacking for more robust conclusions for these traits.

6.5. Conclusions and recommendations for variety testing

A successful selection or recommendation of the best varieties for organic agricultural in a variety testing system depends on two factors. Firstly, the varieties should be evaluated for the traits that are important for organic farmers and processors. A number of these traits (e.g. weed competitiveness) are not regularly included in the official non-organic variety testing procedures and in a number of European countries proposals have been made to consider new traits either in the official testing system or in post registration trials (Chapter 7) (Levy et al., 2007). Secondly, the varieties should be evaluated in trial environments that give the highest probability of selecting varieties that also will be the best for the key traits in organic commercial farms. This study shows how to measure the gain resulting from running organic experiments in addition to non-organic ones. This methodology can be used to make decisions regarding the optimal allocation of additional trial resources for organic farming conditions. Precise interpretation of the parameter estimates may, however, depend on the actual costs of organic experiments in a particular environment. This would lead to economic considerations which are beyond the scope of this study, though we wish to stress that inclusion of economic information is straightforward with our approach. Despite these limitations, our results clearly show that especially for yield non-organic trials provide valuable information also with respect to organic farming systems. Index selection based on a mixed model provides a convenient and efficient framework for making optimal use of this extra information.

Chapter 7:

Variety testing as a policy instrument to stimulate variety development for the organic production chain

The case of spring wheat Value for Cultivation and Use testing in the Netherlands

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Submitted

Abstract

Value for Cultivation and Use (VCU), the mandatory variety testing system for agricultural crops in the European Union (EU), has been used as a policy instrument by favouring the release of variety types that enable desirable developments, such as reducing fungicide use. With this paper we aim to assess whether VCU can be used to enhance the availability of varieties suitable to organic farming. Therefore we analyse data of an organic spring wheat VCU project that was conducted between 2001 and 2004 at three locations in the Netherlands. Varieties selected through organic VCU were clearly more suitable for organic production than those registered through the conventional procedure. However, new varieties could not match the baking quality of the organic standard variety. We conclude that enhancing the number of suitable varieties for the organic sector requires adapting both conventional breeding programmes as well as the VCU system. As we also found that costs of VCU hamper the release of varieties for emerging markets, we reflect on possible adaptations of the VCU system within the EU statutory framework on seeds.

Keywords:

variety testing; Value for Cultivation and Use; EU seed legislation; spring wheat; organic production

7.1. Introduction

To produce results that are relevant to farmers, traders and processors, variety tests should be representative for the growing conditions in farmers' fields and handling and processing practices further down the production chain. Variety testing systems may be biased towards certain plant types, either in a positive or negative sense (Louwaars, 2007). As national and regional variety tests are usually designed to reflect the prevailing crop production system, these may select against variety types that fit newly emerging cropping systems. The variety testing system in the European Union (EU), the so called Value for Cultivation and Use (VCU) testing, has hampered the release of varieties adapted to organic farming. Various cereal breeders state that candidate varieties with traits favoured by organic farmers, such as weed suppression or baking quality, would be rejected in conventional VCU for not matching the minimum requirements for yield (Löschenberger et al., 2008; Rey et al., 2008; Rolland et al., 2008).

VCU testing is a mandatory step in the variety release procedure of field crops, regulated by EU and national legislation (see Box 7.1). In this system varieties that fail to pass VCU testing will not become available to farmers, because the marketing of these varieties is prohibited by law. To overcome this barrier to market release, organic VCU testing protocols have been developed in several European countries including the evaluation of additional traits specific to organic production (Osman & Lammerts van Bueren, 2003; Steinberger, 2003; Kleijer & Schwärzel, 2006; Schwärzel et al., 2006; Löschenberger et al., 2008; Fontaine et al., 2010). Whether and how organic VCU is implemented varies from country to country (Mariegaard Pedersen, 2012). Differences between countries include evaluation criteria, set-up (separate or additional part of the conventional VCU procedure) and height of the fees.

VCU has played an important role in supporting agricultural policy (Wiskerke, 2003; FCEC, 2008). Only allowing the most productive varieties on the market, prevented and protected farmers from growing lower yielding varieties. In this way VCU contributed to one of the main original EU policy goals, namely achieving food security. From the 1980s onwards, VCU testing also has been used to address environmental issues like reducing fungicide and fertilizer use (Oskam et al., 1998; Van Waes, 2011). The objective of this paper is to analyse whether and how VCU testing can be used as a policy instrument to support organic farming by enhancing the availability of varieties with traits specifically required by the organic sector.

The analysis is based on the case of adapting the VCU testing protocol for spring wheat in The Netherlands to the needs of the organic sector. Spring wheat was chosen for this study, because, together with potato, it is one of the major organic field crops in the Netherlands that is subjected to obligatory VCU testing. At the start of our research in 2001 only one out of the five varieties on the Dutch Recommended List of Varieties of Field Crops was considered suitable for organic farming. To diminish its reliance on one single variety and to enhance genetic diversity, the organic sector was looking for other suitable varieties released in neighbouring countries. This orientation on foreign lists illustrates the limited value of the spring wheat section of the Recommended List for Dutch organic farmers at that time.

In this paper we first describe the Dutch VCU system and the possibilities for innovation, namely adapting the spring wheat VCU protocol to the needs of the organic production chain. We will then analyse whether the implementation of four years of organic spring wheat VCU enhanced the availability of varieties matching the needs of the organic sector. Finally, we will reflect on the perspectives for improving the VCU system in the context of an on-going debate on modernizing the EU statutory framework on seeds.

Box 7.1. Definition of Value for Cultivation and Use within the EU

Within the EU, passing Value for Cultivation and Use (VCU) testing is mandatory for field crops (cereals, potato, legumes, fodder crops, etc.), but not for vegetable crops. This is defined and regulated through the two Council Directives 2002/53/EC (Council, 2002) and 2003/90/EC (EC, 2003). According to Council Directive 2002/53/EC on the common catalogue of agricultural plant species, VCU of a variety

"shall be regarded as satisfactory if, compared to other varieties accepted in the catalogue of the Member State in question, its qualities, taken as a whole, offer, at least as far as production in any given region is concerned, a clear improvement either for cultivation or as regards the uses which can be made of the crops or the products derived there from. Where other, superior characteristics are present, individual inferior characteristics may be disregarded."

Annex 3 of Council Directive 2003/90/EC roughly defines criteria that should be considered:

- Yield;
- Resistance to harmful organisms;
- Behaviour with respect to factors in the physical environment;
- Quality characteristics.

The above shows that the EU directives addressing VCU (Council directives 2002/53/EC and 2003/90/EC) only give a general definition of VCU and how it should be implemented, which provides member states the possibility to adapt VCU testing procedures to their specific conditions and leaves flexibility to address new needs.

7.2. The VCU system in The Netherlands

In the Netherlands, the Plant Variety Board (*Raad voor Plantenrassen*, a government agency), is responsible for the registration of new varieties. Since the introduction of the new Dutch Seeds and Plant Materials Act in 2006, VCU tests are fully financed by the main stakeholders in the crop production chain (breeders, farmers, traders, processors). While individual breeding companies make a direct financial contribution, the other stakeholders finance the system indirectly through levies collected through their professional organizations. As a result, contributing parties also have a large influence on testing protocols and release criteria through representation in the Committee for the Compilation of the Recommended List of Varieties (CSAR) and crop-specific advisory groups, linked to both CSAR and the Plant Variety Board.

Successfully passing two years of VCU testing leads to registration in the National List of varieties, which is a prerequisite for market release. However, all breeders go for an optional third year of testing for inclusion in the Recommended List of Varieties because most conventional farmers only choose varieties from the latter list (Wiskerke, 2003). The National List is compiled by the Plant Variety Board. Since the Recommended List is not a legal obligation, the Dutch government has transferred the compilation of the Recommended List to the private sector, represented by CSAR. As a consequence, criteria for National Listing are set by the Plant Variety Board and the criteria for the Recommended List are developed by CSAR. The Plant Variety Board is primarily bound by EU Regulations (see Box 7.1). The Board distinguishes between traits considered of public interest and traits of private interest. The first type of traits includes characteristics related to food safety (e.g. resistance against diseases producing mycotoxins) and resistances against plant diseases that spread beyond the boundary of individual farms (e.g. resistance against air-borne diseases). Grain yield is an example of a trait considered of private interest. Criteria for traits of public interest do not differ between the National and Recommended List, while criteria for traits considered of private interest are less stringent for the National List than for the Recommended List.

The official and most direct route to adopt VCU testing protocols for organic farming is by discussions within the crop-specific VCU advisory groups, which are officially linked to the Plant Variety Board as well as to the CSAR. As an alternative, the Dutch system offers many options to (organised) stakeholders to propose VCU testing protocols adapted to their specific needs, provided they can finance the implementation.

The current Dutch VCU has been operative since 2006. At the time of the research project described in this paper (2001-2004), the same private sector parties, which are currently represented in the CSAR, were also involved in developing VCU protocols and advising on admission in the Recommended List. However, in contrast to the current situation, compiling the Recommended List was still the responsibility of the predecessor of the current Plant Variety Board, the Variety List Commission (*Commissie voor de Samenstelling van de Rassenlijst voor Landbouwgewassen*, also a government agency).

7.3. Material and methods

7.3.1. **Field experiments**

Varieties

Between 2001 and 2003, each year (candidate) varieties were obtained from six Dutch seed companies, one company with a spring wheat breeding programme in the Netherlands and the other five companies representing German, Swedish and UK breeders. All six companies were asked to provide material which would meet the requirements set by an organic variety profile developed by organic end-users (Table 4.1, page 70). Furthermore, four varieties listed in the Dutch Recommended List of varieties were included as standards. Of these four varieties, only *Lavett* was widely grown by organic farmers and according to farmers, traders and millers this variety performed well for all required traits. Therefore *Lavett* was used as a benchmark for a spring wheat variety suitable for organic production.

Table 7.1. Evaluated characteristics in the organic VCU trials.

Characteristic	Evaluation method and dimension
***Field traits*:**	
Emergence	Visual on a scale 1 - 9 where 9 = 100% emergence
Early soil coverage	Visual on a scale 1 - 9 where 9 = good coverage
Leafiness after ear emergence	Visual on a scale 1 - 9 where 9 = dense
Ear density	Visual on a scale 1 - 9 where 9 = lax
Peduncle length	Measurement in cm.
Plant length	Measurement in cm.
Lodging	Visual on a scale 1 - 9 where 9 = no lodging
Earliness ripening	Visual on a scale 1 - 9 where 9 = early
Infection with diseases:	Visual on a scale 1 - 9 where 9 = no infection
Yellow rust *(Puccinia striiformis)*	
Brown rust *(Puccinia triticina)*	
Septoria tritici blotch (*Mycosphaerella graminicola*)	
Sprouting	Visual on scale 1 - 9 where 9 = no sprouts
Grain yield	Measurement in kg/plot
Baking quality traits	
Specific weight	Measurement in kg/hl
Protein content	NIRS in %
Zeleny sedimentation	Measurement in ml
Hagberg falling number	Measurement in s
Loaf volume	Measurement in cm^3
Bread quality	Bakers' overall impression on a scale 1 - 9 where 9 = combination of high loaf volume, and good crust, crumb and dough properties

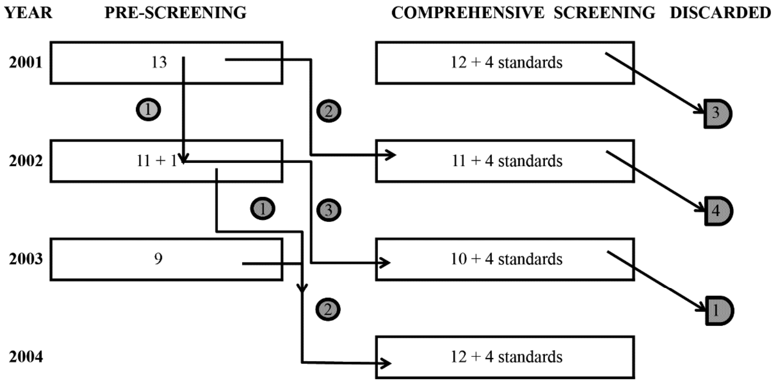

Figure 7.1 Number of accessions per trial and flow of accessions between trials (additions to the comprehensive screening in circles, deletions in half-circles).

Set-up of variety testing

The experimental organic VCU testing was conducted at three certified organic farms during 2001-2004. All farms were situated on clay soils in different parts of the country: Kollumerwaard (North-East), Nagele (Central polders) and Schoondijke (South-Western part of the Netherlands). At the experimental farm at Nagele the trials were sown both under organic and conventional growing conditions.

Like the regular VCU testing in the Netherlands, the organic VCU testing followed a two-step approach that consisted of a pre-screening of new candidate varieties at Nagele, followed by a comprehensive screening at three locations of the most promising lines in the following years. As a result the composition of the set of varieties in the comprehensive test slightly changed over the period of four years (Figure 7.1). The pre-screening was conducted in the first three years of the project and the comprehensive screening was done during all four years. All trials were sown in a randomized complete block design. The pre-screening was sown in two replicates and the comprehensive screening in three replicates.

Traits that were evaluated are listed in Table 7.1. Grain quality analyses were conducted by the laboratory of an industrial mill (Krijger Molenaars, Renesse), following ICC standard methods. Baking tests were conducted and evaluated by an experienced professional test baker (R. Bottemanne, Fontys Hogescholen, Wageningen), following a standard protocol developed for traditional mills (Osman et al., 2005).

Statistical analysis of results

Data were analysed with the software package GenStat (14th edition). To study whether the VCU-protocol stimulated breeders to submit varieties with traits preferred by organic end-users the following procedure was implemented. Separate two-way ANOVAs were conducted, with variety and cropping system (organic, conventional) as treatments, for each of the three pre-screening trials and the first year of the comprehensive testing, including calculation of means and protected LSD-values ($P < 0.05$). The LSD-values were used to distinguish accessions that were significantly better than, equal to or inferior to the mean of the standard variety *Lavett*. Baking quality variables were not statistically analysed, because the baking tests were carried out without repetitions.

To study whether the organic VCU testing procedure improved selection of varieties adapted to organic conditions, data of the organic sites of the comprehensive screening were submitted to a mixed model analysis, with variety as fixed factor and year, location and block as random factors. Due to the large number of missing values, data of Kollumerwaard were not included in the final analysis presented in this paper.

7.3.2. Qualitative data

Information on the development and adoption of the VCU protocol was derived from internal reports, minutes of meetings and workshops and the correspondence of the organic wheat variety working group supervising the implementation of organic VCU (see also results section). Feedback from breeders was gathered through informal and formal qualitative interviews with participating breeders and participant observations during annual field visits and meetings.

7.4. Results

7.4.1. Developing and adopting organic spring wheat VCU in the Netherlands

The VCU test protocol was developed in a participatory manner. A committee of three experienced organic wheat growers and the first author elaborated a first draft protocol, which was presented and discussed in a plenary session with organic farmers, traders, processors, conventional breeders and representatives of the Variety List Commission. The improved final version was submitted to the Variety List Commission which endorsed this protocol in 2001. Table 7.2 shows the adaptations to the conventional protocol that consisted of:

- adapting the protocol for the organic growing conditions, including field and crop management and seed treatment;
- adapting the testing procedure for baking quality to most common organic breadmaking practices, i.e. main product is wholemeal bread and most bakers prefer to restrict the use of additives and processing aids;
- including additional traits of relevance for organic agriculture in the field evaluation.

Table 7.2. Differences between the conventional spring wheat VCU protocol and the organic protocol proposed by stakeholders of the organic bread wheat production chain (adapted from Osman & Lammerts van Bueren, 2003).

	Organic VCU protocol	Conventional VCU protocol
Field and crop management:		
Trial site	Managed organically for at least three years, in accordance with EU regulation 2092/91	Managed conventionally with mineral fertilisers and herbicides. In order to evaluate disease and lodging resistance fungicides and growth regulators are applied to only half of the replicates.
Seed treatment	Not chemically treated	Treated with fungicide
Baking quality test	Evaluation on whole meal bread without artificial bread improvers	Evaluation on white bread with addition of ascorbic acid
Field evaluation	Inclusion of the following additional traits: • Recovery from harrowing • Tillering capacity • Early soil coverage • Canopy density • Stay green index • Peduncle length • Ear density • Black moulds in the ear • Resistance against sprouting	

In the next step a Working Group was formed to guide the implementation of the protocol. The Working Group consisted of representatives of the organic wheat production chain, Variety List Commission and researchers. Breeders actively participated in improving the drafts of the organic VCU protocol, but declined the invitation to nominate a representative in the organic VCU Working Group.

To further embed organic VCU testing in the existing variety release system, it was proposed to include the organic Working Group in the official structure of Working Groups that advised the Variety List Commission. As this was not acceptable for the parties already represented in the system, it was decided to keep the organic spring wheat working group outside the regular structure of advice.

The organic spring wheat VCU testing was implemented between 2001 and 2004 as a research project (see also the Material and Methods section) financed by the Dutch Ministry of Agriculture, Nature Conservation and Fisheries, the Commodity Board for Arable Crops (HPA) and the Foundation for Experimental Farms for Arable Crops in the Northern Region of the Netherlands (SPNA). The Variety List Commission used the results of the organic VCU testing project to introduce an organic spring wheat section in the Recommended List of Varieties (Bonthuis et al., 2005). However, seed companies clearly indicated that they would not apply for specific organic VCU testing in the future if this would involve costs, due to the small acreage (about 2100 ha in 2004; Table 1.1; page 11) of organic spring wheat in the Netherlands. As for organic farmers financing spring wheat VCU testing was not an option either, up to the date of this publication no new trials were set up.

7.4.2. **Effect of the implementation of organic VCU**

In this section we examine whether organic VCU improved the availability of suitable varieties for the organic sector. In contrast to their conventional colleagues, Dutch organic farmers are looking for high baking quality varieties, with traits that contribute to weed suppression (rapid early growth, plant length, leafiness) and a less compact plant architecture (Chapter 4). The latter is thought to slow down the development of diseases. We will first analyse whether the organic VCU stimulated breeders to submit lines with the required traits. Secondly, we assess whether the adapted VCU protocol allowed the inscription of better suited varieties in the Recommended List of Varieties.

Did organic VCU testing stimulate breeders to send in lines with traits preferred by organic end-users?

During the whole trial period breeders presented 45 accessions that were not listed yet in the Netherlands. A relatively large proportion of the accessions showed improved lodging resistance (44%) and resistance to brown rust (*Puccinia triticina*) (31%) (Figure 7.2). Also, 28% of the accessions had a longer peduncle, whereas 39% had a shorter peduncle than *Lavett*. This variation probably indicates that breeders did not select for peduncle length. A relatively large proportion of the accessions were deficient in traits that contribute to weed competition like early ground cover (44%) and tall plants (69%). This shows that breeders did not manage to provide a large proportion of accessions from their breeding programmes that were distinct from the lines they would send in for conventional VCU testing.

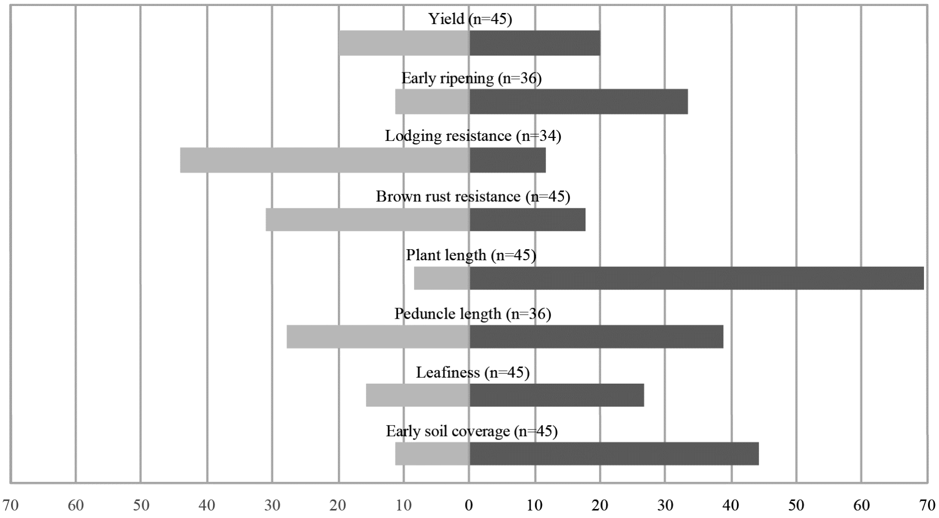

Figure 7.2. Percentage of lines that performed better (light grey) or worse (dark grey) than *Lavett* (P < 0.05) (n = total number of lines).

Candidate varieties without major shortcomings for the evaluated traits passed from the pre-screening to the comprehensive screening. In total 8 out of the 33 (24%) accessions tested in the pre-screening passed to the next phase of VCU testing (Figure 7.1). This percentage only slightly varied between years, ranging between 21% and 27%.

Did organic VCU testing enhance the number of varieties suitable for the organic sector on the Recommended List of Varieties?

Comparing the varieties that were first submitted for organic VCU before registration in the Recommended List of Varieties with those that first passed conventional VCU provides insight in whether organic VCU increased the number of varieties suitable for organic end users. The new organic section included six varieties. Three of these six cultivars (*Melon, Quattro, Thasos*) were new registrations, while the other three varieties *(Lavett, Pasteur, Tybalt*) were already listed in the conventional section (see also Table 7.3). During the same period four new varieties were added to the conventional spring wheat section of the Dutch variety list (*Pasteur, Tybalt, Zirrus, Quattro*). *Quattro* is a special case. Its representative first offered this variety for organic VCU. After two years of satisfactory performance in both the organic and conventional trials of the VCU-project, the seed company decided to apply also for conventional VCU for *Quattro*.

Table 7.3. Spring wheat varieties that entered the Dutch Recommended List of Varieties between 2002 and 2006.

Varieties included in the Recommended List between 2002 and 2006		Early soil coverage	Leafiness	Plant length (cm)	Ear density	Peduncle length (cm)	Brown rust resistance	Septoria resistance	Lodging resistance	Sprouting resistance	Earliness ripening	Grain yield (kg/plot)	Protein content (%)	Zeleny-sedimentation (ml)	Bread quality
A: First application through organic VCU	Melon	6.1	6.2	93	6.4	21	7.8	6.6	8.6	4.7	6.5	15.7	10.6	36	6.2
	Thasos	6.3	6.5	100	5.9	22	6.6	7.0	7.3	4.2	6.9	15.7	11.1	39	6.7
	Quattro	6.3	6.5	100	7.6	25	7.5	7.8	7.1	3.8	5.5	15.8	10.1	37	6.9
B: Listed through conventional VCU	Pasteur	4.7	5.8	91	5.4	18	8.8	8.1	7.9	4.6	5.9	15.5	11.4	39	4.7
	Tybalt	5.8	7.4	87	4.5	14	9.0	7.1	7.9	6.2	6.3	17.4	10.5	33	6.2
	Zirrus	5.6	6.9	90	6.2	18	6.2	7.0	7.3	5.4	5.8	17.5	9.5	34	6.1
Organic standard	Lavett	6.4	6.6	101	8.0	22	8.3	6.1	7.7	4.6	7.5	15.2	10.7	38	8.2
Mean A		6.2	6.4	98	6.7	23	7.3	7.1	7.6	4.2	6.3	15.7	10.6	37	6.6
Mean B		5.4	6.7	89	5.4	17	8.0	7.4	7.7	5.4	6.0	16.8	10.5	35	5.6
SED		0.3	0.4	0.9	0.3	0.5	0.5	0.4	0.5	0.6	0.4	0.4	0.3	2.3	0.6

Table 7.3 shows that varieties selected through the organic VCU (Group A) differed from the varieties that entered the Recommended List through the conventional VCU (Group B) for early soil coverage and plant length, which contribute to weed suppression. Group A varieties were also less compact with a more open ear and a longer distance between ear and leaf canopy than Group B varieties. On the other hand, the two newer varieties (*Tybalt, Zirrus*) that were approved through the conventional VCU procedure were higher yielding and more resistant to pre-harvest sprouting than Group A varieties. Also two of the group B varieties (*Pasteur, Tybalt*) showed the highest resistance to brown rust.

In comparison to the organic standard *Lavett*, the new varieties in the organic section of the Recommended List performed similarly for weed competition, plant health traits and yield, but were slightly later ripening and inferior in bread quality.

7.4.3. Feedback from breeders on the organic VCU testing project

Breeders considered it interesting to learn about the performance of their material under organic growing conditions. At the beginning of the project, they did not exactly know which of their lines fulfilled the requirements of the Dutch organic sector. In interviews, participants indicated that field trial visits and annual project meetings improved their understanding of the needs of the organic sector.

Breeders were asked to submit lines that matched the organic spring wheat variety profile provided to them at the onset of the project (Table 4.1, page 70). However, they admitted that they had added their own requirements to the organic variety profile: for them the submitted lines also needed to be of interest for the conventional market, which meant that they looked for high-yielding varieties. During meetings breeders made clear that they considered the Dutch organic spring wheat market too small to maintain and multiply varieties that are only of interest to the organic sector. Indeed, in two occasions, candidate lines selected by the project for the next phase were withdrawn, because the seed company considered grain yield of these lines too low to compete with other varieties already available on the market.

7.5. Discussion and perspectives

Within the EU, Austria has the longest history of a functional yearly organic VCU. The organic procedure enabled the registration of 12 winter wheat varieties between 2006 and 2011 (AGES, 2012). According to Löschenberger et al. (2008), varieties that passed the Austrian organic VCU would not have passed conventional VCU tests due to their lower yield. The results of the Dutch spring wheat case, presented above, also show that adapting the VCU testing protocol can bring about changes in the assortment of recommended varieties. However, none of the newly recommended varieties reached the required baking quality level of the organic standard *Lavett*. Moreover, the varieties that entered the Dutch Recommended List of Varieties through the organic procedure, *Melon*, *Thasos* and *Quattro*, were newly listed in the Netherlands, but not quite new because all three were already included in the German Recommended List of Varieties between 1994 and 1997. This is quite worrying for the organic sector, as it indicates that current spring wheat breeding programmes are unable to provide suitable new varieties for the organic sector. Below we will discuss the major issues that influenced these results: availability of suitable candidate varieties and the costs of the VCU testing system.

7.5.1. **Availability of breeding lines adapted to the needs of the organic sector**

The conventional seed companies involved in the project did not specifically breed and select spring wheat for organic farming. Therefore they normally do not evaluate their material for traits that are of specific interest to organic farmers, such as weed competition and morphological traits contributing to plant health, but not important for conventional wheat production (Chapter 4). According to breeders they needed the information of the field trials and discussions during meetings to learn about the performance of their material under organic growing conditions and to better understand the needs of the organic sector. However, the percentage of submitted lines with desired traits did not increase from the first to the third year of pre-screening. So, apparently a better understanding of the needs of the organic sector was not sufficient to affect the submission of lines that matched the organic variety profile.

This can be explained by the fact that breeders aimed to register varieties that would fit both the organic and the conventional market. Selecting such varieties is only feasible when priority traits for both cropping systems do not conflict with each other. However, for wheat this is not the case, because “yield” and “baking quality” are known to be negatively correlated (Chapter 5). For the organic sector, baking quality receives a relatively higher priority and yield a relatively lower priority than for the conventional market. Also the high proportion of lines that did not reach the plant length preferred by organic farmers can be explained by the fact that this preference conflicts with the need to breed shorter stature varieties for conventional wheat production. Selection for phenotypes preferred by conventional farmers greatly reduces the chance that advanced breeding lines possess the combination of traits required by the organic sector. In order to also be able to meet the needs of the organic sector, breeders would also need to maintain lines with the required traits earlier in their breeding programme. Thus, it would take several years before results of such an intervention in the ongoing breeding programmes would become visible. However, seed companies are only prepared to invest in this change in their selection programme, when there are sufficient market perspectives for the resulting varieties, which for wheat means a market segment of about 50,000 ha, according to participating breeders.

7.5.2. **Flexibility to adapt VCU to new needs**

Within the EU, VCU testing is regulated by EU directives and national law (Box 7.1). As also shown by the spring wheat case, in principle these laws leave sufficient flexibility to adjust implementation to local conditions and new demands at national level. As a result, organisation and implementation of VCU testing, as well as the way to induce changes in the system, differ between member states. In the case of the Netherlands, the regular VCU testing system is shaped to serve the needs of the stakeholders who fund the testing, namely breeders, conventional farmers, traders and processors. These conventional stakeholders opposed including organic VCU within the existing structure. However, the Variety List Committee, as the supervising authority proved to be open to new developments and used its mandate to install a new organic spring wheat VCU system parallel to the existing ones.

7.5.3. **The role of costs of the VCU procedures**

The spring wheat VCU system which was developed by the project was abandoned when subsidies stopped as both breeders and organic sector were not able or prepared to bear the costs, which both groups considered too high in relation to the spring wheat acreage. Also in other EU countries costs of VCU testing was considered a bottle neck for the relatively small organic sector (Rey et al., 2008).

Application and testing costs also influence the number of varieties that breeders submit. For the current conventional spring wheat VCU testing participating seed companies have limited the total number of candidate varieties to four per year to reduce costs of the VCU system. This is considerably less than the 45 (candidate varieties) they submitted during the four years of the organic VCU project. Hence, the Dutch spring wheat case shows that subsidizing organic VCU, stimulated seed companies to submit more candidate varieties than they usually send in for conventional VCU.

7.5.4. **Perspectives to adapt the VCU system**

The spring wheat case demonstrates that for production systems and crops covering relatively small acreages, costs of VCU testing discourages the release of new varieties. This is not only a problem for the emerging organic sector, but also for initiatives oriented towards the development of regional and speciality food crops for high value niche markets. This was also recognized by policy makers of the EU who reviewed the European statutory framework on seeds (EC, 2011) and drafted a proposal for a new regulation (EC, 2013). The mandatory VCU testing system was also part of these discussions. Some parties consider that in the current era it is not a task of the EU and national governments anymore to decide on which varieties can be grown by farmers and which cannot, as this should be left to the private parties involved. However, others see VCU testing as a valuable and essential tool to support farmers in variety choice by generating independent information on variety performance and also to guide the direction of breeding. The latter parties fear that with leaving VCU testing voluntary, the system will collapse. The proposal for a new EU regulation on seeds follows the latter line of thinking. It even proposes to include rules for testing for suitability for cultivation in resilience and low-input production systems (including organic systems) and testing for so-called sustainable VCU (resistance to pests, reduced use of resources, among others). The proposal sees the latter as "*an important tool to guide the breeding process to a more sustainable direction*" (EC, 2013, p.7).

The proposal also offers member states the possibility to deal with the costs issue. In the first place, the proposal offers the possibility to exempt varieties for small market segments from the obligatory registration. However, stringent restrictions attached to this option (only open to small seed companies, restricted quantities of seeds, package size) may make this route unattractive. In the second place, like in the past, national authorities are left with the liberty to adapt protocols to specific needs and accept information provided by applicants. One option to reduce trial costs would be combining information on variety performance of a limited number of formal trials with information gathered from private trials conducted by breeders and growers (FCEC, 2008; Rey et al., 2008; ECO-PB, 2012) or complementing data from organic variety trials with information from conventional VCU (see also Chapter 3 and Chapter 6).

7.6. Conclusions: can variety testing be used as a policy instrument to direct variety development?

Mandatory VCU testing may prohibit the release of better adapted varieties for emerging cropping systems with only relatively small acreages. This paper demonstrates that adapting the VCU testing protocol enhanced the availability of suitable varieties for the organic sector. However, the spring wheat case study shows that when required variety traits conflict with the traits required for the main cropping system, adapting VCU testing to the needs of the organic sector, is not sufficient to enhance the variety assortment. Breeders also would need to make adjustments in their selection programme to be able to provide appropriate lines adapted to organic and low-input farming systems.

Implementing adapted protocols will only be feasible for small market segments when costs of a formal trial system are in proportion to market size and expected benefits. The EU legislation permits flexibility in the implementation of the VCU testing system. For small market segments, a combination of formal trials and data gathered from breeders and growers may be a way to bring costs more in line with benefits.

General Discussion

Chapter 8:
Reflections on enhancing the variety assortment for the Dutch organic sector

8.1. Preamble

At the beginning of this research trajectory, in 1999, organic breeding programmes were scarce. Consulted organic farmers in the Netherlands expressed their preference to work together with the existing, well developed, conventional seed sector to obtain varieties better adapted to organic growing conditions. They argued that for crops that were not addressed by organic breeders yet, working together with the conventional seed industry would be more cost effective and give faster results than setting up separate organic breeding programmes. At the same time, most conventional breeders were unfamiliar with the organic sector and its needs. Nevertheless, conventional breeders generally disputed the need for separate organic breeding programmes and assumed that their on-going programmes would provide varieties that better suited the needs of the organic sector if they would better know its needs. Based on my research and development activities in onion and spring wheat, in the previous chapters I have analysed whether and how the existing breeding system should be adapted to be able to select varieties that better fit the needs of the organic sector. In this final chapter I first highlight the main findings (Section 8.2). Section 8.3 provides a reflection on how these findings relate to the general principles of organic farming. Finally, I present perspectives to breed varieties that better match the requirements of the organic sector.

8.2. Overview of the main findings

Conventional breeders do not provide the type of varieties needed by the organic sector. The results of the onion (Chapter 3) and spring wheat (Chapter 7) variety tests show that varieties currently on the market display important weaknesses when used in organic production systems. For organic onion growers, the available variety assortment needs to be improved for storability, resistances against main foliar diseases, and the root system. Furthermore, onion varieties need to produce sufficient amounts of seeds under organic growing conditions, to keep the price of organic seeds affordable. In the case of spring wheat, weed suppressiveness and baking quality under relatively low nitrogen input conditions need to be improved.

Conventional breeders would need to make major modifications to their on-going breeding programmes (choose different crossing parents, include organic selection nurseries, give priority to other traits) to be able to select varieties that match the requirements of the organic sector. Interviews with conventional onion breeders (Chapter 2) showed that they do select for storability, but do not pay attention to partial resistances against leaf diseases and improving the root system. Interviewing conventional wheat breeders revealed that they gave a relatively low priority to baking quality and no priority to weed suppressiveness in their selection programmes for the conventional market (Chapter 4). Some traits even conflict with the breeding goals for the conventional market. The latter is especially the case for traits that have trade-offs with yield, like baking quality (Chapter 5). However, private sector breeders will only invest in the necessary modifications in their programmes if the seed market is sufficiently large to recoup their investments. For the organic market this is presently not the case.

Results of independent variety tests assist farmers in their variety choice and give breeders feedback on their breeding progress. Chapters 3 and 7 show that conducting such tests under organic growing conditions and evaluating accessions for traits prioritized by the organic sector make results more relevant for the organic sector. Adapting the variety testing protocol to the needs of the organic sector proved to be essential when variety testing is an obligatory part of the variety admission procedure, such as in the case of Value for Cultivation and Use (VCU) testing of spring wheat. The results of our spring wheat research convinced the variety testing authority to include a separate organic spring wheat section in the Recommended List of Varieties.

Varieties that entered the Recommended List of Varieties through the organic VCU procedure were more weed suppressive than varieties included through regular VCU (Chapter 7). However, organic variety testing did not help to improve the badly needed baking quality, due to an overall lack of high baking quality among new lines from conventional breeding programmes (see above). Therefore we conclude that adapting the VCU protocol is in itself not enough to enhance the diversity in a variety assortment suited for organic agriculture. Breeders would also need to change their breeding strategies.

Chapter 7 demonstrates that the statutory variety testing system is flexible and does not necessarily block the admission of varieties for the organic sector. However, procedures are costly and these costs do block the release of varieties for organic and other small markets. Therefore variety registration authorities should use the space provided by EU seed legislation to adopt more cost-effective ways to establish VCU for varieties for small markets, e.g. using data from informal trials conducted by stakeholders.

The findings, summarised above, are based on two specific crops in a specific context, namely large scale producers of field crops in the Netherlands. More generic indications on how breeding for organic farming should be performed can be derived from the principles that guide organic farming (see also Chapter 1.2.1). In the following section I elaborate the consequences of applying the organic principles to breeding in general, and reflect on whether and how my findings for onion and spring wheat breeding, in specific, relate to these consequences.

8.3. Breeding according to the organic principles

The four organic principles - the principle of health, ecology, fairness and care - elaborated by the global umbrella organisation for organic farming IFOAM (International Federation of Organic Agriculture Movements) provide a comprehensive description of the general norms and values shared by the organic community (Table 8.1) (Luttikholt, 2007; Padel et al., 2009). These four principles only offer general guidelines to organic practitioners and do not specifically address breeding. Therefore in this section I will first elaborate on how the principles could also be applied to breeding, complementing earlier work in this area by Wilbois et al. (2012). In the following section I reflect on how the findings of this thesis relate to the organic principles.

Table 8.1. IFOAM Principles of Organic Agriculture and its main features (elaborated from Luttikholt, 2007)

Principle of Health: *Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.* Main Features: • Maintaining and enhancing health of ecosystems and organisms that form part of these systems, including soil, crops and human beings, is the key role of organic agriculture. • Health is defined in various ways: the wholeness and integrity of living systems, the maintenance of physical, mental, social and ecological well-being. Immunity, resilience and regeneration are considered key characteristics of health. • Organic food products should be of high quality and nutritious, and contribute to (human) health. • Agricultural inputs and food additives with adverse effects on health should be avoided.
Principle of Ecology: *Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.* Main Features: • Ecological processes and recycling are at the basis of organic production. • Farm management and production should be adapted to local conditions, ecology, culture and scale. • Care for the natural environment and its resources (including e.g. genetic resources and biodiversity). At farm level important measures to achieve this are: • Reduced use and recycling of inputs and energy. • Farming systems designed to maintain ecological balances and conserve resources.
Principle of Fairness: *Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.* Main Features: • Fairness is defined as equity, respect, justice and stewardship of the shared world. • Relationships throughout the whole production chain should be based on fairness. • Organic agriculture should improve quality of life, food sovereignty and reduce poverty. • Fair management of natural resources. • Real social and environmental costs of production, distribution and trade should be accounted for.
Principle of Care: *Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.* Main Features: • Precaution and responsibility drive management, development and technology choices. • Besides scientific knowledge, also practical and local knowledge offer valid and validated solutions to improve organic agriculture. • Adopt appropriate technologies and reject unpredictable ones, such as genetic engineering. • Decisions should reflect values and needs of all affected, and achieved through transparent and participatory processes.

8.3.1. **Applying the IFOAM organic principles to plant breeding**

Principle of Health

Health is the maintenance of physical, mental, social and ecological well-being of the whole ecosystem. A healthy soil produces healthy crops that foster health of animals and humans, is an important organic concept. This means that one has to create optimal growing conditions to produce a healthy crop, but also that the plants themselves should contribute to the health of other components of the system, from the living soil to the human being. Breeding should not only contribute to systems health by selecting for resistance against pests and diseases, but also contribute to e.g. soil health and human nutrition. Soil structure and quality may be improved by breeding for a more extensive root system that can penetrate a larger volume of soil and deposits more organic matter, as well as selecting for traits that promote growth of beneficial soil organisms. Furthermore, the concept of health also requires varieties with characteristics that contribute to human health by improving the nutritional quality of the harvested products.

The organic approach to biotic stresses is to find ways to cope with these, by creating conditions that minimize damage. This is in contrast with the conventional approach of trying to eradicate the organisms that cause the stress. The latter approach tends to favour the development of pests and diseases with resistance against the control measures. For breeders the organic approach implies breeding for morphological plant traits that make the crop environment less conducive for the establishment and development of pests and diseases and for partial resistance rather than complete resistance.

Finally, according to the principle of health farmers and processors should avoid agricultural inputs and food additives with putative adverse effects to health. Conventional farmers and processors can compensate a weakness of a variety (e.g. susceptibility to a certain disease, sub-optimal baking quality) with chemical inputs. The organic sector cannot use these chemical products and organic alternatives are often expensive. Therefore breeding is a more important tool for organic farmers to solve their problems and constraints than for their conventional colleagues.

Principle of Ecology

The design of organic farms is based on the natural ecological system of the locality. Key properties of good functioning, resilient systems are: high levels of biodiversity, recycling of energy and resources, and self-regulation. Organic farming seeks to enhance these properties and processes.

Mixed cropping and growing variety mixtures are management practices that enhance biodiversity. Currently, varieties are selected for performance in a sole crop of one single variety. Organic breeders should select for varieties that contribute to a better performance and compatibility in species and variety mixtures. Diversity can also be enhanced by applying breeding methods that maintain a certain level of intra-varietal diversity, such as the evolutionary breeding method currently applied by several organic research groups (Finckh, 2008; Brumlop et al., 2013). The latter would also imply changes in seed regulation as both the variety registration and seed certification system only recognize varieties that are genetically uniform

The engine of the ecological system is the living soil. Stimulating soil life means that breeding should pay attention to the root system, like also elaborated in the previous section.

The Principle of Ecology also implies that crops should be adapted to the local environment, in contrast to what conventional farming does: employing crop husbandry practices aimed at adapting the environment to the crop. For breeding this approach has two implications. First of all, varieties should be adapted to the local growing environment and available resources. Secondly, growing conditions within and between organic farms are often more diverse than in conventional growing conditions. This would either require developing many locally adapted varieties or breeding varieties that perform well and are robust enough under a wide range of growing conditions.

Furthermore focusing on optimising the functioning of the whole farm system instead of single crops means that when evaluating the performance of a variety of a certain crop, breeders should not only look at the productivity of the variety itself, but consider its multi-functionality in the whole farming system, taking into account its positive and negative effects on other components of the system.

Finally, the natural environment and its resources, including genetic resources and biodiversity, should be maintained and protected. The breeding system affects biodiversity and genetic resources by a continuous replacement of varieties. In this respect, the trend of concentration of the breeding industry is a threat to diversity as this will not only lead to fewer varieties on the market, but available varieties will also be genetically more similar as these originate from a smaller number of breeding programmes.

Principle of Fairness

Relationships between actors should be based on fairness and resources should be managed in a fair way. In line with this principle the access to varieties and genetic resources should be fair. On the one hand farmers should ensure a fair remuneration to the breeders of the varieties they use to enable the latter to continue their crop improvement activities. On the other hand breeders should not resort to legal actions (patenting, exclusive contracts) that limit access and use of their varieties by farmers and fellow breeders. Also, as genetic resources are considered a common good, breeders should not apply techniques that shield off the use of varieties for further development, such as the breeding of male-sterile hybrids.

Principle of Care

Activities of organic practitioners should not jeopardize health and well-being of the ecosystem. Therefore, the precautionary principle should be leading in the acceptance of new technologies. For breeding this applies, for example, to genetic modification that is rejected by the organic movement, because of the still unpredictable effects on the environment and human health. In addition, genetic modification also conflicts with the Principles of Ecology and Fairness.

Preventing undesired side effects of technology and policy development also implies involving stakeholders from the beginning and transparency in decision making processes. As traditional and experiential knowledge have been tested in time, valuing and including these sources of knowledge in scientific research and technology development, reduces the risks of unforeseen results. This principle calls for involving chain partners in the breeding process and developing seed policies and legislation. The optimal level of participation depends both on the crop species and the socio-economic context of its production system (Morris & Bellon, 2004; Chable et al., 2008).

8.3.2. **Relation of the findings of the thesis with the IFOAM principles**

The previous paragraph shows that the principles of health and ecology provide organic breeders guidance on the kind of varieties that should be bred to support organic production systems, while the principles of fairness and care deal with ethical and social values, but also with institutional aspects of breeding and variety management. In this section I will review whether and how the findings of this thesis for onion and spring wheat relate to the organic principles.

Onion

Breeding priorities for the organic sector differ from the priorities for the conventional sector for root related traits, resistance against foliar diseases (downy mildew, leaf blight) and bulb dormancy. Below I will show that motivations for preferring these traits are in agreement with norms and values belonging to the Principle of Health and the Principle of Ecology.

According to farmers strong and vigorously growing plants are a precondition for a healthy crop. In the first place, growing such plants requires adequate crop husbandry practices that support soil health and fertility. In addition, farmers look for varieties with the genetic ability to produce a large root system that efficiently absorbs available nutrients and is capable to interact with soil micro-organisms. As a second line of defence against leaf diseases, farmers prioritized traits that help crops to escape disease, such as early bulb formation, and prevent establishment of the disease, such as waxy and erect leaves. As a final measure to keep the crop healthy, farmers also want varieties to carry resistance genes that confer immunity. Thus for organic farmers, health is not only about genetic pest and disease resistances, but also includes growing a vigorous crop and creating a non-conducive environment for pests and diseases. Such a way of thinking is in line with the Principle of Health.

The demand for varieties with increased sprouting dormancy and resistance against leaf diseases is the consequence of the avoidance of inputs that may damage health, i.e. chemical sprout inhibitors and synthetic fungicides. Under a conventional crop management regime, so far, newly released varieties with increased sprout dormancy or downy mildew resistance were lower yielding and therefore not preferred. Unlike their conventional colleagues, most organic farmers rapidly adopted these new varieties (personal communication F. Van de Crommert, Bejo Seeds, 2011). This illustrates that, due to the avoidance of synthetic inputs resistance breeding is more important for organic farmers than for conventional farmers.

The demand for an improved root system is not only related to the Principle of Health, but also related to the Principle of Ecology. In organically managed fields nitrogen availability is relatively low early in the growing season and relatively abundant at the end of the season, as its availability depends on mineralization of organic nitrogen. Under these conditions, early development of direct seeded onions is slow because its relatively small root system is not able to capture sufficient amounts of nitrogen. Increasing the fertilizer supply, a typical conventional solution for such a problem, would conflict with the Principle of Ecology, as this is opposed to the ideas of recycling and reducing external inputs. In addition, increasing organic nitrogen inputs would also compromise quality and storability because these traits deteriorate when nitrogen availability is high at the end of the growing season. Organic farmers therefore would like breeders to increase the size of the root system, so that the crop will be able to scavenge a larger soil volume for nitrogen.

Improving root related traits and traits that contribute to health would require increasing genetic diversity of the gene pool currently used by Dutch breeders. Increasing diversity is also in agreement with the Principle of Ecology. Using more diversity in breeding programmes is one step in this direction that would enable farmers to choose from and grow a larger set of varieties with a distinct genetic background.

Following the Principle of Ecology also means adapting the crop to the local environment. Chapter 2 and Chapter 3 indicate that selecting adapted onion varieties most likely requires conducting the breeding programme in organically managed fields as genotypes react differently to the use of herbicides, spraying with fungicides prevents the selection of genotypes with partial resistance against diseases, and applying synthetic fertilizers most likely interferes with the detection of genotypes that cope better with nutrient stress.

Access to organically multiplied seeds at a reasonable price is another issue for the organic sector. Almost all onion varieties on the Dutch market are hybrids. To produce these hybrids, breeders make use of cytoplasmic male sterility (CMS) (see Chapter 2). This technique not only prevents farmers from multiplying the variety, but also impedes other breeders to use the variety as a crossing parent in breeding programmes As in the early 2000s only few breeders were prepared to multiply their seeds organically and farmers were not happy with the high price of the available organic seeds, farmers decided to set up their own multiplication.

However, due to the limited availability of open pollinated varieties, their variety choice was greatly restricted. This case illustrates that the use of CMS hybrids conflicts with the Principles of Fairness and Ecology. First of all, the dependence created by the technology prevents the establishment of a relationship based on equity, which further restrains the possibilities to negotiate a fair deal on access to the technology. In this onion case the technology also diminishes the availability of genetic diversity, both for use in the field by farmers as well as in breeding programmes.

Spring wheat

Priorities for spring wheat breeding for the organic sector differ from the conventional sector’s priorities for baking quality and weed competitiveness. The need to improve both traits is a result of refraining from inputs and food additives that may compromise human health as integral part of the Principle of Health. Under organic fertility management nitrogen is often scarce during the grain filling period resulting in grains with a lower protein content than required by bakers. In conventional farming, protein content and baking quality are increased by applying highly soluble nitrogen fertilizer at flowering. In addition, the conventional milling industry further boosts baking quality by adding bread improvers, a practice organic food processers want to avoid to comply with the Principle of Health (see Chapter 4). Copying the conventional wheat fertilizing practices with organic amendments is technically possible, but in conflict with the Principle of Ecology that entails reducing external inputs and closing cycles. Similar to the issue of bulb dormancy in onion described above, refraining from synthetic inputs and food additives leaves organic farmers little other economically viable option than the choice of appropriate varieties. Therefore baking quality receives a high priority in the organic variety profile.

Also the high priority given to weed competitiveness is linked to both the Principle of Health and the Principle of Ecology. As synthetic herbicides may damage both soil and human health, in accordance with the Principle of Health, these are banned in organic farming. Following the Principle of Ecology, crops should not be approached as singular entities, but as part of the whole system. So, an appropriate organic weed management strategy takes the whole crop rotation cycle into account. Taller wheat varieties may tolerate a certain weed pressure without a reduction of yield and quality, when weeds are controlled mechanically before the stem elongation phase, specifically. However, for farmers this is not enough as the thus tolerated weeds increase the weed seed bank and in this way cause economic damage to subsequent crops in the rotation. Therefore they look for more traits than just tallness to effectively suppress weed growth and give these high priority.

Chapter 5 and Chapter 6 address the choice of selection environment to breed varieties adapted to the organic growing environment as required by the Principle of Ecology. For traits like yield and resistances against diseases, genetic correlations between organic and conventional environments are high and therefore varieties improved for these traits could also be indirectly selected in a conventionally managed breeding nursery. However, for organic farmers an optimally adapted variety should not only perform well in the field, but also should satisfy the needs of millers and bakers. Improving baking quality would require selection under conditions that resemble organic soil fertility conditions.

Within the EU, marketing of spring wheat varieties, and hence access to genetic diversity, is regulated by law. The Principle of Care advocates participation of involved actors in decision making processes. Chapter 7 shows that involving the actors of the organic bread wheat production chain in the development of an organic variety testing procedure, increased and improved the variety assortment.

8.4. Perspectives to enhance the organic variety assortment

The major hurdle we encountered to bring about changes to enhance the variety assortment for the organic sector is the socio-economic organization of breeding. In Western Europe, breeding is almost entirely conducted by the private sector. Commercial breeding companies recoup their investments in breeding through a levy on seed sales. This way of financing breeding favours the development of varieties that occupy the largest possible acreage. Moreover, this financing system blocks the possibility to breed for production chains that occupy relatively small acreages. Indeed, during discussions on variety testing and breeding for the organic sector, which we organised during our variety testing projects (Chapter 3, Chapter 7), breeders continuously argued that they considered the organic market too small to justify investments.

An alternative to commercial breeding are the non-profit breeding initiatives that have emerged within German and Swiss bio-dynamic circles (Chapter 1.2.2). According to the bio-dynamic movement, seeds and varieties are part of the cultural heritage and therefore breeding should not be submitted to economic pressures and should be conducted within the public domain. These non-profit organic breeding initiatives mainly depend on donations of charities, organic food businesses and consumers. The amount of funds they manage to mobilise in this way, does not meet the needs of the few organic breeders, though (Willing, 2007).

Public funding of plant breeding projects has been reduced considerably in developed countries from the 1980s onwards. In the Netherlands, this was part of a general reduction in public funding of agricultural research due to a change in view on the role of the state in society and the need to cut government expenditures (Roseboom & Rutten, 1998; Meerburg et al., 2009). At present, the Dutch government funds are available for a limited number of "cutting-edge" breeding research projects. Such projects require private sector co-financing and will not directly result in new varieties, as the government considers variety development the task of the private sector.

Below I elaborate ways to deal with the problem of financing breeding, namely:

1) exploring more cost effective breeding strategies; and

2) looking for alternatives to deal with investments in breeding.

8.4.1. **Exploring more cost effective breeding strategies**

This is the approach I followed, when I started the research trajectory that forms the basis for this thesis. Selecting varieties for organic farming, from the already ongoing conventional breeding programmes, requires fewer resources than setting up a complete new organic breeding programme. Complementary to Wolfe et al. (2008), I will discuss the following options for this route (in order of increasing investments):

1. Organising organic variety trials to select the best suited varieties among the existing assortment;
2. Selecting among candidate varieties that are under evaluation for release;
3. Adapting the mainstream breeding programme to the needs of the organic sector.

Although varieties on the market are developed for conventional agriculture, some of these may also perform well under organic growing conditions. Detection of such varieties will be enhanced by systematic screening of available varieties in organically managed trials. Both the results of the onion and spring wheat variety testing projects, presented in this thesis, underline the importance of including all traits prioritized by the organic sector in the testing protocol. Such organic variety trials provide breeders feedback information, which helps them to better understand the needs of the organic sector. This learning process intensifies when breeders together with the actors of an organic crop production chain are invited to jointly evaluate trials in the field and discuss results in meetings.

With an improved understanding of the needs of the organic sector, breeders will be able to recognise interesting lines for the organic sector prior to release. Breeders limit the number of varieties they bring on the market, to reduce costs of registration procedures, marketing, and seed production. Some of the lines discarded in the final phase of the selection programme may be of interest of the organic sector due to differences in priorities between the organic and conventional sector. For example, at the onset of the research trajectory that led to this thesis, wheat breeders claimed that they discarded varieties with resistance against Septoria tritici blotch with yield levels that may be acceptable for the organic sector, but not for the conventional market. However, the wheat case taught us that selecting among lines of the final stage of a breeding programme may only lead to successful results when selecting goals do not strongly conflict with the selection goals for the conventional sector. Both the strong selection against a desired trait (plant length) and a strong trade-off between desired traits (high yield and high baking quality) greatly reduced the probability to find lines suited for organic within the final generations of a wheat breeding programme.

When genotypes desired by the organic sector do not make it to the final stage of a conventional breeding programme, one could consider a combined conventional and organic breeding programme (Löschenberger et al., 2008; Baenziger et al., 2011). In such an approach the breeding programme is split-up up into a conventional and an organic sub-programme starting from the generation in which one expects that selection for the conventional market results in a loss of desired genotypes for the organic market. In spring wheat, for example, most breeders only start to select for yield and indirectly against high baking quality, due to the trade-off between these traits, in the F5 or F6 generation. Splitting the breeding programme up into an organic and a conventional sub-programme from this stage onwards would allow targeted selection for higher baking quality. Additionally, one could consider including parents with traits specifically required by the organic sector, such as weed suppressiveness, in the crossing scheme. As during the first generations the breeding programmes are not separated yet, this approach requires less resources than implementing two completely independent breeding programmes.

First years of an onion breeding programmes usually consist of selfing plants from bulbs of desired size and quality aspects. At present it is not known whether selection for such traits, reduces the chance to select traits for field resistance against diseases and a better root system, needed for organic farming, in later generations. As selfing, followed by only maintaining a limited number of selfed lines, reduces genetic variation rapidly, most likely specific selection for organic should start as early as possible. In this case, alternating generations between organic and conventional environments, in combination with selection for the field traits desired for organic agriculture, would be a way to simultaneously breed for organic and conventional agriculture. This is similar to the shuttle breeding approach proposed by CIMMYT to improve N-use efficiency and drought resistance in wheat (Van Ginkel et al., 2001; Kirgiwi et al., 2004) and also applied by one of the interviewed onion breeders (Chapter 2). Conventional breeders will only apply such an approach when it does not impede breeding progress in their conventional programme. The efficiency of a shuttle-breeding approach compared to two separate (conventional, organic) programmes would be topic for further research.

8.4.2. **Alternatives to deal with investments in breeding**

Following the traditional model of recouping investments in breeding, seed companies could increase the levy on seeds for specific varieties for certain niche markets to compensate for the limited seed sales. When the new varieties are mainly improved for quality and to a lesser extent for yield, farmers would face an increase in product costs per unit of harvested product. Recouping these extra costs is possible when the harvested product has a unique, well recognizable trait that sells well. An example is the introduction of better tasting tomato varieties that are sold under the brand *Tasty Tom* by a small group of Dutch farmers (www.tastytom.nl/en).

For bulk products like wheat and onion, farmers fear that they will not be able to recover the increase in production costs from their buyers. Both the price of onion and wheat are determined by supply and demand on the international market. Farmers suspect that onion traders and millers would simply choose to buy from their foreign competitors, when they would try to convince them to pay a higher price. This implies that looking for a solution for the financing of breeding requires the involvement of the whole production chain. Firstly, such an approach would ensure a more equitable division of breeding costs, which is in line with the Principle of Fairness. Secondly, in agreement with the Principal of Care, collaboration of the whole production chain in breeding would also open possibilities for a more direct exchange of knowledge and experience between breeders and the other stakeholders, which enhances the probability that their selections will be better adapted to the needs of its end-users.

Box 8.1. Spring wheat breeding consortium

In discussions on releasing specific varieties for the organic sector between breeders and organic stakeholders, breeders would point to the fact that the organic acreage was too small to justify investments while the organic sector also would consider breeding costs too high to be borne by the small sector alone. To break this deadlock, for spring wheat, Louis Bolk Institute organised a workshop in which stakeholders were shown real calculations of costs and alternatives to cover these costs (Osman et al., 2007a; 2007b). These calculations showed that, e.g. recouping costs through a levy on loaves of bread instead of on seeds, would only require about half a cent per loaf. The workshop changed the perception that breeding specific varieties was unattainable for a small sector. The workshop and subsequent follow-up meetings motivated a group of key stakeholders - consisting of the main specialised organic bakeries and their millers (see also Chapter 4 for a description of the organic baking industry), the main trader, organic farmers and the author’s research institute– to form a wheat breeding consortium. In addition, five breeders agreed to provide the consortium with advanced breeding lines for an initial screening.

Millers and bakers conducted baking trials with the most promising lines of this first screening. Unfortunately results of these tests were disappointing. On the one hand these poor results convinced two of the conventional breeders that they needed to make changes in their selection programme. On the other hand the results made the other organic stakeholders doubt about the feasibility of improving baking quality through breeding. This initial screening was partly financed by the Dutch Ministry of Agriculture, Nature Conservation and Fisheries, with breeders, trader, millers and bakers contributing in kind (breeding lines, baking quality tests), but for the next phase the consortium needed to arrange the financial resources. As success was not guaranteed on beforehand the trader, bakers and millers became hesitant to invest a relative large sum of money in a breeding project. To reduce investment risks we formulated an organic wheat breeding project for a “green breeding” fund, of the Ministry of Agriculture, in which the consortium and three breeders agreed to provide considerable in kind contributions (early generation breeding material, fields, labs, personnel). As the proposal was not granted, the consortium decided to continue on a low budget scale, with unsatisfactory results. Therefore, in 2014, chain partners decided to revive their plans to set up a collaborative breeding programme.

BOX 8.2. Involving the whole organic onion chain in the adoption of organic seeds

For onion, at the time, the organic sector was discussing the possibility to replace the use of conventionally multiplied seeds by organically multiplied seeds. Abandoning the use of conventionally multiplied seeds is necessary to close the organic production cycle and thus follow the Principle of Ecology. As this change would imply a doubling to tripling of the seed price, the seed issue was considered more pressing than breeding. In a project we invited stakeholders to discuss the seed issue (Lammerts van Bueren et al., 2006). However, packers and traders were not prepared to attend a common meeting on the issue. In separate interviews, traders specialised in organic products, without business activities in non-organic products, expressed commitment to compensate farmers for their increased production costs. However, companies with conventional products as core business were against sharing farmers' crop production costs. As only part of the organic onion sector was willing to adopt the use organic seeds on a voluntary basis, the government decided to enforce its use through the regulation for organic production. From 2007 onwards Dutch growers have to use organically produced onion seed and a reasonable assortment of varieties is now available from several seed companies (www.biodatabase.nl).

Louis Bolk Institute explored possibilities to involve stakeholders in seed and breeding issues in separate projects, reported elsewhere (Lammerts van Bueren et al., 2006; Osman et al., 2007a; 2007b). For spring wheat, this led to an initiative to develop a collaborative breeding consortium (Box 8.1). For onion, at the time, the organic sector was discussing the possibility of replacing the use of conventionally multiplied seeds by organically multiplied seeds. As this change would imply a doubling to tripling of the seed price, the seed issue was considered more pressing than breeding. Similar to sharing breeding costs by the whole chain, a study was conducted to divide the increase in seed price over all chain partners (Box 8.2). The onion project failed to achieve long-term commitment of the whole chain to support the use of organic seeds, while the wheat breeding project was recently revived. Both cases serve to draw lessons on key aspects to consider for the successful development of an approach that involves the whole production chain in breeding, which I elaborate below.

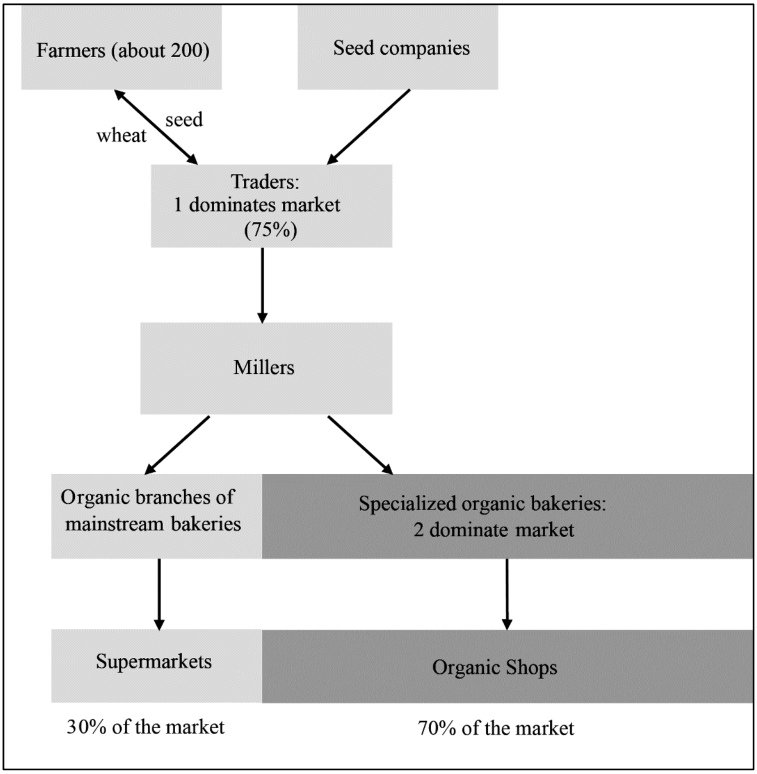

Figure 8.1. Dutch organic bread production chain during the research period.

Composition and structure of the production chain

Our approach was to involve key stakeholders of the whole production chain in solving seed and breeding issues. Achieving this is not easy, because actors further down the production chain usually consider production related issues like seeds and breeding the farmers' responsibility. The onion and wheat cases gave us insight in which type of traders and processors were more open to collaboration and why. In both cases only the specialised organic traders and processors were open to discussions on organic seeds and breeding. An explanation for this difference between specialised organic stakeholders and conventional stakeholders may be that the former may have incorporated organic principles, like the Principal of Fairness that calls for shared responsibility, in their way of doing business. In addition, at the time specialised organic businesses felt threatened by mainstream companies that entered the organic market and were therefore looking for ways to differentiate themselves from their competitors. Specialized organic bakers saw participation in breeding and products made of organically bred varieties as unique selling points, while also one of the onion traders proposed to create a premium brand. So, the need to differentiate themselves from mainstream businesses may also explain their interests in getting involved in breeding.

An important difference between the organic onion and bread production chain is that the latter is considerably less fragmented than the former. While there are many onion traders active on the organic market, in baking quality wheat only a few players dominate a major part of the market (Figure 8.1). Millers and bakers considered it important that their main competitors would also participate in the breeding consortium, to prevent that their competitors would benefit from their investments without collaborating themselves. Involving the major part of the market is easier to achieve in a clearly structured market with a limited number of dominant players than in the highly fragmented onion market. An additional important difference between the onion and bread production chain is that the former is mainly export oriented while the latter operates mainly on the Dutch and Belgian market. With multiple export oriented chain actors, it is harder to involve the whole chain as some of the key players are based abroad.

Importance of the problem and feasibility of a solution

A shared vision or recognised problem with an attainable solution is a key motivation for stakeholders to get involved in an innovation network (Douthwaite et al., 2002; Schot & Geels, 2008; Klerkx et al., 2010). In the case of onion, farmers considered the conversion to the use of organic seeds a necessary step to improve the organic production system. Those traders, who shared adherence to the organic principles with the farmers, were willing to help farmers to move forward. However, besides improving the image of the organic onion, the change to organic seeds would not bring them any other tangible benefits, such as a cheaper or more distinguishable end product. Therefore, for the onion traders the seed issue lacked urgency. In the case of spring wheat key players did share the sense of urgency of the problem, namely the need to have access to varieties with improved baking quality, but assumed that breeding such varieties specifically for the organic sector would be too costly. We managed to change this perception by presenting real calculations of costs. Discussing these calculations among each other convinced stakeholders that the solution for their problem was within their reach and motivated them to set up a breeding consortium.

Trust and long-term commitment

Engaging in a breeding project is a risky business which only delivers results on the long term. Stakeholders are only prepared to take these risks and commit themselves to investments when they trust their partners and believe in the positive outcome of the collaboration. Indeed, in many publications on collaboration and innovation networks, trust is mentioned to be essential ingredient for commitment (e.g. Olsen et al., 2008; Deveaux et al., 2009). Vangen & Huxham (2003) argue that in everyday life mistrust prevails, though. Such is also the case in organic production chains. Breeders assume that organic farmers try to evade paying breeders' rights through multiplying farm saved seeds and farmers doubt the possibilities to establish long-term commitments with traders as they think the latter always go for the lowest price. Vangen & Huxham (2003) advocate an action research approach and recommend to start with modest, low risk, joint actions and taking bigger steps that involve more risk when trust has increased. We followed a similar approach in the spring wheat case. The three steps of increasing investments in breeding (selecting among finished varieties, selecting among candidate lines, modifying the existing breeding programme) described in the previous section can be considered steps with incremental risks. During the variety testing project we built a loose network of stakeholders that were interested in improving baking quality. As the project was financed by the government there were almost no risks involved for participants. With the project and subsequent activities we established a long-term relationship that probably helped to build trust between stakeholders and made it easier for us to convene them to discuss a collaborative breeding project (Box 8.1). In a first phase of that project we started a joint screening of advanced breeding lines. Unfortunately, results of the screening of advanced breeding lines did not meet the expectations of millers and bakers and thus reduced trust. A complicating factor in the wheat project was the fact that most spring wheat breeding companies were based abroad, which made it difficult to realize the necessary frequent direct meetings between foreign breeders and the Dutch organic stakeholders. The reduced trust of bakers and millers in a positive outcome of the project could probably have been prevented when they would have had the opportunity to directly interact with the foreign breeders.

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Summary

Introduction

The research project described in this thesis addresses the common lack of specific plant breeding and variety testing for organic agriculture. Consulted organic farmers in the Netherlands expressed their preference to work together with the existing, well developed, conventional seed sector to obtain varieties better adapted to organic growing conditions. They argued that for crops that were not addressed by organic breeders yet, working together with the conventional seed industry would be more cost effective and would give faster results than setting up separate organic breeding programmes. At the same time, most conventional breeders were unfamiliar with the organic sector and its needs. Moreover, conventional breeders generally disputed the need for separate organic breeding programmes and assumed that their on-going programmes would provide varieties that better suited the needs of the organic sector if they would better know its needs.

In this thesis I analyse how the current breeding, variety assessment and registration process should be changed to provide varieties that fulfil the needs of organic farmers, traders and processors. Transforming breeding in such a way that it is able to address new needs, is not just a matter of prioritizing other plant traits or adjusting the selection environment, but also involves dealing with (different) institutional constraints. In addition, options for change depend on the crop and its context. To broaden the applicability of the findings, I have chosen to analyse the cases of two crops, onion (*Allium cepa*) and spring wheat (*Triticum aestivum*), differing in key issues that influence the outcome of the research: breeding and variety registration aspects; organic seed and crop production issues; destination of the harvest; and composition of and relations between actors in the production chain.

The analysis is based on data and experiences gained during my work at the organic breeding section of the Louis Bolk Institute, The Netherlands, between 1999 and 2010. While this thesis focusses on the research components of the work, the overarching purpose of the projects was to bring about changes in the breeding and varietal assessment systems. We followed an Action Research approach to achieve this, i.e. participation of key stakeholders and an open ended research

trajectory, in which gained insights were used to decide on subsequent research steps.

The thesis addresses the following questions for onion and spring wheat:

1. Does the organic sector need other types of varieties than the ones currently provided?
    1.1. Which variety traits are prioritized by actors in the organic production chain?
    1.2. Are newly released varieties suited to the needs of the organic sector?
2. Which adaptations are required in conventional breeding programmes to develop varieties suited to the needs of the organic sector?
    2.1. Which variety traits are prioritized by breeders?
    2.2. Does the selection environment influence the evaluation of traits desired by the organic sector?
    2.3. Dealing with trade-offs: How to breed simultaneously for varieties that provide high grain yield and high baking quality under organic growing conditions?
3. Do variety testing protocols influence the release of varieties suited to the needs of the organic sector?
    3.1. How should variety testing protocols be adapted to the needs of the organic sector?
    3.2. Does implementing Value for Cultivation and Use (VCU) testing, following a specific organic protocol, stimulate the release of spring wheat varieties adapted to the needs of the organic sector?
4. How to deal with economic barriers that prevent breeding for small markets?

Main findings

Onion

Organic farmers need varieties with resistance against foliar diseases (downy mildew, leaf blight), with an erect plant type – to facilitate mechanical weeding - and good storability traits (Chapter 2). Complementary to disease resistance, they look for early bulbing varieties - to escape foliar diseases - with waxy leaves to prevent disease attachment and establishment. Onion varieties tested (Chapter 3) lacked resistances against downy mildew and leaf blight. Varieties with an erect plant type were available, but not among the highest yielding. Therefore to better attend the needs of the organic sector, breeders should combine both traits. In Chapter 3 we further conclude that the variety assortment should be improved for bulb dormancy and the size of the root system. Finally, we found a limited availability of open pollinated varieties.

Interviewed breeders gave low priority to selection for field traits and a high priority to storability (e.g. bulb dormancy) and other quality traits (e.g. shape, size colour). The reason for this is that in conventional onion production traders strongly influence variety choice and their main concern is high quality. Additionally, breeders see no reason to dedicate more time to field selection because the traditional Dutch *Rijnsburger* populations, they select from, lack genes that confer high levels of resistance against foliar diseases. They do try to incorporate resistance against downy mildew and leaf blight in their breeding material, through introgression of genes from wild *Allium* species, but so far resistance breeding programmes are kept separate from the regular breeding programmes (see Chapter 2).

Improvements in storability and quality are also beneficial to organic farmers, because the bulk of their onions are sold through mainstream market channels that employ the same quality standards as for conventional onions. Organic farmers require a higher level of bulb dormancy than their conventional colleagues, because the latter use chemical sprouting inhibitors. In addition the period between packing and purchase is longer for organic onions. Furthermore, to improve field traits also required by organic farmers (improved root system, early bulbing, waxiness, erectness in combination with high yield), breeders would need to increase their time spent in the field. Breeding for an increased root system would probably also benefit from broadening the genetic base.

Besides changes in selection procedures, breeding for organic farming would also need changes in the selection environment. Breeders should refrain from the use of fungicides and herbicides they normally apply in their nurseries. Without fungicides they will be able to select for partial resistance available in the *Rijnsburger* gene pool. Herbicide applications influence plant density which in turn affects proper evaluation of important traits like bulb size distribution, earliness and dormancy. An area for further research would be identifying the most appropriate environment to select for an improved root system.

Spring wheat

Spring wheat varieties provided by breeders for VCU tests (Chapter 7) did not meet the baking quality required by organic millers and bakers. In addition, farmers need varieties that facilitate and complement organic weed management practices, such as tolerance to harrowing, rapid early growth, leafiness and plant length. Only a limited proportion of tested candidate varieties possessed traits that contributed to weed suppressiveness such as plant length and leafiness.

Interviews with breeders confirmed that they do not select for the traits that enhance weed suppression (Chapter 4). Moreover, most breeders strongly select against taller plant types, because they associate long stems with reduced yield potential en susceptibility to lodging. The strict selection against tall plants reduces the probability to find genotypes with the height desired by Dutch organic farmers among their advanced breeding lines. Also the lack of baking quality can be explained by the fact that this trait receives lower priority than yield in conventional breeding programmes. In general, breeding for baking quality goes at the expense of yield. For the conventional market breeders select for high yield, while maintaining baking quality at a level that is considered too low for the organic baking industry. Conventional farmers improve baking quality through additional nitrogen dressing at flowering. In addition, the conventional milling industry has more, relatively cheap, options to enhance flour quality than its organic counterpart.

Increased yield is also a priority for organic farmers, but only when the baking quality required by their market can be maintained. In Chapter 5 we explore ways to simultaneously improve yield and baking quality, by improving two important factors that determine baking quality: protein content and protein quality. Protein content could be increased by selecting for increased total plant biomass. In organic wheat, almost all protein in the grain originates from nitrogen stored in the plant biomass before grain filling, as soil nitrogen is often scarce after this phase. In conventional farming, nitrogen absorbed from the soil during grain filling also ends up in the kernel. Especially grain protein content of modern varieties is affected by nitrogen scarcity during grain filling. Modern breeding has achieved high yield by increasing the harvest index. So, grain mass was increased without increasing vegetative plant mass, resulting in a relative decrease of grain protein content. Increasing both grain yield and plant biomass simultaneously would prevent this so-called dilution effect. In addition, such varieties would also be more competitive against weeds.

The other approach would be improving protein quality. This strategy is thought to be especially attractive for organic farming, because in theory high baking quality could be achieved with grains of lower protein content and thus less nitrogen would be required to grow the crop. The literature review presented in Chapter 5 shows that protein composition is strongly influenced by environment (soil nitrogen availability). Due to genotype × environment interaction, selection for improved protein quality should be conducted under organic or low nitrogen input conditions.

The choice of the selection environment is further addressed in Chapter 6. A joint analysis of datasets of cereal variety trials of seven European countries showed high genetic correlations (0.8 – 1.0) between organic and non-organic environments for traits like yield, protein content, plant height, soil coverage, and disease resistances. This implies that breeders could improve these traits for the organic sector through selection in conventional nurseries. The research also shows that combining results from conventional and organic trials improves selection results.

Adapting protocols of variety tests to the needs of the organic sector

Results of independent variety tests assist farmers in their variety choice and give breeders feedback on their breeding progress. Chapters 3 and 7 show that conducting such tests under organic growing conditions and evaluating accessions for traits prioritized by the organic sector make results more relevant for the organic sector. Adapting the variety testing protocol to the needs of the organic sector proved to be essential when variety testing is an obligatory part of the variety admission procedure, such as in the case of VCU testing of spring wheat. The results of our spring wheat research convinced the variety testing authority to include a separate organic spring wheat section in the Recommended List of Varieties.

Varieties that entered the Recommended List of Varieties through the organic VCU procedure were more weed suppressive than varieties included through regular VCU (Chapter 7). However, organic variety testing did not help to improve the badly needed baking quality, due to an overall lack of high baking quality among new lines from conventional breeding programmes (see above). Therefore we conclude that adapting the VCU protocol is in itself not enough to enhance the diversity in a variety assortment suited for organic agriculture. Breeders would also need to change their breeding strategies.

The VCU project showed that the statutory variety testing system is flexible and does not necessarily block the admission of varieties for the organic sector. However, procedures are costly and not in proportion to market size and in this way prohibit the release of varieties for organic and other small markets. Therefore variety registration authorities should use the space provided by EU seed legislation to adopt more cost-effective ways to establish VCU for varieties for small markets, e.g. using data from informal trials conducted by stakeholders.

Conclusions and perspectives

The research showed that both for onion and for spring wheat current conventional breeding programmes do not properly address the needs of the organic sector. This is especially true for properties that conflict with breeding priorities for the conventional sector, such as high yield and baking quality in spring wheat. For organic farmers high yield is also important, but to achieve high yield, varieties need to be able to cope with biotic (e.g. diseases) and abiotic (nutrient scarcity) stresses, which conventional farmers can also control with synthetic inputs. Organic farmers´ and processors´ motives to prioritize other traits than their conventional colleagues are based on values belonging to the IFOAM Organic Principles of Health and Ecology (Chapter 8.3). These principles also give general guidance to the direction of breeding for organic farming.

The major hurdle we encountered to bring about changes to enhance the variety assortment for the organic sector is the socio-economic organization of the breeding and varietal assessment and registration systems. Commercial breeding companies recoup their investments in breeding through a levy on seed sales. This way of financing blocks the possibility to breed for production chains that occupy relatively small acreages. Costs could be reduced by combining conventional and organic breeding programmes. In addition, involving all actors of the production chain in a collaborative breeding effort could generate the necessary resources. Such an approach to breeding would also be in line with the IFOAM Principle of Fairness, as it would ensure a more equitable division of breeding costs and risks. In addition, in agreement with the Principle of Care, this approach to breeding would generate transparency in the breeding process and open possibilities for a more direct exchange of knowledge and experience between breeders and the other stakeholders; the latter should also enhance the probability that the selected varieties comply with the needs of the organic sector.

Samenvatting

Inleiding

Plantenveredeling en rassenonderzoek voor de biologische sector zijn de thema's van dit proefschrift. Biologische telers hebben behoefte aan rassen die beter aangepast zijn aan hun manier van telen en die voldoen aan de wensen van hun afnemers. Geraadpleegde biologische akkerbouwers gaven er de voorkeur aan om samenwerking te zoeken met de bestaande, goed ontwikkelde, gangbare zaadindustrie, voor de ontwikkeling van dergelijke rassen. Volgens hen zou samenwerking met de gangbare sector, voor gewassen, die nog niet biologisch veredeld werden, kostenefficiënter zijn en sneller resultaten opleveren dan de weg van het opzetten van aparte eigen biologisch veredelingsprogramma's. Aan het begin van het onderzoek waren de meeste gangbare veredelaars onbekend met de biologische sector en zijn behoeften. Specifieke veredeling, gericht op de biologische sector, leek de meeste veredelaars echter overbodig. Ze gingen er vanuit dat ze geschikte rassen in hun reguliere programma's konden selecteren, als de biologische sector zijn wensen kenbaar zou maken.

In dit proefschrift analyseer ik hoe de huidige veredeling en het rassenbeoordelings- en registratieproces aangepast dienen te worden om rassen op de markt te kunnen brengen, die voldoen aan de wensen van biologische telers, handelaars en verwerkers. Het transformeren van het veredelingsproces, om in te kunnen spelen op nieuwe wensen, omvat meer dan andere keuzes maken tijdens de selectie van planten en/of het aanpassen van het selectiemilieu. Een dergelijk proces vergt ook oplossingen voor eventuele institutionele knelpunten. Bovendien, hangen de oplossingsrichtingen af van het gewas en de productieketen. Voor de bredere toepasbaarheid van de resultaten van dit onderzoek, heb ik ervoor gekozen om de *cases* van twee gewassen te analyseren, ui (*Allium cepa*) en zomertarwe (*Triticum aestivum*). Deze gewassen verschillen voor belangrijke aspecten, die de uitkomst van het onderzoek beïnvloeden: veredelings- en rassentoelatingsprocedures, problemen bij de biologische teelt van het zaad en het gewas, bestemming van de oogst, en samenstelling van en relaties tussen de actoren van de productieketen.

Voor de analyse maak ik gebruik van gegevens en ervaringen, die ik heb verzameld tijdens mijn werk voor het Louis Bolk Instituut, Driebergen, Nederland, tussen 1999 en 2010. Het overkoepelende doel van de projecten was het stimuleren van veranderingen in het veredelings- en rassenbeoordelings- en registratiesysteem. Daarbij volgden we een *Action Research* benadering, d.w.z. participatie van *stakeholders* en een flexibel onderzoekstraject, waarbij voortschrijdend inzicht de volgende stappen bepaalden. In het proefschrift concentreer ik me op de onderzoekscomponent van dit werk en behandel ik de volgende vragen voor ui en zomertarwe:

1. Zijn er andere typen rassen nodig voor de biologische sector dan de typen die op dit moment op de markt worden gebracht?
    - 1.1. Welke raseigenschappen zijn belangrijk voor de actoren van de biologische productieketen.
    - 1.2. Voldoen nieuwe rassen aan de eisen van de biologische sector?
2. Hoe moeten gangbare veredelingsprogramma´s worden aangepast om rassen te kunnen selecteren die voldoen aan de wensen van de biologische sector?
    - 2.1. Aan welke raseigenschappen geven veredelaars prioriteit?
    - 2.2. Heeft het selectiemilieu invloed op de evaluatie van de eigenschappen die belangrijk zijn voor de biologische sector?
    - 2.3. Omgaan met *trade-offs*: Hoe kunnen veredelaars rassen selecteren met zowel een hoge opbrengst als een goede bakkwaliteit onder biologische omstandigheden?
3. Beïnvloeden de protocollen voor rassenonderzoek het op de markt brengen van geschikte rassen voor de biologische sector?
    - 3.1. Hoe moeten protocollen voor rassenonderzoek aangepast worden om te voldoen aan de wensen van de biologische sector?
    - 3.2. Stimuleert het toepassen van Cultuur- en Gebruikswaaarde Onderzoek (CGO), volgens een specifiek biologisch protocol, het op de markt brengen van rassen die beter aangepast zijn aan de wensen van de biologische sector?
4. Hoe kunnen economische knelpunten, die de veredeling voor kleine markten belemmeren, opgelost worden?

Belangrijkste resultaten

Ui

Biologische akkerbouwers hebben behoefte aan rassen, die resistent zijn tegen de belangrijkste bladziekten (valse meeldauw, bladvlekkenziekten), met een rechtopstaande bladstand – om mechanische onkruidbeheersing mogelijk te maken – en een goede bewaarbaarheid (Hoofdstuk 2). Ter ondersteuning van de ziekteresistentie, zoeken ze rassen met een vroege bolvorming – om te ontsnappen aan bladziekten – en met een waslaag op het blad om de vestiging van pathogenen te voorkomen. Resistentie tegen valse meeldauw en bladvlekkenziekten ontbrak in de geteste rassen (Hoofdstuk 3). Rassen met een rechtopstaande bladstand waren beschikbaar, maar deze rassen gaven niet de hoogste opbrengst. Voor de biologische sector zouden veredelaars nieuwe rassen moeten selecteren, die beide eigenschappen combineren. In Hoofdstuk 3 concluderen we verder dat het rassenassortiment verbeterd dient te worden voor bewaarbaarheid (spruitrust) en de omvang van het wortelstelsel. Tenslotte was ook het aanbod van openbestoven rassen beperkt.

Geïnterviewde veredelaars gaven lage prioriteit aan selectie in het veld en hoge prioriteit aan bewaarbaarheid (o.a. spruitrust) en andere kwaliteitseigenschappen (o.a. vorm, grootte, kleur). De reden hiervoor is dat in de gangbare sector handelaren een grote invloed hebben op de rassenkeuze en zij geven vooral prioriteit aan kwaliteit. Daarnaast zagen veredelaars geen reden om meer tijd aan selectie in het veld te besteden, omdat de traditionele *Rijnsburger* populaties waaruit ze selecteerden, geen absolute resistentie genen tegen bladziekten bevatten. Ze probeerden resistentie in hun selectiematerial te introduceren via introgressie van resistentiegenen uit wilde *Allium* soorten, maar in aparte resistentieveredelings-programma´s, gescheiden van hun reguliere programma (zie Hoofdstuk 2).

Biologische akkerbouwers profiteren ook van verbeteringen in bewaring en kwaliteit, omdat het grootste gedeelte van hun oogst bestemd is voor reguliere supermarkten, die aan biologische uien dezelfde kwaliteitseisen stellen als aan gangbare uien. De biologische teelt vereist wel een hoger niveau van spruitrust dan de gangbare teelt, omdat gangbare telers chemische spruitremmers inzetten. Daarnaast duurt de periode tussen verpakken en aankoop in het biologische circuit langer. Echter, om ook de door biologische telers vereiste veldeigenschappen (verbeterd wortelstelsel, vroege bolvorming, waslaag op het blad, rechtopstaand blad in combinatie met hogere opbrengst) te verbeteren, zouden veredelaars meer tijd in het veld moeten besteden. Het verbeteren van het wortelstelsel vereist waarschijnlijk ook een verbreding van de genetische basis.

Naast veranderingen in selectieprocedures, vereist veredeling voor de biologische sector waarschijnlijk ook een aangepast selectiemilieu. Veredelaars zouden moeten stoppen met het gebruik van fungiciden en herbiciden. In velden zonder fungiciden kunnen ze op partiële resistentie, die aanwezig is in de *Rijnsburger* populaties, selecteren. Het gebruik van herbiciden heeft een effect op de plantdichtheid, die op haar beurt de evaluatie van belangrijke eigenschappen als bolsortering, vroegheid en spruitrust beïnvloedt. Het bepalen van het meest geschikte selectiemilieu voor verbetering van het wortelstelsel vereist verder onderzoek.

Zomertarwe

De zomertarwerassen, die veredelaars aanboden voor biologisch CGO (Hoofdstuk 7), voldeden niet aan bakkwaliteitseisen van biologische molenaars en bakkers. Daarnaast zochten biologische telers rassen met eigenschappen die biologische onkruidbeheersings-strategiën ondersteunen, zoals tolerantie tegen wiedeggen, een snelle beginontwikkeling, bladrijke en langere stengels. Slechts een beperkt deel van de ingezonden kandidaatrassen bezat dergelijke eigenschappen.

Interviews met veredelaars bevestigden, dat ze niet selecteerden op eigenschappen, die bijdragen aan onkruidonderdrukking (Hoofdstuk 4). De meeste veredelaars selecteerden juist tegen langere planttypes, omdat ze langer stro associëerden met lagere opbrengst en gevoeligheid voor legering. Door de strenge selectie tegen langer stro, maken genotypen met de plantlengte, die biologische telers wensen, slechts een klein deel uit van de laatste generaties van een gangbare veredelingsprogramma. Het te lage niveau van bakkwaliteit van nieuwe rassen wordt ook veroorzaakt door het feit dat deze eigenschap in gangbare veredelingsprogramma´s een lagere prioriteit krijgt dan opbrengst. In het algemeen gaat selectie voor kwaliteit ten koste van opbrengst. Voor de gangbare markt selecteren veredelaars voor een hoge opbrengst, terwijl ze de bakkwaliteit handhaven op een niveau dat te laag is voor de biologische verwerking. Gangbare telers verbeteren de bakkwaliteit via een extra stikstofgift tijdens de bloei. Daarnaast heeft de gangbare maalindustrie meer, relatief goedkope, opties om de kwaliteit te verbeteren dan hun biologische collega´s.

Een hoge opbrengst is ook prioriteit voor biologische telers, maar onder voorwaarde dat ze kunnen blijven voldoen aan de bakkwaliteitseisen van hun afnemers. In Hoofdstuk 5 exploreren we mogelijkheden om opbrengst en bakwaliteit tegelijkertijd te verbeteren, via de selectie op twee belangrijke factoren, die een bijdrage leveren aan bakkwaliteit: eiwitgehalte en eiwitkwaliteit. Eiwitgehalte zou verhoogd kunnen worden door te selecteren op een verhoogde totale biomassa. In biologische tarwe is vrijwel alle eiwit in de graankorrel gevormd uit stikstof, dat voor de bloei opgeslagen is in de biomassa, omdat tijdens en na de bloei stikstof in de bodem schaars is. In de gangbare teelt wordt een deel van het eiwit ook gevormd uit stikstof dat na de bloei uit de bodem is opgenomen. Vooral moderne rassen vertonen een gereduceerd eiwitgehalte bij een tekort aan stikstof tijdens de bloei. Moderne veredeling heeft de opbrengst verhoogd door de oogstindex te verhogen. Een verhoging van de korrelmassa, zonder de totale vegetatieve plantmassa te verhogen, resulteert in een relatieve afname van eiwitgehalte. Een simultane verhoging van korrelopbrengst en vegetatieve biomassa zou dit zogenaamde verdunningseffect kunnen voorkomen. Bovendien zouden dergelijke rassen een betere onkruidonderdrukking vertonen.

Een andere benadering is het verhogen van de eiwitkwaliteit. Deze strategie lijkt aantrekkelijk voor de biologische teelt, omdat, in theorie, zo een hogere bakkwaliteit kan worden bereikt met korrels met een lager eiwitgehalte. Daardoor zou het gewas ook minder stikstof nodig hebben. Literatuuronderzoek (Hoofdstuk 5) laat zien dat de eiwitsamenstelling van de korrel sterk beïnvloed wordt door het groeimilieu (stikstofaanbod uit de bodem). Vanwege genotype×milieu interactie vereist selectie op eiwitkwaliteit biologisch beheerde veredelingsvelden of gangbare velden met gereduceerde stikstofbemesting.

De keuze van het selectiemilieu wordt verder behandeld in Hoofdstuk 6. Een gezamenlijke analyse van rassenproeven uit zeven Europese landen toont hoge genetische correlaties (0.8-1.0) tussen biologische en niet-biologische proeven voor eigenschappen als opbrengst, eiwitgehalte, plantlengte, bodembedekking, en ziekteresistenties. Dit betekent dat veredelaars deze eigenschappen voor de biologische teelt kunnen verbeteren door te selecteren in hun gangbare velden. Dit onderzoek laat ook zien dat het combineren van data van gangbare en biologische proeven het selectieresultaat verbetert.

Aanpassen van de protocollen voor rassenonderzoek aan de behoeften van de biologische sector

Resultaten van onafhankelijk rassenonderzoek ondersteunen telers bij hun rassenkeuze en leveren veredelaars informatie over de voortgang van hun veredelingsprogramma. Hoofdstuk 3 en Hoofdstuk 7 laten zien dat de relevantie van rassenproeven voor de biologische secor toeneemt, als deze plaats vinden onder biologische omstandigheden met evaluatie van eigenschappen, die belangrijk zijn voor de biologische sector. Het aanpassen van het onderzoeksprotocol aan de behoeften van de biologische sector bleek essentieel wanneer het rassenonderzoek een verplicht onderdeel is van de officiële toelatingsprocedure van rassen, zoals het Cultuur en Gebruikswaarde Onderzoek (CGO) bij zomertarwe. De resultaten van het biologische zomertarwe CGO overtuigden de officiële *Commissie voor de samenstelling van de rassenlijst voor landbouwgewassen* om een aparte biologische categorie op te nemen in de *Aanbevelende Rassenlijst*.

Rassen, die via de biologische CGO-procedure opgenomen werden in de Aanbevelende Rassenlijst, vertoonden een betere onkruidonderdrukking dan rassen, die de reguliere procedure hadden gevolgd (Hoofdstuk 7). Echter, het biologische CGO leverde geen verbeteringen op in de urgent gewenste bakkwaliteit. De oorzaak hiervoor is dat de huidige gangbare veredeling vrijwel geen nieuwe lijnen met hoge bakkwaliteit oplevert (zie boven). Daarom concluderen we dat aanpassing van het CGO alleen niet voldoende is om het rassenassortiment voor de biologische sector te verbeteren. Veredelaars zouden tegelijkertijd hun veredelingsstrategie moeten veranderen.

Het CGO-project toont aan dat het officiële rassentoelatingssysteem voldoende flexibel is en niet noodzakelerwijs de toelating van geschikte rassen voor de biologische sector blokkeert. Echter, de kosten van de procedures zijn hoog en staan niet in verhouding tot de omvang van de markt. De kosten voor de procedures belemmeren de toelating van rassen voor de biologische sector en andere productieketens die zich richten op specialiteiten. Daarom zouden de officiële rassentoelatingsinstanties de ruimte moeten gebruiken, die de EU-wetgeving hen biedt, om meer kostenefficiënte CGO-procedures te ontwikkelen voor rassen, die bestemd zijn voor kleine markten, bijvoorbeeld door gebruik te maken van data verzameld in informele rassenproeven van actoren uit de productieketen.

Conclusies en perspectieven

Voor zowel ui als zomertarwe toont het onderzoek aan dat in gangbare veredelingsprogramma's niet geselecteerd wordt op een aantal eigenschappen, die belangrijk zijn voor de biologische sector. Dit geldt vooral voor eigenschappen, die botsen met prioriteiten in de selectie voor de gangbare sector, zoals hoge opbrengst en goede bakkwaliteit bij zomertarwe. Voor biologische telers is hoge opbrengst ook belangrijk, maar om een hoge opbrenst te halen moeten rassen biotische (bijvoorbeeld ziektes) en abiotische (bijvoorbeeld schaarste aan nutriënten) stress kunnen weerstaan, die hun gangbare collega´s kunnen beheersen met synthetische producten. De beweegredenen van biologische telers en verwerkers om de voorkeur te geven aan andere raseigenschappen dan hun gangbare collega´s zijn terug te voeren op waarden die onderdeel uitmaken van de Principes van Gezondheid en Ecologie van IFOAM (Hoofdstuk 8.3). Deze principes vormen ook een globale leidraad voor biologische veredeling.

Het belangrijkste obstakel voor veranderingen, die het rassenassortiment voor de biologische sector helpen te verbeteren, bleek de sociaal-economische organisatie van veredeling, rassenonderzoek en –registratie. Commerciële veredelingsbedrijven verdienen hun investeringen in veredeling terug via een kleine heffing op het zaad. Deze manier van financieren belemmert de mogelijkheid om voor productieketens te selecteren, die een klein areaal vertegenwoordigen. Veredelingskosten zouden beperkt kunnen worden door de selectie voor gangbaar en biologisch te combineren. Aansluitend, zou het betrekken van alle actoren in de keten bij de veredeling, de benodigde financiële middelen kunnen opleveren. Een dergelijke benadering zou ook in harmonie zijn met het Principe van Billijkheid van IFOAM, omdat kosten en risico´s van veredeling eerlijk verdeeld worden over de hele keten. Daarnaast zou de benadering, in overeenkomst met het Principe van Zorg van IFOAM, ook het veredelingsproces transparant maken en een directere uitwisseling van kennis en ervaring tussen veredelaars en andere ketenpartners mogelijk maken; dat laatste vergroot ook de kans dat rassen voldoen aan de eisen van de biologische sector.

About the author

Aart Osman was born in Goes, The Netherlands, 10th of October 1964. From 1983 to 1990 he studied plant breeding at Wageningen University, with additional specialisations in tropical crop production and rural development. During his study he conducted thesis research in The Philippines on partial disease resistance breeding in rice (Laboratory of Plant Breeding) and farmer driven innovation (Rural Sociology Department). In addition, he spent a practical period at the Legume Breeding Programme of the *Malang Research Institute for Food Crops* (MARIF), East Java, Indonesia.

After his study, he was employed at MARIF to set up an insect resistance breeding programme for soybean (1991-1992). After a political conflict between the Dutch and Indonesian government, he was posted at the Regional Office for Latin America and the Caribbean of the FAO in Santiago, Chile, where he coordinated variety trials of horticultural crops that consisted of varieties developed by national and university breeding programmes of Latin America (1993-1995). In addition, he co-organised regional meetings on genetic resources and research priorities for horticultural crops and was involved in the development of educational material.

From 1995-1996 he was involved in the coordination of field projects on organic farming of a group of NGOs and universities (COAGRES) in El Salvador, that participated in the *Sustainable Agriculture Networking and Extension* (SANE) programme of UNDP. This work involved guiding field technicians of the member organisations and organising courses and workshops on organic farming; project evaluation and documentation; and strategical planning.

During his next job (1997-1999) at the International Potato Center (CIP)/ Consorcio para el Desarollo Andino (CONDESAN) he studied farmers' soil fertility management practices in potato based cropping systems in the Andean region of Cajamarca, Peru. In addition, he facilitated collaboration between local NGOs, research institutes and universities in the area of soil fertility management.

At Louis Bolk Institute, Driebergen, The Netherlands (1999-2010), he conducted projects aimed at enhancing the availability of varieties suited to the needs of the organic sector. These projects involved facilitating communication and collaboration between the organic sector and the conventional breeding industry as well as resolving knowledge gaps through research.

At present, he lives in Chile, where he works as independent consultant in the fields of sustainable and organic farming and seed production.

Publications related to the thesis

Journal papers

Dawson J, Serpolay E, Giuliano S, Schermann N, Galic N, Berthellot J.-F, Chesneau V, Ferté H, Mercier F, Osman A, Pino S, Goldringer I (2013) Phenotypic diversity and evolution of farmer varieties of bread wheat on organic farms in Europe. Genetic Resources and Crop Evolution 60:145-163

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Proceedings Workshops

Rey F, Fontaine L, Osman A, van Waes J (eds) (2008) Proceedings of the COST ACTION 860 SUSVAR and ECO-PB Workshop on Value for Cultivation and Use testing of organic cereal varieties. What are the key issues? 28th and 29th February 2008, Brussels, Belgium. SUSVAR, COST, ECO-PB, ITAB, Paris, France

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Donner D, Osman A (eds) (2006) Handbook Cereal variety testing for organic and low input agriculture. COST860-SUSVAR, Wageningen, Netherlands

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PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)
- Approaches to stimulate the development of new varieties for organic agriculture

Writing of project proposal (4.5 ECTS)
- Approaches to stimulate the development of new varieties for organic agriculture. Based on spring wheat and onion research (2006)

Post-graduate courses (3.4 ECTS)
- Winterschool functional biodiversity for sustainable crop protection; PE&RC / EPS (2001)
- Onderzoek anders; CIS / WUR (2002)
- Scenario development: understanding and applying multi-scale and participatory concepts and tools; PE&RC (2007)

Laboratory training and working visits (1.2 ECTS)
- Participatory plant breeding; INRA, Montpellier & Rennes, France (2005)

Invited review of (unpublished) journal manuscript (0.9 ECTS)
- Journal of the Science of Food and Agriculture: baking quality of organic wheat (2011)
- Journal of Cereal Science: baking quality breeding (2012)

Competence strengthening / skills courses (1.5 ECTS)
- Faciliteren van groepsprocessen; ITV-Wageningen (2000)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)
- PE&RC Day: the scientific agenda: who pulls the strings? (2006)
- Darwinian agriculture: the evolutionary ecology of agricultural symbiosis (2007)
- PE&RC Day: accelerate scientific progress: expect the unexpected (2008)
- PE&RC Day: intelligent nature: on the origin of the communication (2009)

Discussion groups / local seminars / other scientific meetings (6.5 ECTS)
- Working group on cereal diseases; Royal Netherlands Society for Plant Pathology (2002-2010)
- COST Network: sustainable low-input cereal production: required varietal characteristics and crop diversity (2004-2008)
- The sustainability camp; IFOAM, Bonn, Germany (2012)

International symposia, workshops and conferences (9 ECTS)
- First International Symposium on Organic Seed Production and Plant Breeding; European Consortium for Organic Plant Breeding (ECO-PB); Berlin ,Germany (2002)
- First World Conference on Organic Seed; FAO/IFOAM/ISF, Rome, Italy (2004)
- International Frontis Workshop: Gene-Plant-Crop Relations: scale and complexity in plant systems research; Frontis, Wageningen, the Netherlands (2006)
- Plant breeding for organic and low-input agriculture: dealing with genotype-environment interactions; EUCARPIA/ ECO-PB/ISOFAR, Wageningen, the Netherlands (2007)
- 16th IFOAM Organic World Congress: cultivating the future; IFOAM, Modena, Italy (2008)

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