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Research paper

Adapting spring wheat breeding to the needs of the organic sector

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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.

1. Introduction

Organic farmers need varieties that grow well without synthetic inputs and possess traits that complement organic crop management practices [1–3]. 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. 4–6]. 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). 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, breederśdecision 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. 7]. 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.

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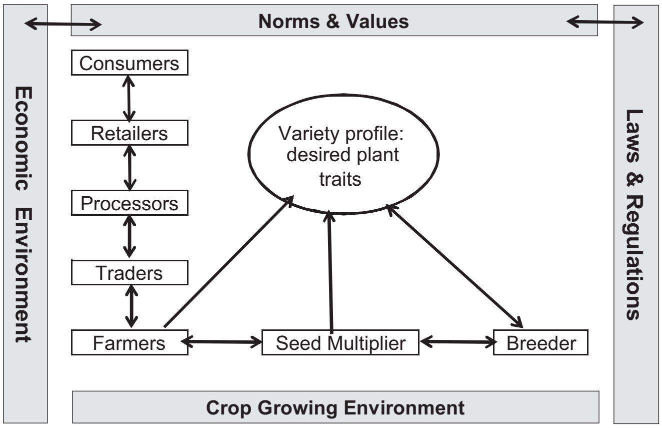

Figure 1. The breeding system and its influence on the shaping of a variety.

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 provoked 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);
- 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 at 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.

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 2000 to 2010. Data from an earlier study by Osman & Lammerts van Bueren [8] 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 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 content of 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 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.

3. Particularities of Dutch organic wheat production and processing

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 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 [9]. 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 [10].

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 3). Organic subsidiaries 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 [11]. 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.

Table 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 [8].

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)	$\pm$ 100 cm (= standard variety Lavett)	+
Reducing risk of diseases		
Plant length (also because of weed suppression)	$\pm$ 100 cm (= standard variety Lavett)	+
Peduncle length	$\pm$ 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 ($\pm$ 6 tonnes/ha)	++
Milling and Baking quality		
Specific weight	$\geq$ 76 kg/hl	++
Hagberg falling number	$\geq$ 260 s	++
Protein content	$\geq$ 11.5%	++
Zeleny sedimentation value	$\geq$ 35 ml	++
Marketable loaf of wholemeal bread	Loaf volume like variety Lavett	++

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.

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 [15]. According to organic thinking fostering biodiversity, ecological processes and cycles enhances and sustains system health. On the other hand synthetic inputs are rejected, because they 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 1). Below we elaborate on the consequences for variety requirements.

4.1. Seed quality

In the Netherlands, seed quality of organic spring wheat is mainly compromised by Fusarium head blight [16]. 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 [3,17]. 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.

4.2. 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 [18].

Table 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 [19–21]. Important for Dutch organic farmers as well are varieties that tolerate intensive harrowing (Table 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.

Table 2
Selection criteria and priorities of the four interviewed breeders (A, B, C, D).

Traits	Priority[1] for conventional market				Change in priority if breeder would also select for organic[2,3]			
	Breeder:				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. 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.) [22–25].

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 [26]. 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 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 [27]. 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

Table 3
Key features of Dutch organic and conventional wheat production and bread distribution.

	Conventional	Organic	Source[a]
Acreage in hectares and % per crop type (average between2009 – 2012)			
Winter wheat	128500 (84.5%)	687 (35.4%)	c: [9] o: CBS, not published
Spring wheat	23500 (15.5%)	1252 (64.6%)	
Spring wheat production			
Nitrogen application (recommended rate in kg/ha)	150	100	c: [12] o: [13]
Spring wheat yield (tonnes/ha)	7.1	5.3	c: [9] o: CBS, not published
Bread distribution: market share /channel (2010 – 2011)			
Supermarkets	65.0%	30.2%	c: [14] o: [11]
Bakeries	28.5%		
Specialised organic shops		45.7%	
Out of home		20.1%	

[a] c = conventional; o = organic.

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 [28,29].

All four breeders give high priority to resistance for brown rust and Fusarium head blight despite the availability of fungicides (Table 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. Soil fertility management

In organic cropping systems nitrogen is usually limiting productivity [30] and baking quality. Organic farmers' nitrogen application is 33% less (50 kg/ha) than the recommended rate for conventional spring wheat production (Table 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 [31,32], 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 tradersádvice 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 [33]. 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 farmersṕractices 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 [34]. 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 [35]. 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).

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 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 [36,37]. Breeders make different choices in the way they evaluate baking quality (Table 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 [38], 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 [39]. 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 [40–43]. 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 [35,44,45]. 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.

6. Influence of the institutional environment on breeding

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 [46]. EU seed legislation provides national authorities flexibility to adjust criteria and testing protocols to local needs and new demands. As a result procedures and criteria differ among EU countries. However, in most EU countries (including The Netherlands and Germany) candidate varieties have to reach a minimum yield level to pass the regular VCU tests. 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 [47,48]. 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.

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 [49,50].

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 hectare to be able to maintain a cereal breeding programme. As it only occupies a small portion of the acreage of conventionally managed wheat (Table 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.

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 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 [17,51]. 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 [52].

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 [17,53,54]. 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 [35,55]. 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 [56,57]. 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 seems highly relevant for the organic sector as well [58].

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