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Breeding for organic agriculture: the example of winter wheat in Austria

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Abstract Breeding for organic agriculture (BFOA) is a strategy for a commercial breeding company based on the exploitation of the frequently observed high correlation for many traits between conventional, low input (LI) and organic agriculture (ORG). Indirect selection under LI can be useful to roughly divide the germplasm into the genotypes better adapted to high input and those better adapted to LI or ORG conditions. BFOA is an evolving process, in which two methods are currently applied: early generations are either selected following the pedigree system under LI, or grown as bulk populations on ORG fields. In the latter case the system switches to LI after individual ear selection under ORG conditions. In both methods, the first replicated yield trial is grown parallel under ORG and LI. Subsequently, the genotypes are grouped into conventional or ORG advanced trial series. The BFOA strategy allows that the larger genetic variability of both the organic and conventional gene pool can be exploited in the selection for ORG. Hitherto, seven winter wheat varieties were released in Austria after exclusive organic VCU testing.

Keywords Breeding strategy · DUS · Indirect selection · Low input · *Triticum aestivum* · VCU

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Abbreviations

BFOA	Breeding for organic agriculture
DUS	Distinctness, uniformity and stability
HI	(Conventional) high input agriculture
LI	(Conventional) low input agriculture
N	Nitrogen
ORG	Organic agriculture
VCU	Value for cultivation and use

Introduction

In the last decade growing environmental concern and decreasing prices stimulated an increasing number of European farmers to favour agricultural systems with lower input levels. Especially organic farming has experienced a steady development since the 1990s. In the beginning, organic farmers relied on untreated, but conventionally produced seed. With the EU regulation 2092/91, organic farmers were urged to use organically produced seeds and vegetative multiplication material. As yet, organic agriculture still depends strongly on organic seeds of varieties originally bred for conventional agriculture. However, voices for distinct breeding programmes are continuously arising as varieties suitable for organic farming and/or conventional, low input agriculture have to exhibit specific characters, e.g. nutrient-efficiency, weed suppression, high disease resistance, and often a unique product quality.

In Austria organic production has a high relevance in agriculture for both local consumption and export. Organic cereal acreage increased from 24,656 ha in 1997 to 67,874 ha in 2007. Winter wheat (*Triticum aestivum* L.) is the most widely grown cereal in organic agriculture (ORG); its acreage increased 4.7-fold within the past 11 years, reaching 22,852 ha in 2007 (AMA 2007). The organic sector approaches 10% of the wheat seed market in Austria and 2–3% in Europe. Therefore, considering economics, a private wheat breeding company that relies on royalty income can spend at maximum 5–10% of the breeding expenses on 'extras for organic' (Birschitzky 2007). The winter wheat varieties currently used in organic agriculture in Austria include old varieties, e.g. Erla Kolben which was released in 1961, and varieties bred by biodynamic breeders in Switzerland (Kunz et al. 2006). However, the largest part of organic wheat acreage is cultivated with varieties developed in conventional programmes under selection strategies for low input (LI) conditions (Hänsel and Fleck 1990; Spanakakis 1990) as well as from programmes with final selection on organic fields and organic value for cultivation and use (VCU) testing.

Plant breeding is a process evolving from the interaction between genetic material, selection environments and involved persons. Organic variety trials started in Austria in 1995, which led to the establishment of a pure organic VCU test for winter wheat and spring barley (*Hordeum vulgare* L.) in 2001 and 2002, respectively. The decision for an organic VCU test was a first stimulus for Austrian breeders to test their material parallel under LI and ORG conditions, develop breeding strategies and investigate diverse aspects of organic plant breeding. Extrapolation of literature, collaboration with other breeders and/or within specific networks, e.g. the COST860-SUSVAR action (www.cost860.dk), as well as Austrian collaborative research projects gave rise to the development of a specific and flexible breeding strategy for organic agriculture (BFOA). In the present paper the Austrian organic VCU test and two BFOA methods as developed and currently applied for winter wheat by the Saatzucht Donau breeding company will be outlined and discussed.

Organic VCU test

In Austria the majority of conventional production takes part in specific environmental, low input programmes in which nitrogen (N) and fungicide application is limited; the conventional VCU test is carried out correspondingly. The conventional VCU testing for winter wheat is performed independently in two agro-climatic regions of Austria, i.e. locations in the northwestern 'wet and transition region' WEST (260–585 m a.s.l.; 643–957 mm long-term annual precipitation; 6.8–9.1°C long-term average annual temperature) and the eastern 'dry' region EAST (117–256 m a.s.l.; 508–658 mm; 8.7–9.9°C). Considering precipitation processes, WEST resembles the maritime influence of the Atlantic Ocean, while EAST shows the eastwards increasing continentality causing mainly convective precipitation (Ehrendorfer 1987). Entries can be tested in either one region or in both; 'check' varieties are partly the same. While in EAST all conventional VCU trials are performed without fungicide application, the WEST trials are partly treated with fungicides and growth regulators, a procedure comparable to most western European countries. In the present paper LI refers to trials under conventional growing conditions with mineral fertilisers and herbicides but without the application of growth regulators and fungicides. The average nitrogen rate is 120 and 130 kg ha^{-1} in the EAST and WEST region, respectively. The organic growing of winter wheat in Austria includes a rotation of 3–4 years, mechanical harrowing to manage weeds and application of organic manure or compost with an average N supply of 120–130 kg ha^{-1}. The average yield level of organic winter wheat of high baking quality is 4 t ha^{-1} which is similar to the average yield level under LI conditions.

Results over several years have been used for a comparison of organic and conventional low input trials in the Austrian target areas. While many characteristics were highly correlated between the two growing systems in both regions, correlations for yield were variable ($r = 0.55^{ns}$ to $r = 0.83^{**}$). Moreover, genotype ranking was not satisfactorily consistent for baking volume, N use efficiency and weed suppression (Oberforster et al. 2000; AGES 2002; Oberforster 2006). Therefore, organic VCU trials were established for winter wheat and spring barley, i.e. varieties of these crops can be exclusively tested and released under ORG without the necessity of parallel conventional tests (Oberforster 2003). In contrast, VCU testing of winter barley, winter rye (*Secale cereale* L.), winter and spring triticale (× *Triticosecale* Witt.), spring oats (*Avena sativa* L.) and spring wheat is carried out parallel both at ORG and LI locations. Thereby varieties suitable for organic farming can be recommended.

The five testing locations for the 3 years of organic VCU trials cover the main wheat growing regions of WEST and EAST, thus giving results from 15 organic environments for the decision on variety release. An additional set of parameters was introduced into the organic VCU trials, mainly concerning competitive ability and weed suppression, N use efficiency and yield stability (Oberforster 2003). Competitive ability/weed suppression is evaluated indirectly by crop ground cover, leaf area index and light interception measurements at different developmental stages, the measurement of crop height and recording of leaf inclination at stem elongation (Eisele and Köpke 1997a, b; Hoad et al. 2005; Kruepl et al. 2006).

The VCU entries comprise new breeding lines as well as check varieties commonly used in organic agriculture. With this approach, new entries can be compared directly to the most widely grown varieties. From 2002 onwards, between 16 and 22 entries per year were tested in the organic winter wheat VCU trials. Until now seven winter wheat and two spring barley varieties have been released after passing the organic VCU test in Austria. At present six 'organic' winter wheat varieties are on the national variety list (AGES 2008).

The implementation of an organic VCU test has lead to a greater number of varieties available for ORG. Most probably, all of the varieties released after organic VCU test would have failed the conventional VCU test in Austria due to significant lodging or yield penalty. In ORG, other traits, e.g. end use quality, disease resistances, weed suppression are of major importance for which the released varieties meet the requirements. Furthermore, variety release in Austria enables marketing in all EU countries. While Austria is the only EU country performing a pure organic VCU test, Switzerland and Germany use combined conventional and organic trials for the decision on the release of varieties especially suited for ORG (Kempf 2003; Schwaerzel et al. 2006).

Principles of breeding for organic agriculture

The implementation of an organic VCU test stimulated Austrian wheat breeders to test their material under organic conditions. New breeding strategies were stepwise developed in order to best meet the criteria of organic agriculture. Several years of experience with parallel ORG and LI testing of a wide range of breeding material led to the formulation of two breeding methods which are currently applied at Saatzucht Donau to achieve varieties for the organic sector. Besides our own experiences the results from a broad review of literature on comparisons and selection strategies for low input and high input (HI) environments influenced the decision making concerning breeding for organic agriculture. With regard to variation induction and selection techniques, maintenance and multiplication, our Breeding For Organic Agriculture (BFOA) methods comply with the IFOAM Plant Breeding Draft Standards (IFOAM 2004) allowing only whole plant breeding techniques, and also with the Austrian negative list of techniques which agrees with the IFOAM draft standards but additionally bans *aestivum* introgression into spelt (*T. spelta* L.) wheat (Surböck et al. 2003). Before we explain the two breeding methods we will first discuss the basic principles behind the required traits and selection strategy.

Traits

Comparing breeding goals for LI and ORG farming systems, one can differentiate between (a) traits that are relevant for both systems and (b) additional traits only or predominantly relevant in ORG (Table 1).

Table 1 Traits for winter wheat that are relevant for both organic (ORG) and conventional, low input (LI) farming systems (signs 0, +, ++ and +++ are given for increasing importance)

Trait	Low input	Organic	Remarks
Tillering capacity	++	+++	Better differentiation found in ORG by the authors
Regeneration ability after harrowing	0	+++	In low input systems harrowing is rarely practised
Crop ground cover*	+	+++	Important for weed suppression ability, see below
Leaf architecture and leaf area index*	+	++	
Early vigour in spring	+	++	
Adaptation to geographic latitude	++	++	Equal importance; adaptation is necessary
Earliness*	+	+	This factor positively influences early vigour
Rapid nutrient uptake	++	+++	Periods of drought and nutrient deficiency can be overcome
Weed suppression ability*	+	+++	
Plant height—taller genotypes*	++	+++	Tallness can enhance stability in yield and quality in both systems
Good shading ability*	+	+++	Advantageous also for soil water conservation
Competition ability*	0	+++	In high input systems sometimes disadvantageous for yield level
Nutrient efficiency*	++	+++	Approximated by measurement of protein yield per unit area
Good rooting	++	++	
Disease resistance*	++	+++	More and other diseases are important in ORG
Powdery mildew*	++	+	In many cases less important in ORG due to less dense stand
			Dependent on N level
*Septoria tritici**	++	+	Differential reaction, especially influenced by crop rotation
*Septoria nodorum**	++	+	Differential reaction, increases in combination with stresses
Yellow-, leaf-* and stem-rust	+++	++	Important in both, importance often decreases with intensity
Resistance to seed borne diseases	0	++	Important in ORG, very variable between years and locations
Lodging resistance*	++	+	Related to plant height; tall, lodging resistant types are favourable
Wide ecological adaptation	++	+++	Could enhance stability in more diverse ORG environments
Adaptation to local climate	++	++	Is measured through yield level and yield stability in relation to adapted standard varieties
Specific adaptation	+	+++	Example: special quality traits in (local) specialities
Adaptation to variability of influencing factors	+	+++	A variety for ORG must not have any major weekness
Grain yield*	+++	++	Yield has to be seen in relation to quality; protein yield is usually influenced to a higher degree by grain yield than by protein content
Yield stability	++	+++	Eventually less cultivation measures exist for control in ORG
High protein content*	++	+++	Minimum requirements are common in ORG marketing
Grain quality/baking quality*	++	+++	Mostly higher, but sometimes different kind of demand for quality in ORG

* Traits that are scored/measured in organic Value for Cultivation and Use (VCU) test

Disease incidence is often influenced by the cropping system. Typical high input diseases, e.g. powdery mildew (*Blumeria graminis* f.sp. *tritici*), and diseases connected to unfavourable crop rotation, e.g. eyespot (*Tapesia yallundae, T. acuformis*), are less important in ORG. On the other hand, specific quality traits, e.g. protein content and baking quality have a relatively higher impact in ORG. Our trial series and the studies of Oberforster (2006) and Kleijer and Schwaerzel (2006) revealed that most quality traits are highly correlated between ORG and LI. Among the parameters specific for ORG the ability for weed suppression, nutrient efficiency, resistance to seed borne diseases as well as yield and quality performance under organic conditions create new parameters to be measured and therefore require new methodology and additional efforts in the selection for ORG (Osman and Lammerts van Bueren 2003; Surböck et al. 2003; Donner and Osman 2006). The new methods must permit a rapid, easy, accurate and cheap determination of the parameters in order to allow the screening of a multitude of breeding lines. For instance rating of plant growth habit, leaf habit and inclination, visual scoring or image analysis of ground cover (Richardson et al. 2001) is more feasible for a practical breeder than light interception measurement or the determination of weed biomass per unit area (Hoad et al. 2005). Likewise protein (grain N) yield per unit area (Spanakakis and Viedt 1990; Oberforster 2003) is easier to determine than an exact analysis of N uptake and utilization efficiency (Moll et al. 1982).

Selection strategy

Next to looking for additional traits also the choice of the selection environment is of importance (Falconer 1989; Wolfe et al. 2008). Conventional LI trials can be regarded as indirect selection environments for ORG (Wolfe et al. 2008). To maximize selection gains, breeding programmes targeting ORG or LI environments should include at least LI environments. The relative efficiency of indirect selection at HI levels was never shown to be more efficient than direct selection at LI (Ceccarelli et al. 1992; Sinebo et al. 2002; Brancourt-Hulmel et al. 2005). Heritabilities and relative efficiency of direct versus indirect selection vary greatly with the pairs of environments. Lower heritabilities at low input levels have been related to lower genetic variance and an increased error variance by some authors (Ud-Din et al. 1992; Brancourt-Hulmel et al. 2005). This latter aspect needs a long-term foresighted weed and soil management as the prerequisite for accurate field trials under ORG.

The development of a combined breeding system for organic agriculture requires a sound analysis of all envisaged selection environments. The choice of appropriate selection environments that allow differentiation in all important traits for organic agriculture, turned out to be crucial. This experience is highly supported by selection theory, comprising genetic variance, heritability and selection intensity as major factors influencing selection gain (Falconer 1989). Yield data from a COST-SUSVAR winter wheat ringtest carried out in Austria, France, Germany, Romania and Switzerland revealed that LI and ORG environments in these countries were correlated with each other, whereas no relationship was found between HI and ORG environments (Löschenberger et al. 2007). Based on a series of comparative ORG and LI trials and the SUSVAR ringtest Saatzucht Donau has developed a breeding method that combines indirect and direct selection.

Methods of breeding for organic agriculture (BFOA)

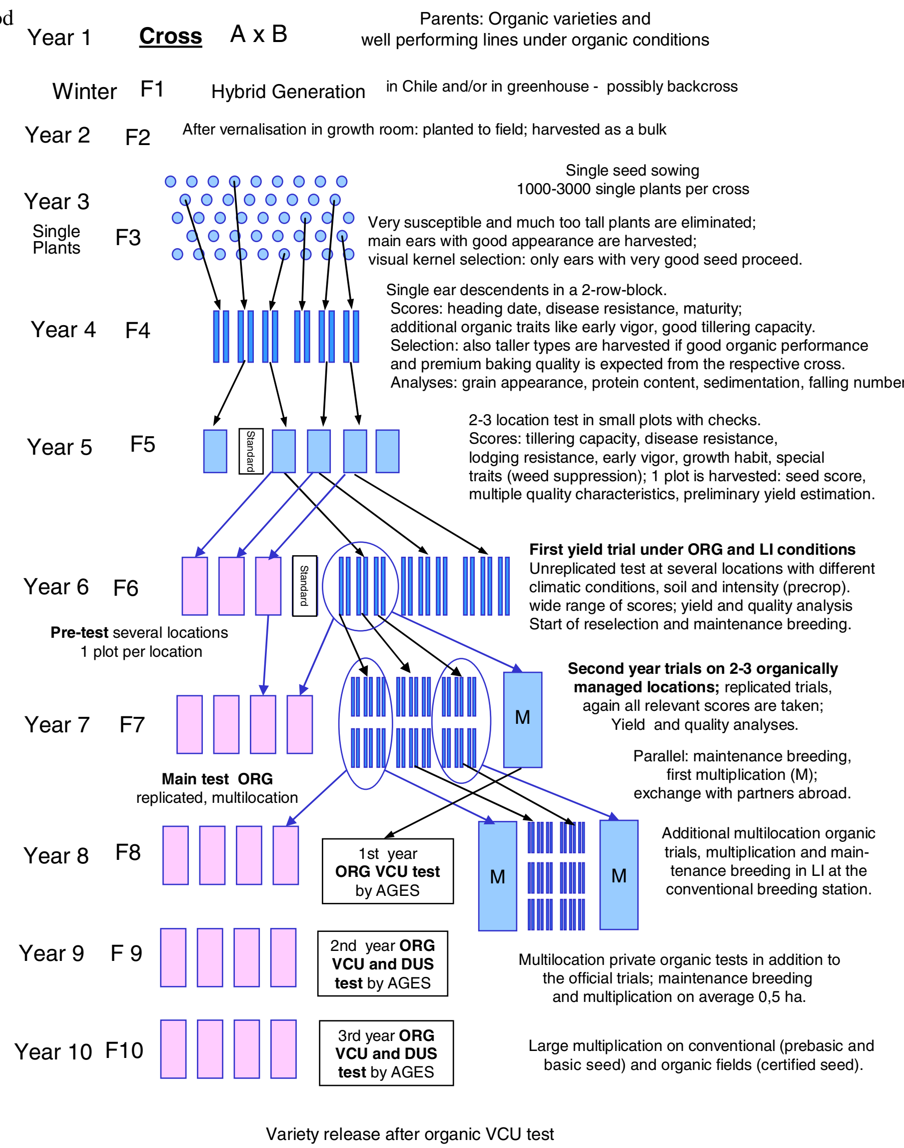
Genetic material

Creating genetic variability is the first principle of every breeding strategy. In BFOA, the broad genetic variability available in the conventional crossing populations is enriched by a number of crosses involving varieties especially suited for ORG. Furthermore, genetic material containing traits specifically required in ORG, such as vigorous growth, weed suppression, disease resistance and excellent end-use quality (see, e.g. Table 1 and Wolfe et al. 2008), are included. Sound knowledge of the parental lines used in crosses allows a prediction of the expected attributes of the progenies. Testing of parental genotypes in multi-environment ORG or LI trials is essential for an accurate evaluation of their performance and trait expression under extensive conditions. Together with additional information, e.g. genetic similarity, these data can be used for the prediction of breeding values of the respective genotypes applying advanced biometrical methods (Bauer et al. 2006; Bauer and Léon 2008). Thereby it should be possible to increase the genetic gain in BFOA in the long run.

Selection in early generations

Within the concept of BFOA of Saatzucht Donau, we can consider the first steps of selection for ORG as indirect selection because it is conducted under LI conditions. From here we can distinguish two different methods: scheme A and scheme B, which will be elaborated below.

Fig. 1 Scheme of BFOA method A for organic winter wheat as mainly performed by Saatzucht Donau

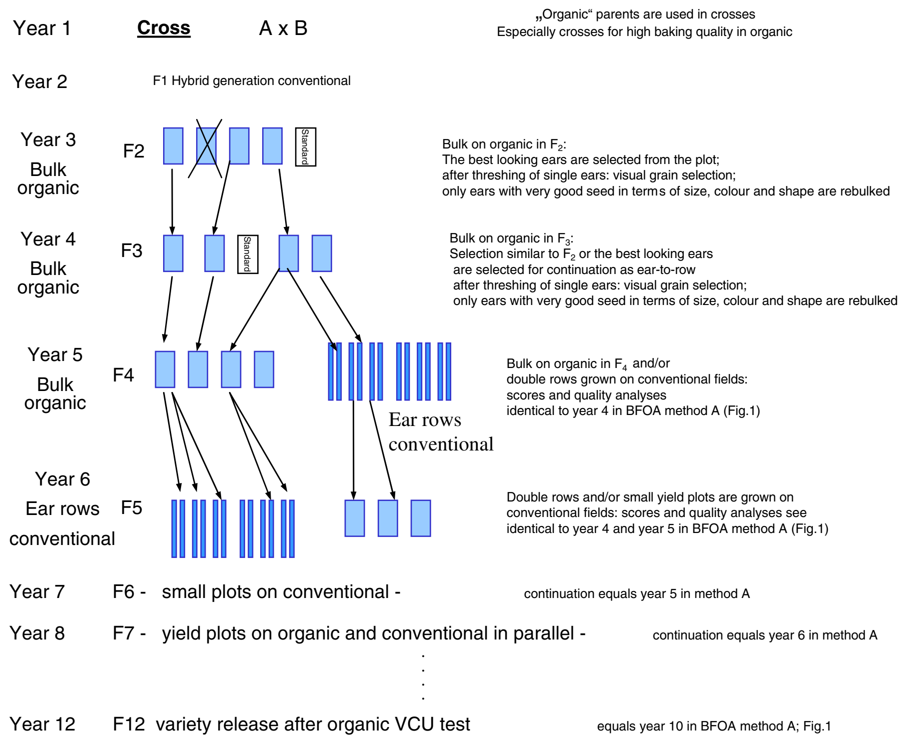


In scheme A (Fig. 1) the F_1 to F_5 generations are grown under LI, followed by 5 years of testing on organic fields. Selection starts in F_3 on single plants. Single ears are cut from selected plants and continued as F_3-derived lines. In F_4 the most important selection occurs by means of scores and measurements for highly heritable traits, e.g. tillering capacity, plant height, grain weight and some disease resistances. For these traits a high correlation between ORG and LI environments was demonstrated. Indirect selection for ORG is performed by including specific characters especially valuable for ORG. $F_{3:5}$-lines are grown at three locations for observation and estimation of yield potential. Quality is analysed from the harvested grain of one location.

In the second approach (scheme B) the multiplication of early generations is carried out on organic fields (Fig. 2). The F_1 is grown conventionally in Austria, from F_2 to F_3 or $F_{4,}$ bulk population plots are grown under organic condition which favours plant–plant competition and sufficiently suppresses weed growth. In F_3 or F_4, single ears are selected and continued as ear-to-row in a LI nursery. Thereafter scheme B equals scheme A.

In the early generations, all material is selected using visual scores. In both breeding schemes in four

Fig. 2 Scheme of BFOA method B for organic winter wheat, including more 'organic' steps



selection years around 1% of the breeding material is selected for entering the first ORG yield test. Space-planting and single plant selection under ORG would pose severe weed problems. To realize maximum genetic gain, it is suggested that space-planting in BFOA methods is carried out under herbicide treatment, but with intermediate N levels as described for scheme A.

Selection in advanced generations

According to their individual behaviour in different environments, the genotypes are divided after F_5 or F_6 into material primarily for conventional agriculture, which in our case is mostly LI, and material for ORG. Those intended for ORG undergo their first yield trial under ORG and LI conditions in parallel. Usually, the breeding lines are tested for 2–3 years under ORG conditions before the application for organic VCU testing, which takes another 3 years.

The organic location Dörfles in the EAST region has shown equal trial accuracy to LI trials for several years, which was measured in terms of least significant differences (data not shown). Based on this experience, in 2008, the majority of all advanced breeding material for the EAST region is tested at this location. Testing under ORG adds variability of the growing conditions to the network of testing sites, especially concerning nitrogen dynamics or soil structure. Based on the results of parallel testing under ORG and LI, genotypes can be regrouped for continuation in either system. Decision for either organic or conventional VCU test is based on weed suppression ability, disease and lodging resistance and most important, on protein content and baking quality. The BFOA system led to the VCU application of wheat with excellent baking quality which would have been discarded in the previous conventional system because of yield penalty. Protein yield per unit area on ORG and LI is one of the most important selection criteria for organic winter wheat varieties. Furthermore, stability of yield and quality is more important for organic than for conventional agriculture, as less measures exist for crop control in ORG. As discussed in Wolfe et al. (2008) the question of stability has to be considered over space (geographic regions) and time (years). By consciously choosing and including a wider range of geographic testing regions, the annual variation in climatic conditions could eventually be mimicked 'a priori'.

Maintenance breeding

The standard breeding system for cereals takes at minimum 10 years from the original cross to variety registration. For maintenance breeding, several lines are derived from an ear-to-row system, further selected (as mentioned above) 'indirectly' for 2 years on conventional fields, and then again tested for yield on organic fields. Maintenance breeding is not based on repeated retrieval of a single line, but on selection of a few morphologically indistinguishable, near-isogenic varietal sublines which are tested in LI and ORG trials and then composed to form the variety. At Probstdorfer Saatzucht, a predecessor of Saatzucht Donau, the strategy was to maintain a variety once it had passed the DUS test as 'broadly' as possible in order to retain some heterozygosity which might favour buffering capacity of the variety. The multi-line character was demonstrated, e.g. for 'Extrem' (Hänsel 1970) and 'Amadeus' (Gröger et al. 1997). Hänsel et al. (1994) described that the two lines of 'Amadeus' were selected in F_7 from the same F_3 derived bulk. According to Fig. 1 the grains of one single F_3 spike, being a row in F_4, a small plot in F_5, and the harvested material of a first multiplication plot in F_7 is entering the VCU test. The ear-to-rows in F_4 are strongly selected for morphological homogeneity, which probably leads also to a markedly higher degree of genetic homogeneity that is able to meet the criteria of the DUS test, which is started in the second year of VCU test. In case of morphological similarity, few $F_{3:5}$ lines can be combined to form the variety for starting of the DUS test. This system was for example applied for the winter wheat variety 'Ludwig' which was released after conventional VCU tests in Austria (1997), Czech Republic (2004), Germany (1997), Hungary (2004), Poland (2006), Slovenia (2004) and Switzerland (2004). 'Ludwig' is an example of a multiline variety developed by that breeding system and an example of broad adaptability. On the other hand, a combination of $F_{3:5}$ derived lines can be risky for DUS, as not all morphological characters can be determined each year. Some DUS traits can be masked by specific environmental conditions, like heat or drought. The majority of recent varieties are derived from single ears of later generations, mostly F_5 up to F_8. A general preference for multiline varieties must be questioned as there are new doubled haploid varieties like 'Mulan' that show a broad environmental adaptability from Sweden over Germany and Austria to Hungary, in spite of being genetically homogenous (Schachschneider, pers. commun.).

Discussion

Above we have described BFOA as a process, in which two methods are currently applied: early generations are either selected following a modified pedigree system under LI (scheme A), or grown as bulk populations on ORG fields (scheme B). Method B is mainly used for 'specific organic crosses', i.e. crosses with the goal to extract primarily varieties for organic farming.

Breeding and selection strategy

BFOA as interpreted by the authors is an evolving system which depends on the dynamic inclusion of research results on breeding methods and genetic material. Our general attempt of first selecting in LI environments and in a second step shuttle between, or use both LI and ORG environments, is similar to the method described by Kirigwi et al. (2004) for the selection of wheat across water regimes. The authors concluded that alternating selection between high and low yielding environments in the early breeding stages is the most effective way to develop wheat germplasm adapted to environments where intermittent stress occurs. Also Mishra et al. (2006) emphasize the usefulness of categorizing environments as low-stress or as high-stress for the purpose of selection. They propose that understanding relationships among testing locations within years and determining the causal environmental factors of crossover interactions between sites and/or management systems is essential. In Austria, the results of a comparable kind of analysis led to implementation of the organic VCU test (Oberforster 2003).

Former research results which were gained at times of prevailing LI levels in (wheat) breeding should again be considered with respect to BFOA (Hänsel 1961, 1976; Hänsel and Ehrendorfer 1973; Buddenhagen 1983; Yonezawa 1983). Analysis of regression and correlation, either single (DePauw et al. 2007), multiple, partial (Hänsel 1976, 1984) or using residuals from regression (Hänsel 2001) or new methods such as the GGE biplot technique (Yan and Kang 2003) or advanced mixed models (Smith et al. 2002) can serve as tools for better knowledge of the existing selection environments and the behaviour of the genetic material of the respective breeding program therein. Furthermore, breeding challenges and solutions for the developing countries can be reinterpreted and discussed in the frame of ORG, e.g. in both systems crop rotations are crucial in order to minimize pathogen populations (Duveiller et al. 2007).

Shortening the time from cross to variety release and increasing selection efficiency is a major driving force for development of new breeding methods and technologies, like doubled haploids and the use of molecular markers. On the other hand, these rapid methods are economically resource demanding and some technologies are questioned by the organic movement (Lammerts van Bueren et al. 2003, 2007). In our BFOA method A, we use only one off-season generation in Chile for shortening the time of breeding. Since method B takes 1 or 2 years longer than method A it should be more efficient for some criteria. Using method B, which includes a few years of bulk breeding in ORG fields, eventually lines with a higher plant–plant competitiveness and better weed suppression and nutrient uptake, relative to their sister lines, might be selected. Furthermore, retrieval of lines in later generations leads to a higher degree of intervarietal homozygosity which can be of advantage for DUS, but might also have a disadvantage with respect to stability. Principally, method A could equally be applied in ORG fields for all generations. According to our experiences, the inclusion of 'specific traits for organic' into all steps of selection is crucial in either breeding scheme. When selecting under moderately high input conditions, while considering ORG, e.g. tall genotypes must not be excluded systematically, as probably is often the case in breeding for conventional agriculture only. In case of a highly heritable trait, one single high input selection step could easily eradicate useful or even crucial characters for ORG.

In our BFOA scheme A, all pre-tests of advanced material designated to ORG are performed in untreated LI and ORG trials in parallel. The same approach is applied in Switzerland for VCU tests (Schwaerzel et al. 2006). In accordance with the results obtained by Przystalski et al. (2008), a combination of both systems, conventional and ORG can lead to more accurate results, especially in case of economic constraints preventing extension of the ORG testing network. As organic production has a broad variability concerning biotic and abiotic external effects on cereal production, either the variability of varieties for organic agriculture should be increased and/or broad adaptability and compensation ability is of utmost importance for varieties used in ORG. Selection methods for improving the stability of a variety should have high priority (Grausgruber et al. 2000). Private breeding companies have to concentrate on broad adaptability and widely usable varieties also for economic reasons.

VCU test, DUS test and variety protection

Breeding method A implies that the first year of VCU test is provided with partly heterogeneous plant material, whereas more homogeneous material enters the DUS test. Nevertheless, some heterogeneity is saved by using several lines for maintenance breeding instead of limiting the material to a single plant progeny. It remains to be proved whether this procedure really favours a better adaptability. Probably, a favourable overall combination of traits in a single genotype can outbalance the possible advantage of some heterogeneity in a limited or less favourable genetic background.

By putting the trial results and experiences together, the breeder searches for rare, but extraordinary combinations of favourable alleles in one variety. More than 2 million different recombinants are possible in a single wheat cross combination in case of just one differing allele per chromosome (DePauw et al. 2007). When considering this broad genetic recombination potential, it is close to impossible that any selection method can lead to a similar variety from the same cross by any other breeder. Variety protection systems play a significant role for ensuring long-term investment in the development of varieties for ORG. The proposed BFOA strategy is one way to meet this challenge. Interestingly, the market often reflects a dominance of few varieties which best meet the requirements of the majority of the farmers. On the other hand, using a greater number of diverse varieties at all levels of the market chain would contribute to stable supply, as e.g. unfavourable weather conditions might occur or new races of diseases might rapidly evolve.

Conclusions

Organic farming conditions are extremely diverse between and even within European countries. Therefore, varieties used and adapted to ORG reflect a wide variability of required traits and different breeding strategies (Wolfe et al. 2008). International trial networks between breeders and researchers engaged in BFOA can significantly contribute to the still evolving breeding strategies. Such ring tests by European breeders were already established by both the Association of Biodynamic Plant Breeders (www.abdp.org) and within the COST 860-SUSVAR network (Löschenberger et al. 2007). The presented methods of BFOA are possible ways for a practical wheat breeder to take questions of both, organic and/or low-input and even high input systems, into account. According to Hänsel (1984), a breeder should always adjust the details of the breeding system and the selection process to the behaviour of the genetic material encountered. It was highlighted that organic varieties require different characteristics. LI environments can be very valuable for selection of morphological and quality characteristics which are favourable for ORG. On the other hand, in many cases, different yield ranking of varieties was observed in organic and conventional trials, which highlights the importance of breeding and selecting under organic conditions. Establishing the flexible BFOA scheme allows the larger genetic variability of both the organic and conventional gene pool to be exploited. This BFOA strategy also enabled Austrian plant breeders in the last few years to release varieties which were tested exclusively for organic farming. Including 'organic characteristics' already at the very beginning of the breeding process, i.e. parent selection, crosses and selection in early generations, should lead to a greater number of better adapted organic varieties in the nearest future.

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References

AGES (2002) Österreichische beschreibende Sortenliste 2002, Landwirtschaftliche Pflanzenarten, Weizen im biologischen Landbau. Bundesamt und Forschungszentrum für Landwirtschaft (BFL), Wien, Austria, Schriftenreihe 21/2002, pp 34−37

AGES (2008) Österreichische beschreibende Sortenliste 2008. http://www.ages.at/servlet/sls/Tornado/web/ages/content/B0A708F4A83608C8C1256F730021909E. Accessed 29 Apr 2008

AMA (2007) Daten und Fakten – Getreide und Ölsaaten, Getreideanbauflächen Ernte 2007 (inkl. Bioflächen). Agrarmarkt Austria, Vienna. http://www.ama.at/Portal.Node/ama/public?gentics.rm=PCP&gentics.pm=gti_full&p.contentid=10008.46403&165_anbaufl_oesterr_ab_2005_10_2007.pdf. Accessed 29 Apr 2008

Bauer AM, Léon J (2008) Multiple-trait breeding values for parental selection in self-pollinating crops. Theor Appl Genet 116:235–242

Bauer AM, Reetz TC, Léon J (2006) Estimation of breeding values of inbred lines using best linear unbiased prediction (BLUP) and genetic similarities. Crop Sci 46:2685–2691

Birschitzky J (2007) Economic perspectives of breeding cereals for organic farming through a combination of organic and conventional selection strategies. In: Osman AM, Müller K-J, Wilbois K-P (eds) Different models to finance plant breeding, Proceedings of the ECO-PB International Workshop, Feb 27, Frankfurt, Germany. European Consortium for Organic Plant Breeding, Driebergen/Frankfurt, pp 13–16

Brancourt-Hulmel M, Heumez E, Pluchard P, Beghin D, Depatureux C, Giraud A, Le Gouis J (2005) Indirect versus direct selection of winter wheat for low-input or high-input levels. Crop Sci 45:1427–1431

Buddenhagen IW (1983) Breeding strategies for stress and disease resistance in developing countries. Annu Rev Phytopathol 21:385–409

Ceccarelli S, Grando S, Hamblin J (1992) Relationship between barley grain yield measured in low- and high-yielding environments. Euphytica 64:49–58

DePauw RM, Knox RE, Clarke FR, Wang H, Fernandez MR, Clarke JM, McCaig TN (2007) Shifting undesirable correlations. Euphytica 157:409–415

Donner D, Osman A (eds) (2006) Handbook cereal variety testing for organic and low input agriculture. COST860-SUSVAR, Louis Bolk Institute, Driebergen, The Netherlands

Duveiller E, Singh RP, Nicol JM (2007) The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. Euphytica 157:417–430

Ehrendorfer M (1987) A regionalization of Austria's precipitation climate using principal component analysis. J Climatol 7:71–89

Eisele J-A, Köpke U (1997a) Choice of cultivars in organic farming: new criteria for winter wheat ideotypes. 1. Light

conditions in stands of winter wheat affected by morphological features of different varieties. Pflanzenbauwissenschaften 1:19–24
Eisele J-A, Köpke U (1997b) Choice of cultivars in organic farming: new criteria for winter wheat ideotypes. II. Weed competitiveness of morphologically different cultivars. Pflanzenbauwissenschaften 1:84–89
Falconer DS (1989) Introduction to quantitative genetics, 3rd edn. Longman Scientific & Technical, Harlow, UK
Grausgruber H, Oberforster M, Werteker M, Ruckenbauer P, Vollmann J (2000) Stability of quality traits in Austrian-grown winter wheats. Field Crop Res 66:257–267
Gröger S, Oberforster M, Werteker M, Grausgruber H, Lelley T (1997) HMW glutenin subunit composition and bread making quality of Austrian grown wheats. Cereal Res Commun 25:955–962
Hänsel H (1961) Untersuchungen über theoretische Häufigkeiten 'erwünschter' und 'brauchbarer' Genotypen bei 1 bis 10 unabhängigen Spaltungseinheiten, in Hinblick auf die Effektivität der Auslese in einer bestimmten Filialgeneration. Z Pflanzenzüchtg 46:265–284
Hänsel H (1970) Die Züchtung eines ertragreichen Winter-Qualitätsweizens: 'Probstdorfer Extrem'. Bericht 21. Tagung 1970 der Arbeitsgemeinschaft der Saatzuchtleiter, Dec 1–3. BAL Gumpenstein, Irdning, Austria, pp 45–68
Hänsel H (1976) Heritabilität von Teileigenschaften und deren Korrelation zu Komplexeigenschaften ('Tafeln für die indirekte Selektion'). Bericht 27. Tagung 1976 der Arbeitsgemeinschaft der Saatzuchtleiter, Nov 23–25. BAL Gumpenstein, Irdning, Austria, pp 3–10
Hänsel H (1984) Selection for components of complex characteristics—indirect selection. In: Selection in mutation breeding, Int Atomic Energy Agency, Vienna, Austria, pp 49–55
Hänsel H (2001) Yield potential of barley corrected for disease infection by regression residuals. Plant Breed 120:223–226
Hänsel H, Ehrendorfer K (1973) Intervarietale Korrelationen zwischen Ertrags-, Entwicklungs- und Qualitätsmerkmalen bei Winterweizen, das Verhältnis von Klebergehalt zu Rohproteingehalt als Sortenmerkmal, und Fortschritte der Qualitätsweizenzüchtung im Pannonischen Gebiet Österreichs. Z Pflanzenzüchtg 69:169–209
Hänsel H, Fleck A (1990) Reaktion verschiedener Winterweizen bezüglich Kornertrag, Proteingehalt und Proteinertrag auf das Produktivitätsniveau in Versuchen ohne Fungizid- und CCC-Behandlung im Trockengebiet (Ein Beitrag zur Low-Input-Diskussion). Bericht 41. Tagung 1990 der Arbeitsgemeinschaft der Saatzuchtleiter, Nov 20–22. BAL Gumpenstein, Irdning, Austria, pp 145–154
Hänsel H, Seibert L, Gröger S, Lelley T (1994) HMW-Glutenin-Untereinheiten von 22 seit 1948 in Österreich gezüchteten Qualitätswinterweizen und von deren Eltern. Genetische Ertragssteigerung und Qualitäts-Stabilisierung unter Beibehaltung der Glu-B1/Glu-D1 Kombination 7 + 9/5 + 10. Bericht 45. Tagung 1994 der Arbeitsgemeinschaft der Saatzuchtleiter, Nov 22–24. BAL Gumpenstein, Irdning, Austria, pp 15–22
Hoad S, Neuhoff D, Davies K (2005) Field evaluation and selection of winter wheat for competitiveness against weeds. In: Lammerts van Bueren ET, Goldringer I, Østergård H (eds) Organic plant breeding strategies and the use of molecular markers, Proceedings of the COST-SUSVAR/ECO-PB Workshop, Jan 17–19. Louis Bolk Institute, Driebergen, The Netherlands, pp 61–66
IFOAM (2004) IFOAM Draft standards. D1 Plant breeding draft standards. International Federation of Organic Agriculture Movements, Bonn, Germany
Kempf H (2003) Weizenzüchtung für den ökologischen Landbau – Züchtung und Zulassung der Sorte Ökostar in Deutschland. Bericht 53. Tagung 2002 der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, Nov 26–28. BAL Gumpenstein, Irdning, Austria, pp 65–70
Kirigwi FM, van Ginkel M, Trethowan R, Sears RG, Rajaram S, Paulsen GM (2004) Evaluation of selection strategies for wheat adaptation across water regimes. Euphytica 135:361–371
Kleijer G, Schwaerzel R (2006) Backqualität von Winterweizen in Bio- und Extenso-Zulassungsprüfungen. Agrar Forschung 13:56–61
Kruepl C, Hoad S, Davies K, Bertholdsson N-O, Paolini P (2006) Weed competitiveness. In: Donner D, Osman A (eds) Handbook cereal variety testing for organic and low input agriculture. COST860-SUSVAR. Louis Bolk Institute, Driebergen, The Netherlands, pp W1–W16
Kunz P, Becker K, Buchmann M, Cuendet C, Müller J, Müller U (2006) Die Züchtung von Top-Qualitätsweizen für den Biologischen Landbau. Bericht 56. Tagung 2005 der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs, Nov 22–24. HBLFA für Landwirtschaft Raumberg-Gumpenstein, Irdning, Austria, pp 3–7
Lammerts van Bueren ET, Struik PC, Tiemens-Hulscher M, Jacobsen E (2003) Concepts of intrinsic value and integrity of plants in organic plant breeding and propagation. Crop Sci 43:1922–1929
Lammerts van Bueren ET, Verhoog H, Tiemens-Hulscher M, Struik PC, Haring MA (2007) Organic agriculture requires process rather than product evaluation of novel breeding techniques. NJAS Wageningen J Life Sci 54:401–412
Löschenberger F, Ittu G, Kempf H, Rolland B, Schneider D (2007) SUSVAR—Winter wheat ringtest over 15 environments in Europe—Results. In: Lammerts van Bueren ET, Goldringer I, Scholten O, Østergård H (eds) Plant breeding for organic and sustainable, low-input agriculture: dealing with genotype-environment interactions, Book of Abstracts, EUCARPIA Symp Working Group Organic Plant Breeding, Nov 7–9. Wageningen University, Wageningen, The Netherlands, p 18
Mishra R, Baenziger PS, Russell WK, Graybosch RA, Baltensperger DD, Eskridge KM (2006) Crossover interactions for grain yield in multienvironmental trials of winter wheat. Crop Sci 46:1291–1298
Moll RH, Kamprath EJ, Jackson WA (1982) Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron J 74:562–564
Oberforster M (2003) Verfahren der Wertprüfung für den ökologischen Landbau in Österreich. In: Bundessortenamt (ed) Sortenwertprüfungen für den ökologischen Landbau, Workshop, May 14–15, Hannover, Germany, pp 20–27
Oberforster M (2006) Ist die Sortenzulassungsprüfung biogerecht? Österreichische Fachtagung für biologische Landwirtschaft, Mar 21–22. HBLFA für Landwirtschaft Raumberg-Gumpenstein, Irdning, Austria, pp 15–20

Oberforster M, Plakolm G, Söllinger J, Werteker M (2000) Are descriptions of conventional variety testing suitable for organic farming? In: Alföldi T, Lockeretz W, Niggli U (eds) The world grows organic, Proceedings of the 13th International IFOAM Scientific Conference. Research Institute of Organic Agriculture (FiBL), Frick, Switzerland, p 242

Osman AM, Lammerts van Bueren ET (2003) A participatory approach to designing and implementing organic 'Value for Culivation and Use' research. In: Lammerts van Bueren ET, Wilbois K-P (eds) Proceedings of the ECO-PB 1st International Symposium on Organic seed production and plant breeding—strategies, problems and perspectives, Nov 21–22, 2002. European Consortium of Organic Plant Breeding, Driebergen/Frankfurt, The Netherlands/Germany, pp 46–49

Przystalski M, Osman A, Thiemt EM, Rolland B, Ericson L, Østergård H, Levy L, Wolfe M, Büchse A, Piepho HP, Krajewski P (2008) Comparing the performance of cereal varieties in organic and non-organic cropping systems in different European countries. Euphytica. doi:10.1007/s10681-008-9715-4

Richardson MD, Karcher DE, Purcell LC (2001) Quantifying turfgrass cover using digital image analysis. Crop Sci 41:1882–1888

Schwaerzel R, Levy L, Menzi M, Anders M, Winzeler H, Dörnte J (2006) Winterweizensorten im biologischen und extensiven Anbau. Agrar Forschung 13:68–73

Sinebo W, Gretzmacher R, Edelbauer A (2002) Environment of selection for grain yield in low fertilizer input in barley. Field Crop Res 74:151–162

Smith A, Cullis B, Thompson R (2002) Exploring variety-environment data using random effects AMMI models with adjustment for spatial field trend: Part 1: Theory. In: Kang MS (ed) Quantitative genetics. genomics and plant breeding. CABI Publishing, Wallingford, UK, pp 323–335

Spanakakis A (1990) Grain yield and quality characters of genotypes in F_5 generation under low and high nitrogen input. In: El Bassam N, Dambroth M, Loughman BC (eds) Genetic aspects of plant mineral nutrition. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 147–164

Spanakakis A, Viedt A (1990) Performance of winter wheat cultivars under reduced nitrogen conditions. In: El Bassam N, Dambroth M, Loughman BC (eds) Genetic aspects of plant mineral nutrition. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 465–473

Surböck A, Grausgruber H, Freyer B (2003) Zuchtziele, Züchtungskriterien und Bewertung von Züchtungsmethoden. Saatgut für den Biologischen Landbau. ARGE Bio-Landbau, Wien, Austria, pp 1–147

Ud-Din N, Carver BF, Clutter AC (1992) Genetic analysis and selection for wheat yield in drought-stressed and irrigated environments. Euphytica 62:89–96

Wolfe M, Baresel JP, Desclaux D, Goldringer I, Hoad S, Kovacs G, Löschenberger F, Miedaner T, Østergård H, Lammerts van Bueren E (2008) Developments in breeding cereals for organic agriculture. Euphytica. doi:10.1007/s10681-008-9690-9

Yan W, Kang MS (2003) GGE Biplot analysis. A graphical tool for breeders, geneticists. and agronomists. CRC Press, Boca Raton, USA

Yonezawa K (1983) Practical implication of improving the precision of genotype assessment in selection–a theory. Euphytica 32:543–555