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Performance of spring barley (*Hordeum vulgare*) varieties under organic and conventional conditions

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Abstract Organic agriculture needs spring barley varieties that are adapted to organic growing conditions and have good and stable grain yield across years, even under less favourable growing conditions. The aim of this study was to compare how varieties differ in yield and yield stability under conventional and organic management conditions. The results help to decide under which growing conditions selection of genotypes for organic farming can be most effective. Grain yield and yield components of 10 varieties were estimated in field trials for three years at four sites: two conventionally and two organically managed sites. Varieties differed in stability: some varieties had high yield under conventional conditions and relatively high and stable yield under organic conditions. Heritabilities for yield and yield components were lower under organic (especially in the field with low weed control) than under conventional conditions. Heritabilities for yield components were lower than those for yield itself. Selection for yield components, therefore, may be less effective than selection directly for grain yield. Our data showed that generally the top performing cultivars under conventional conditions also performed as the best under organic conditions, but there were also exceptions. Therefore we conclude that selection of genotypes for organic farming may take place under conventional conditions, but that a final testing should be conducted under organic conditions to confirm the suitability of the selected varieties for cultivation on organic farms.

Keywords Barley · Heritability · Organic farming · Yield components · Yield stability

Introduction

Organic agriculture is defined by the International Federation for Organic Agricultural movements (IFOAM 2013) as a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions. Organic agriculture searches continuously for optimisation of the farming systems through agronomic improvements and it needs adequate varieties to realise its potential. In Latvia, the area under organic agriculture is increasing rapidly and accounted for about 10 % (approximately 184,120 ha) of the total crop production area in 2011 (Agricultural Report 2012).

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Barley is the main cereal crop for feed in Latvia. The current yields under organic conditions range from approximately 1.5 to 4.5 t ha^{-1}, compared to 4.0 to 6.0 t ha^{-1} in conventional farming (unpublished data summarized from 18 farms over two years in the project "Technological solutions in cereals production in Latvia" financed by the Latvian Ministry of Agriculture). Those differences in yield range are mostly due to differences in the crop management system, especially with respect to weed control and the level of fertilisation. In conventional barley production the average amount of applied nitrogen (N) ranges from 60 to 150 kg ha^{-1} whereas in organic barley production the amount of nitrogen applied through organic fertilizers is approx. 30–40 kg ha^{-1}. The main sources of nitrogen in organic farming are stable manure, green manure or crop residues. Mechanical weed control during crop growth establishment is often insufficient as knowledge and equipment for adequate mechanical weed management is often lacking. Also there are in organic cereal production no other means available to control pathogens causing e.g. netblotch and leaf stripe than choosing resistant varieties and apply adequate crop rotation. For some seed-borne diseases there are more options, such as hot air treatment for common bunt (*Tilletia caries*) for wheat and loose smut (*Ustilago nuda)* for barley (Forsberg et al. 2003), and seed treatments based on mustard powder for bunt. Latvian organic farmers still depend on varieties developed for (high-input) conventional agriculture, as plant breeding in Latvia has only recently included a focus on organic farming. 'Rubiola' is the first Latvian spring barley variety, which was registered specifically for organic farming; the selection for this variety was conducted under conventional conditions but testing in the final breeding stage was carried out under organic growing conditions (Legzdina et al. 2008). Until recently, most organic variety research in Latvia concentrated on the evaluation of conventionally bred varieties grown under organic conditions (Strazdina and Bleidere 2004; Legzdina et al. 2005; Kokare and Legzdina 2006). From the results, it has been argued that organic growers urgently need varieties that are better adapted, as levels of important traits such as weed competitiveness and adaptation to low nitrogen availability in conventional varieties are inadequate.

Organic farmers have fewer tools at their disposal than conventional farmers to influence the growing environment to accommodate their crops. Therefore, organic breeding programs should aim for varieties that can cope with varying levels of abiotic and biotic stress factors without excessive fluctuations in performance level. Successful barley varieties for organic conditions should not only show a good yield under favourable growing conditions, but also a good yield stability across different years and farms under less favourable growing conditions. For economic reasons conventional breeders involved in breeding for organic farming also want to know which is the most appropriate selection environment to obtain varieties that are adapted to organic management conditions. Testing and selection under organic management then could be an option, but the question is whether the heritability for relevant traits may be too low under low-input and heterogeneous conditions (e.g. Ceccarelli 1996).

To get more insight into the prerequisites for an efficient breeding program to improve adaptation of two-row spring barley for organic, low-input growing conditions in Latvia, a three year field trial was conducted. The performance of a set of contrasting varieties grown in two organically and two conventionally managed fields with different input levels was compared. The research focused on the following questions: (a) do the varieties differ in yield and yield stability under organic conditions and conventional management conditions? (b) does the ranking of the varieties change under organic conditions compared to conventional conditions? and (c) is heritability for yield and yield components under organic growing conditions lower than under conventional conditions? These questions are necessary to decide under which growing conditions selection for barley genotypes for organic farming is most effective.

Materials and methods

Experimental design

A diverse set of 10 two-row old and modern spring barley varieties (Table 1) was evaluated during three growing seasons (2006–2008) in four replicates of 12.3 m^2 plots in a randomised complete block design at four sites: two conventionally and two organically managed sites (Table 2).

Table 1 Description of the varieties included in the variety trials in Priekuli 2006–2008, based on a priori experience at the State Priekuli Breeding Institute

Variety	Country of origin	Year of registration or market release	Characteristics
Rubiola	Latvia	2011	tall plants, bred for organic farming
Idumeja	Latvia	2000	medium-tall plants, early plant growth, early maturing
Annabell	Germany	1999	short plants, high-input type,
Ansis	Latvia	1995	short plants, high-input type
Inari	Finland	1994	medium-tall plants, medium early maturing
Anni	Estonia	1993	short plants, good yield under low-input conditions, good stress resistance
Abava	Latvia	1978	tall plants, good yield under poor growing conditions
Dziugiai	Lithuania	1947	tall plants, very rapid early development, resistant to acid soil conditions
Primus	Sweden	1901	very tall plants, late maturing, high TGW, test weight
Latvijas vietejie (Latvian local)	Latvia	landrace ~ 1800	very tall plants, very late maturing, high TGW, test weight

Plant material

All varieties originate from Baltic or Nordic regions (Table 1), are generally adapted to local climate conditions and have been grown in Latvia except for ‘Inari’, ‘Anni’ (still grown in Estonia), ‘Primus’originated from Sweden and ‘Dziugiai’ (planned to be re-introduced as a heritage variety in Lithuania). Currently ‘Abava’, ‘Annabell’, ‘Ansis’, ‘Idumeja’and ‘Rubiola’are in the Latvian Plant Variety Catalogue. ‘Annabell’was the variety most widely grown in Latvia during 2005–2011. ‘Abava’and ‘Rubiola’are currently recommended for organic farming in the catalogue; organic farmers grow also ‘Idumeja’ and ‘Annabell’. Our choice for this set of varieties was based on their different times of release, some specific traits which might be beneficial for organic farming, *e.g.* early maturing, rapid development, tall plants, good stress tolerance. Varieties that were contrasting for traits important for conventional and organic farming were included e.g. short –tall, early–late maturing etc. (see Table S1).

Sites

For the comparison between conventional and organic conditions two different sites within each farming system were included (Table 2). Two conventional (C1 and C2) and organic O1 sites were situated within approximately 1 km distance from each other. The conventional sites were part of the Priekuli Plant Breeding Institute conventionally managed fields. C1 was part of the breeding and experimental fields, and C2 was situated in the commercial seed production field. Organic site O1 was part of the Priekuli Plant Breeding Institute’s organically managed trial fields. The organic site O2 was within 5 km distance from institute fields and was located at an organic, commercial farm. The organic fields at both sites have been officially certified for organic agriculture for more than 5 years. All four sites had a similar sod-podzolic soil type with light loamy soil texture. The largest differences are based on the management differences, see Table 2.

The nitrogen availability (N fertilisation + N in soil) in both organic sites was similar over the three years, viz. approx. 60 kg N ha^{-1}. However, the input for weed control differed to a large extent. At the organic farmer’s field (O2) no weed control was applied, as is the case in most of the current organic barley production fields in Latvia (see introduction), whereas at the institute’s organic field (O1) adequate mechanical weed control was applied (Table 2). The data from site O2 in 2006 were not included in the statistical analysis due to an extremely low yield level of 0.31 t ha^{-1} and an average of three kernels/tiller.

Table 2 Description of the soil characteristics and crop management systems of the trials under medium-input organic (O1), low-input organic (O2), medium-input conventional (C1) and high-input conventional (C2) in Priekuli, 2006–2008

Experiment Site	Year	Sowing date	pH	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	Humus content (g kg^{-1})	Available N in soil in spring (kg ha^{-1})	Precrop	Fertility management		Management of	
									Type	Amount	Diseases and pests	Weeds
Organic 1 (O1)	2006	28.04	5.9	159	120	23	48	Rape as green manure after potatoes	Rape as green manure	20 tonnes ha^{-1} (ca. 26,5 kg N/ha)	No	1 × harrowing at tillering stage
	2007	19.04	5.1	92	95	17	33					
	2008	23.04	6.0	133	126	19	16					
Organic 2 (O2)	2006	8.05	6.0	242	157	35	33	Perennial grassland	Manure (cows)	20 tonnes ha^{-1} (ca. 41 kg N/ha) for precrop	No	No
	2007	2.05	6.1	236	114	35	38	Perennial grassland				
	2008	30.04	6.0	183	123	23	12	Oats + pea				
Conventional 1 (C1)	2006	3.05	5.9	155	124	20	31	Potato	Inorganic (Kemira 18-9-15)	N 80 kg ha^{-1}, 40 kg $ha^{-1}$of P and 68 kg $ha^{-1}$of K	Insecticides: Fastak 50 (alfa-permethrin), Sumi-alfa (esfenvalerate) Fungicides: not applied	Granstar Premia 50 SX (tribenuron-methyl 50 %) + Primus (florasulam)
	2007	27.04	5.4	161	137	25	24					
	2008	26.04	6.4	400	153	27	8				No	Secator 19 d.g. (NA-methil-iodosulfuron)
Conventional 2 (C2)	2006	8.05	6.5	129	202	25	48	Potato	Inorganic (Kemira 18-9-15) and NH_4NO_3	120 N kg ha^{-1} (100 kg ha^{-1} N before sowing and 20 kg ha^{-1} at tillering stage), 50 kg ha^{-1} P and 83 kg ha^{-1} K	Insecticides: Fastak 50 (alfa-permethrin) Sumi-alfa (esfenvalerate) Fungicides: not applied	Granstar Premia 50 SX (tribenuron-methyl 50 %) + Primus (florasulam)
	2007	26.04	6.1	199	130	19	30					
	2008	30.04	6.3	294	145	23	9				No	Secator 19 d.g. (NA-methil-iodosulfuron)

This crop failure was due to early drought, poor establishment and subsequent high weed pressure.

Both conventional fields were treated according to standard agricultural practices in Latvia, including the use of synthetic fertilizers, herbicides and insecticides, but no fungicides (Table 2). The target seed rate at all four sites was 400 germinating seeds per m^2. The main difference between the two conventionally managed trial fields was the level of nitrogen application; a medium–high nitrogen application level (ca. 80 kg N ha^{-1}) at C1 and a high nitrogen application level (120 kg N ha^{-1}) at C2.

Meteorological conditions

Weather data were collected from the local Priekuli meteorological station. Meteorological conditions in the years of study varied widely. In 2006, at the beginning of the growing season it was warm and dry with some rain at the end of May and the beginning of June; in the second half of the growing period (after flowering) it was extremely dry and hot (Fig. 1). In 2007, the conditions were favourable for crop growth with sufficient amount of precipitation at the beginning of the growing season; June was warmer and dryer than normal and July provided sufficient rain (more than normal). In the growing season of 2008 rainfall was not sufficient in the first part of the vegetation period, and it was completely dry by the end of May and beginning of June; in the second half of the vegetation period there was more rain than normal.

Parameters

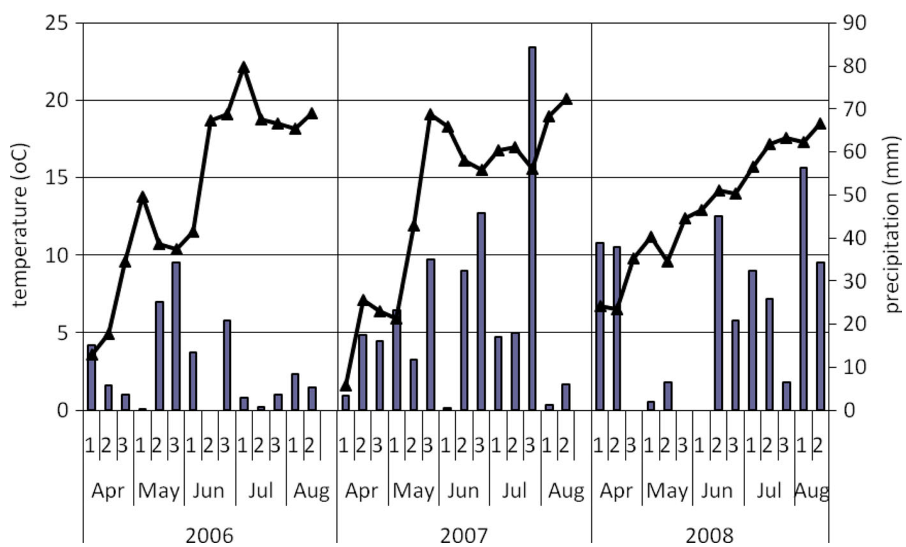
During the experiment the following parameters were evaluated: grain yield (GY, t ha^{-1}), number of tillers per m^2 (NT, measured after harvest on the basis of the stubble; two counts per plot in 0.25 m^2 frame), and thousand grain weight (TGW, g). The number of kernels per tiller (NK) was calculated from the following formula:

$$NK = GY/NT/TGW*100{,}000.$$

Statistical analysis

Analysis of variance (Anova) and the calculation of phenotypic correlation coefficients were carried out using GENSTAT 14.0 (2011). Anova was used to determine the impact of the organic versus conventional management systems and other factors such as year and site effects on the yield and yield components. The statistical model used was a split plot structure with environment/block/plot for the experimental design factors (block statement in Genstat; environment is the combination of a year and a site within a farming system) and year × (farming system/site) × variety for the treatment factors (sites nested within farming systems and crossed with variety and year). This model allows to split up the variance among sites into a part that is due to the effect of farming systems and another part that is due to site effects within each farming system (local conditions

Fig. 1 Amount of precipitation and average air temperature in Priekuli during 2006–2008



of the site plus management on that site), while still being able to contrast site effects within and across different management systems. Significance of pairwise differences between levels of each treatment factor were assessed using the least significant difference (LSD) tables for each treatment factor from Anova ($\alpha = 0.05$). An additional analysis was done to calculate and compare variance components: the REML procedure for analysis of linear mixed models of Genstat was used, using the same structure as was used in the Anova, this time with all terms designated as random factors. For comparison of the ordered yields of the varieties in the different environments, Spearman's rank correlation coefficient (R_s) between sites and treatments was calculated using the following formula:

$$R_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

where $\sum d^2$ is the difference in rank change of each variety squared and summed over the 10 varieties ($n = 10$). Significance was assessed at the 95 % confidence level.

Heritability was estimated from the variance components, for yield and yield components, for organically and both conventionally managed environments separately. The heritability (h^2) was estimated per site and was expressed as a percentage, using:

$$h^2 = (V_g)/(V_g + V_{gy}/y + V_e/ry).$$

where (V_g) denotes genotypic variance (between varieties), V_{gy} genotype $\times$ year interaction variance, V_e error variance and r denotes the number of replications and y the number of years. V_{gy}/V_g, the ratio of G $\times$ Y to genotype variance components was used to show relative size of these effects on variation of traits. The value of V_{gy}/V_g ratio > 1.0 indicates a larger contribution of the G $\times$ Y interactions to the variance than that of genotypic differences per se for a trait.

Finlay-Wilkinson regression

The joint regression analysis method proposed by Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Perkins and Jinks (1968) was used to calculate, per variety, the regression coefficient for the slope (b) of the Finlay-Wilkinson regression line, and variance due to deviation from regression (s^2d) as parameters of adaptability and stability, respectively. These parameters were estimated using GENSTAT 14.0 (2011). According to Finlay and Wilkinson (1963), genotypes with a slope larger than 1 are responsive to favourable environments, but the genotypes with a high yield over environments and a slope close to 1 would be stable and have wide adaptation. Genotypes with relatively high average yield values and a slope lower than 1 perform relatively well under unfavourable growing conditions. Eberhart and Russell (1966) proposed the deviation from regression (s^2d) as an alternative parameter of stability. A variety with a low (s^2d) value is presumed to be highly stable. Each genotype was defined by three values: (1) mean yield over 11 environments, (2) the slope in the Finlay-Wilkinson regression (b), and (3) the deviation from the regression line (s^2d value).

Results

Comparison of grain yield and yield components over the environments

The mean grain yield (GY) of all varieties over three years did not differ significantly between the conventional medium input C1 (3. 87 t ha^{-1}) and high input C2 sites (3.73 t ha^{-1}) (Table 3). The mean GY under the organic conditions of O1 (3.12 t ha^{-1}) and O2 (2.69 t ha^{-1}) was significantly lower than under the conventional growing conditions. The mean GY of the organic farmer's field O2 was significantly lower than that of organic O1.

In all three years there was a high correlation for GY over the 10 varieties between C1 and C2 (r = 0.88–0.95; Table S4 A.). High correlations were also found between O1–C1 and O2–C1, (ranging from 0.74 to 0.89) and between O1–C2 and O2–C2 (0.64–0.91). If old varieties 'Latvijas vietejie' and 'Primus' were excluded from the analysis, correlations between growing sites for GY, NT and NK were weaker, but stronger for TGW, in comparison to the correlations of the whole set of varieties; however the trend remains the same (Table S4 B).

The mean yield in O1 was 48 % (in 2007) lower than the average value of the two conventional conditions whereas in 2008 no significant differences were found. The performance of O2 was poorer with a yield that was 57 % (2007) and 12 % (2008) lower

Table 3 The average grain yield (GY, t ha^{-1}), number of tillers (NT, number per m^2), thousand grain weight (TGW, g) and number of kernels per tiller (NK) of ten varieties grown at two organic sites (O1 and O2) and at two conventional sites (C1 and C2), 2006–2008

Traits	Site	Years of observations			Mean
		2006	2007	2008	
GY (t/ha)	C1	2.85 b[1]	4.62 a	4.15 a	3.87 a
	C2	3.44 a	3.79 b	3.96 ab	3.73 a
	O1	2.55 b	2.54 c	4.28 a	3.12 b
	O2	–	1.80 d	3.57 b	2.69 c
	Mean over the sites	2.95	3.19	3.99	
NT (number/$m^{2)}$	C1	577 a	553 b	640 a	590 a
	C2	498 b	604 a	531 b	545 b
	O1	417 c	446 c	458 c	441 c
	O2	–	392 d	453 c	423 d
	Mean over the sites	498	499.6	521.3	
TGW(g)	C1	39.7 c	48.0 a	46.6 c	44.8 b
	C2	42.3 b	46.1 b	47.1 c	45.1 ab
	O1	45.7 a	46.1 b	48.7 b	46.8 a
	O2	–	34.5 c	50.9 a	42.70 c
	Mean over the sites	42.61	43.69	48.32	
NK (number/tiller)	C1	12.6 b	17.6 a	14.2 b	14.9 a
	C2	16.5 a	13.7 b	15.8 b	15.3 a
	O1	13.7 b	12.5 b	19.2 a	15.1 a
	O2	–	13.3 b	15.7 b	14.5 a
	Mean over the sites	14.24	14.27	16.28	

[1] Mean values in each comparison between sites within a year with no letter in common are significantly different at $p < 0.05$ according to the least significant difference (LSD) for sites from Anova

than at the conventional conditions. GY under O2 conditions was 29 % (in 2007) and 17 % (in 2008) lower compared to O1.

On average over all years, the low-input management level of O2 also affected the yield components (NT, TGW) and resulted in significantly lower values compared to O1 and to both conventional sites (Table 3). The least affected component was the NK. However, the TGW was extremely low in 2007 due to incidence of cockchafers (*Melolontha melolontha*) in O2 which damaged plant roots and caused premature senescence.

Variance components

The partitioning of variance components for GY and yield components indicated that environmental components (year, farming system, site within each farming system and their interactions) were the largest sources of variation for grain yield and yield components (Table 4, and for the significances of the terms in analysis of variance see Table S2). Variance components for genotype and interactions with genotype were relatively small compared to those caused by environmental effects (year, site). Comparatively larger variation due to genotype and interactions (Genotype × Year, Genotype × Year × Site) were found for TGW compared to other yield components. Site effects within farming systems were not very consistent across years so that variability among the four sites was attributed mostly to year × farming system and year × site interactions, while the variance components associated with site effects per se (over years and varieties, within farming systems) was small (or even estimated as negative), relative to effects involving the year differences, differences and interactions with farming system, the overall variety differences, and, especially for number of kernels per tiller, the residual variance.

Heritability

The estimates of the variance components for GY and yield components of each site indicated that in most of

Table 4 Partitioning (%) of variance components for grain yield (GY), number of tillers (NT), thousand grain weight (TGW) and number of kernels per tiller (NK) in two organic (O1 and O2) and two conventional (C1 and C2) sites in 2006–2008. 'Site' refers to Farming system/site, so in the statistical model sites were nested within farming systems. Full replicates (the complete blocks) were nested within years and sites

Component	GY	NT	TGW	NK
Year	4.7	0.0	5.1	1.1
Farming system (conventional versus organic)	16.4	50.2	0.0	0.0
Site	0.0	0.2	0.0	0.0
Year × Farming system	29.9	0.0	18.6	1.6
Year × Site	12.0	8.5	43.6	24.4
Genotype	10.4	11.5	11.9	11.6
Genotype × Year	4.2	1.0	5.8	1.2
Genotype × Farming system	0.4	0.1	0.0	0.2
Genotype × Farming system × Year	0.0	4.4	0.1	2.8
Genotype × Site	0.0	0.0	0.0	0.0
Genotype × Year × Site	1.0	2.2	6.4	2.6
(Year × Site)/Replication	9.9	2.6	0.4	13.6
Residual	11.1	19.2	8.0	40.9

the cases the heritability was lower under organic than under conventional conditions (Table 5). Heritability was always the lowest under the conditions of the organic farmer's field O2, due to the large sizes of G × Y interaction and residual variance under organic conditions. For most environments the heritability of yield components was lower than for grain yield with exception of TGW in O1 and C2. The lack of consistent differences between varieties across years in the O2 field caused a negative value for genetic variance and lead to an estimate of the heritability of 0, see Table 5.

Comparison of grain yield and yield components per variety

Under conventional conditions there was group of six varieties: 'Anni', 'Abava', 'Annabell', 'Inari', 'Ansis' and 'Rubiola' that had significantly higher yields (GY) than the other varieties (Table 6). These varieties were also the highest yielding under organic conditions with exception of 'Annabell. Under organic conditions all varieties yielded lower than under conventional conditions. 'Annabell' had the largest yield differences compared to other varieties between both farming systems. Under both conventional and organic growing conditions 'Latvijas vietejie' was the lowest yielding variety.

For all varieties NT was lower under organic growing conditions than under conventional conditions. Under conventional and organic conditions 'Annabell' had the highest NT but this was at the cost of the TGW. The highest TGW was observed for 'Latvijas vietejie' but that variety had low NT and NK under conventional and organic conditions. Under conventional conditions NK was highest for 'Inari' but under organic conditions it was highest for 'Ansis'. To get more insight in how yield components influence the yield under conventional and organic conditions, we analyzed the phenotypic correlations between GY and yield components within both conventional and within both organic sites across all varieties over the years. Differences between the sets of varieties included in the correlation were obtained. Analyzing the correlative relationships of the whole set of varieties, NT and NK positively correlated with GY,

Table 5 Estimates of broad sense heritability (h^2, %) and ratio of the genotypic variance and the variance of genotype x year interaction (V_{gy}/V_g) for grain yield (GY), number of tillers (NT), number of kernels per tiller (NK) and thousand grain weight (TGW) of ten varieties grown at two organic sites (O1 and O2) and at two conventional sites (C1 and C2), 2006–2008

Growing conditions								
Traits	C1 h^2 (%)	C2	O1	O2	C1 V_{gy}/V_g	C2	O1	O2
GY	70	61	45	24	0.5	0.4	0.4	1.5
NT	40	50	28	18	0.6	0.1	2.0	3.0
TGW	46	73	80	0	1.5	0.4	0.3	n.e.[1]
NK	27	37	31	12	1.1	0.3	0.4	1.4

[1] n.e. = not estimated

Table 6 Average grain yield (GY t ha^{-1}), number of tillers (NT, number per m^2), thousand grain weight (TGW, g) and number of kernels per tillers (NK) of ten varieties grown under organic (O) and conventional sites (C), 2006-2008

Variety	GY		NT		TGW		NK	
	C	O	C	O	C	O	C	O
Anni	4.28a	3.29a	637b	461bc	43.5d	44.4cf	16abcd	16bc
Abava	4.24a	3.28a	551de	447bc	46.9b	46.9ab	16a	16bc
Annabell	4.14a	2.97bcd	687a	527a	40.4e	41.2f	15cd	14d
Inari	4.12a	3.20ab	541e	442bc	46.7b	47.5a	17a	15bcd
Ansis	4.10a	3.27a	592c	427bcd	43.3d	43.8de	16abcd	17a
Rubiola	4.00a	3.07abc	558cde	424bcd	45.7bc	45.9bc	16abcd	16bc
Dziugiai	3.63b	2.89cd	543e	420cd	43.5d	42.8e	16abcd	16ab
Idumeja	3.35c	2.78de	584cd	411cd	45.2c	46.6ab	13e	14bcd
Primus	3.25c	2.55e	492f	391d	46.1bc	46.0b	14d	14cd
Latvijas vietejie	2.90d	2.19f	502f	388d	48.6a	46.9a	12e	12e

[1] Mean values with no letter in common within each organic or conventional site are significantly different at $p < 0.05$

but TGW had a positive correlation with GY at O2 only in 2007 (see Table S3 a). If old varieties ‘Latvijas vietejie’ and ‘Primus’ were excluded from the analysis NT had a positive correlation with GY in 2006 and 2007 in all growing sites, while in 2008, TGW and NK had a positive correlation with GY (see Table S3 b).

Variety ranking

Spearman’s ranks correlation coefficients were calculated to determine if the differences in yield between different conventional and organic growing sites resulted in changes in rank for varieties. All sites showed a significant and positive rank correlation for yield indicating that generally ranks between sites are retained, with $R_s = 0.53$ to $R_s = 0.90$ (Fig. 2). ‘Anni’ and ‘Abava’ showed high top position ranks according to the average GY in both conventional C1 and C2 and organic O1 sites (Fig. 2 a, b, d). However, the ranking of some individual varieties for GY under conventional sites differed from that under the organic ones. ‘Ansis’ took higher ranking position in conventional medium input C1and also in organic O1 and O2 sites compared to conventional high input C2 site (Fig. 2 a, b, c). ‘Annabell’ showed an opposite tendency with a lower rank under organic than under conventional conditions. The smallest changes in varieties ranking were from medium input conventional site C1 to organic O1 site (Fig. 2 d). The lowest correlation was obtained between both organic sites ($R_s = 0.53$). The ranking of some individual varieties changed considerably between both organic sites (Fig. 2 f). ‘Ansis’ and ‘Rubiola’ took a higher ranking position in organic O2 than in O1, whereas ‘Abava’, ‘Inari’ and ‘Idumeja’ ranked lower in O2 than in O1. The overall rank correlation between conventional and organic conditions was high ($R_s = 0.90$). Here ‘Anni’ and ‘Abava’ showed the highest ranks according to the average GY under conventional and organic conditions (Fig. 2 g). Landrace ‘Latvijas vietejie’ ranked lowest at all sites.

Stability of genotype performance

Stability parameters of grain yield of the 10 tested spring barley genotypes evaluated in six conventional and five organic environments (year and site combination) (Table 7) are presented.

We are interested in the varieties which can provide a yield level higher than the mean of all tested varieties and are stable according to the regression coefficient (b close to 1) and with the smallest possible deviation from the regression (s^2d close to 0). Our trials showed that variety ‘Anni’ was high yielding and stable according to the regression coefficient ($b = 1$) and according to the deviation from the regression (s^2d) under both organic and conventional growing conditions (Table 7). This variety is therefore suggested to have a general adaptation under both conditions. ‘Abava’, ‘Inari’ and ‘Ansis’ displayed above average yield under conventional and organic conditions, but according to the regression coefficient, ‘Ansis’ was responsive to more favourable conditions under

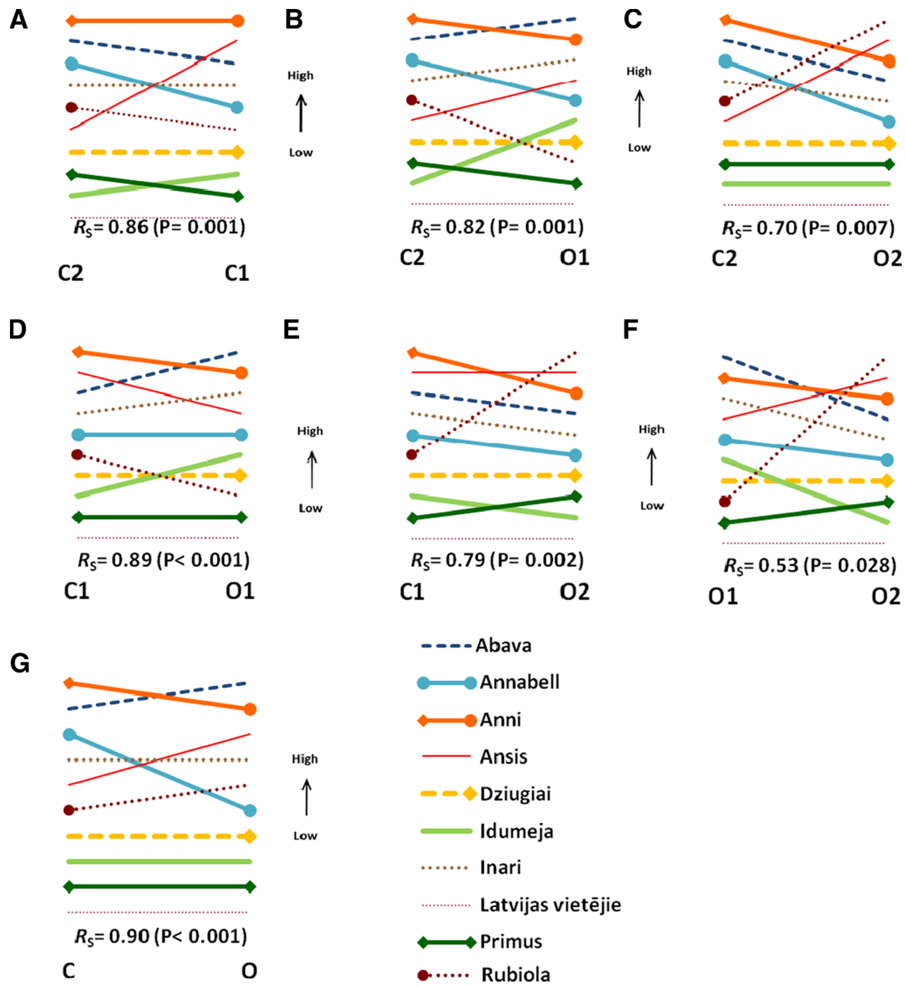


Fig. 2 The ranking order of varieties with respect to their mean yield (averaged over 2006–2008) between the all site combinations: C2–high input conventional, C1–medium high-input conventional; O1–organic institute site; O2–farmer's field site

conventional management (b = 1.41), while 'Abava' (b = 1.21) and 'Inari' (b = 1.33) were responsive to more favourable conditions under organic management. 'Rubiola' had an average mean performance under organic and conventional environments and was stable according to the b-value. 'Idumeja' and 'Dziugiai' also had a regression coefficient (b) close to 1 under both conditions, but exhibited below average yield under conventional, while under organic conditions were close to the average yield level, and therefore suited better organic environments.

The landrace 'Latvijas vietejie' and the old variety 'Primus' had a slope (*b*) close to 1, but low mean performance under organic and conventional conditions and they are considered to be poorly suited to both conditions. Under conventional conditions 'Annabell' exhibited above average yield and had a regression coefficient (*b*) close to 1, but the deviation from the regression (s^2d) was the largest and coefficient of determination was the lowest ($R^2 = 0.49$, Table 7). Under organic conditions 'Annabell' yielded not in the top group with a low value for the deviation from the regression ($s^2d = 0.06$, $R^2 = 0.84$. Table 7). The regression coefficient for the slope of the regression line was the lowest of all varieties (b = 0.54), indicating that it does not seem to be an adaptable variety under organic conditions.

Discussion and conclusions

Do varieties and their ranking differ in yield under organic versus conventional conditions?

In our trials grain yield of all tested varieties under organic conditions was generally lower than under

Table 7 Comparison of yield stability parameters: the regression coefficient for the slope of the regression line (b), and variance due to deviation from regression (s^2d) and determination coefficient (R^2) in Finlay-Wilkinson regression of ten spring barley varieties under organic and conventional conditions in Priekuli 2006–2008

Variety	Conventional				Organic				All environments			
	Mean yield (t ha^{-1})	b	s^2d	R^2	Mean yield (t ha^{-1})	b	s^2d	R^2	Mean yield (t ha^{-1})	b	s^2d	R^2
Anni	4.28*[1]	1.07	0.04	0.93	3.29*	1.12	0.08	0.95	3.82*	1.12	0.04	0.96
Abava	4.24*	1.18	0.06	0.92	3.28*	1.21	0.04	0.98	3.80*	1.18	0.04	0.97
Ansis	4.10*	1.41	0.01	0.99	3.27*	1.01	0.14	0.90	3.72*	1.10	0.08	0.93
Inari	4.12*	0.71	0.08	0.74	3.20*	1.33*[2]	0.01	0.99	3.70*	1.12	0.09	0.92
Annabell	4.14*	0.85	0.34	0.49	2.97	0.54*	0.06	0.84	3.60*	0.83	0.27	0.68
Rubiola	4.00	1.24	0.06	0.92	3.07	0.92	0.12	0.90	3.58*	1.04	0.08	0.92
Dziugiai	3.63	0.76	0.03	0.90	2.89	0.87	0.04	0.96	3.29	0.85	0.03	0.68
Idumeja	3.35*	0.80	0.10	0.75	2.78	1.00	0.14	0.90	3.09*	0.86	0.11	0.86
Primus	3.25*	1.11	0.10	0.85	2.55*	0.99	0.13	0.90	2.93*	0.98	0.10	0.89
Latvijas vietejie	2.90*	0.88	0.05	0.89	2.19*	1.00	0.01	0.99	2.58*	0.93	0.03	0.96
Environmental mean	3.81	1			2.95	1			3.41	1		

*[1] Mean values of varieties within this column are significantly different from environmental mean at $p < 0.05$

*[2] values within this column are significantly different from 1 at $p < 0.05$

conventional conditions. The main factor for this was most likely the lower level of fertilisation in both organic fields compared to conventional management, and in addition the high weed pressure in the organic farmer's field, as is often the case under organic management (e.g. Wolfe et al. 2008). In 2008 when the weather conditions in the second half of the vegetation period promoted high yield formation, the organic sites O1 and O2 yielded as well as the conventional ones. This has also been reported in other studies for wheat (Ryan et al. 2004; Lueck et al. 2006; Murphy et al. 2007) and for lentil (Vlachostergios and Roupakias 2008). The largest changes of the variety ranking were between both organic conditions, which could be partially explained by differences in the weed management. In organic farms growing conditions may be very variable. Practical experience showed that it is not always favourable to perform harrowing, due to metrological conditions; the crop may be damaged considerably if the soil is too wet or when harrowing is followed by heavy rain. There are differences not only in use of harrowing, but also in type of fertilizer (green manure, stable manure), crop rotation etc. For that reason and because the organic production area is comparatively small, the choice for resilient varieties appropriate for most of organic farms, which might be in the range from O1 (fairly stable and comparatively high yield level) till O2 with an unstable yield performance between the years, is needed.

Higher positive correlation between conventional medium input and both organic GY, compared to conventional high input or between both organic GY, suggests that results of GY under conventional medium input conditions provide a better prediction for the average variety performance under organic conditions (see Table S4). However there were some notable exceptions on the level of individual varieties. The results showed that not all varieties took the same ranking position between conventional C1 and organic O1 and O2 conditions and particularly between the two organic sites, which could be explained by differences in management practices. For example, 'Annabell', which is the shortest variety, may have suffered from high weed pressure and the low nutrient availability under both organic conditions. In 2008, a high infection level of netblotch (*Pyrenophora teres)* particularly affected the yield of 'Annabell' (data not shown). Overall, 'Annabell' ranked lower under organic than under conventional conditions. This suggests that some high-input varieties could be more sensitive to abiotic and biotic stress than others, making them less suitable for organic farming systems. These differences in ranking make additional testing under organic conditions for traits such as weed competitiveness and disease resistance necessary to identify varieties with relatively high performance under low-input management. This is consistent with results obtained by Przystalski et al. (2008) who analysed datasets of cereals under organic and non-organic sites in six European countries. They concluded that despite an overall high genetic correlation for yield, and other traits such as plant height, there were exceptions on individual variety ranking level in both directions that could be relevant for the selection process. A variety that had a medium yield under conventional conditions could perform among the top under organic conditions or those that perform best under conventional condition might be moderate under organic conditions. In order not to miss potentially valuable genotypes for organic farming systems these authors advised combining information from both organic and non-organic trials.

Do varieties differ in yield stability under organic conditions compared to conventional conditions?

Yield stability across years is one of the most important breeding objectives for organic, low input conditions where pesticides and (high levels of) fertilizers are not available to stabilize yield (Ceccarelli 1994; Lammerts van Bueren et al. 2008; Østergård et al. 2005; Przystalski et al. 2008). In our trials the grain yields (GY) between farming systems and sites within farming systems were more variable across years than between genotypes due to a larger Year × Farming system and Year × Site effect on GY as is often reported by other authors (e.g. Wolfe et al. 2008; Przystalski et al. 2008). To improve yield stability Bernardo (2002) suggested that breeders must select their lines on the basis of the mean yield performance and the slopes of the Finlay-Wilkinson regression (b) of varieties across all environments. Özgen (1994) cited by Ülker et al. (2006) considered that a stable genotype should have above average grain yield and a regression coefficient (*b*) close to 1.0. Becker et al. (1982) regarded small deviations from regression to be the most appropriate criterion for measuring stability in an agronomic sense because this parameter measures the predictability of the genotypic reaction across varying environments.

Our trials showed that landraces and old varieties were the lowest yielding over organic and conventional environments; they did not meet our expectations for good yield under organic conditions. This corresponds with Bernardo (2002), who also pointed out that genotypes which exhibit stability across environments tend to have a low performance. As organic farmers are interested not only in stability, but also in high yield, such varieties with low adaptability should be less suitable for organic conditions (Pswarayi et al. 2008). Most of the other varieties that were included in our study responded better to favourable organic conditions, and could be suitable for organic management. The high input type variety ‘Annabell’ had the largest decrease in yield under organic compared to its performance under conventional conditions, and showed to be sensitive to irregular growing conditions. For example, in 2008 there was a dry spell from the end of May until the beginning of June for a period of two weeks, which was followed by much cooler and rainy weather until the end of June and into July causing additional late tillering, especially for ‘Annabell’. The effect of this late tillering in the middle of the growing period caused small grains on the secondary shoots, which resulted in low TGW and finally in a low yield of ‘Annabell’ under organic growing conditions in 2008 (data not shown). The situation was similar under both conventional conditions in 2008 and might explain the large deviation from the regression (s^2d) under conventional conditions. The low value for the slope of the regression line under organic conditions indicates that in the years with a higher overall yield level Annabell did not profit as much as other cultivars (possible reasons might be infection with netblotch and drought) and its adaptability was lower than for other cultivars, therefore we doubt its suitability for organic farming. This indicates that some modern varieties were more unpredictable to changes in the environment than the old landraces and varieties developed before the 1980s. Also Ceccarelli (1996) and Pswarayi et al. (2008) argued from their research that modern genotypes are more adapted to stress-free, high yielding environments, and will not always give good results under unfavourable conditions.

Within this set of varieties, suitability to organic farming seems to be associated mainly with time of release (see Table 1). The landrace ‘Latvijas vietejie’ and the old variety ‘Primus’ which were grown more than 100 years ago and currently are not in production, are very tall, with a good and rapid soil cover, resulting in good weed competitiveness. But the consistently low yield level make these varieties not suitable for direct growing under organic farming. However, the old genotypes can be useful in breeding for organic farming if yield potential can be improved by crossing with newer material. Stable and high yielding varieties differed in time of release (see Table 1) and in plant height at the beginning of stem elongation stage and at maturity as well as days to heading and days to maturity (Table S1). For example 'Anni', 'Inari', 'Idumeja' are short to medium short straw varieties, while 'Rubiola' and 'Dziugiai' are tall. Analyzing the correlative relationships between yield and previously mentioned morphological and biological traits showed that grain yield was mainly negatively associated with plant height at maturity and days to heading and days to maturity in conventional and also in both organic growing sites, which is in contrast to the results found by Murphy et al. (2008) and Reid et al. (2009). This negative correlation between plant height and yield could be explained by the way the present set of varieties was composed including old varieties ('Latvijas vietejie' and 'Primus') that were very tall and low yielding. In an analysis without the two old varieties then was no significant correlation between yield and plant height at maturity time, see Table S3 b.

The current study suggests that the varieties differ in yield potential. Modern varieties developed after the 1990s have higher yield potential compared to varieties released in the first half of the 20th century and before. Mason et al. (2008) and Calderini and Slafer (1999) reported that modern varieties may outperform older ones in poor environments even despite their limited stability. Our trials suggest that the high input type variety 'Annabell', which has a high tillering capacity can produce a good yield in low yielding environments (e.g. in organic farmer's field O2 in 2007), but only if during the first part of the vegetation period the conditions are favourable for tillering.

One can conclude that modern barley breeding can in principle provide high-yielding varieties for organic growing conditions, but one cannot state that those varieties will always be the most stable under variable organic conditions. Their suitability for organic farming should be verified in tests under organic growing conditions, as discussed in the previous paragraph.

Is the heritability lower under organic growing conditions than under conventional conditions?

Low heritability of yield traits in poor or stressful environments is one of the arguments for conducting selection in environments at optimal plant growth conditions (Rajaram et al. 2006). Our data confirm that heritability for barley grain yield in organic, low-yielding environments was indeed lower than in more optimally controlled conventionally managed environments (see also Atlin and Frey 1990 and Ceccarelli 1994, 1996). This suggests that selection for yield for organic conditions could be succesfully carried out under conventionally managed conditions. In our trials the heritability for yield components was very low in the organic farmer's field O2 compared to the other sites; this was mainly due to a high proportion of V_{gy} interaction in the total phenotypic variance. In the better managed organic site O1 the heritability for yield and its components was higher than in the farmer's field O2 but still lower than under conventional conditions (with exception of TGW and NK when compared to C1).

Banzinger and Cooper (2001) and also Löschenberger et al. (2008) suggested that optimally managed on-station experimental trials may be used for assessing qualitative traits which are highly heritable, but that these would not be useful for quantitative traits (yield and yield components) which are more affected by genotype × environment interaction. Our results indicated that yield components had a lower heritability than GY itself, which is consistent with the conclusions drawn by Alexander et al. (1984), Aycicek and Yildirim (2006) and Zecevic et al. (2010) for wheat experiments, and by Bezant et al. (1997) and Yin et al. (2002) for barley QTL studies. Yin and Struik (2008) suggested that this is because yield depends on various interactions and compensating mechanisms from its components. Effect of a QTL can be small on individual components but can altogether result in a significant impact on grain yield itself. In our experiments on yield components, results showed that genotypes can have different combinations of traits to ensure a good yield level. For example, for 'Anni' the high and stable yield performance under conventional and organic conditions was based on a combination of high NT and NK, while for 'Abava' the high yield was based on a combination of high NT and TGW. For practical breeding, harvesting and measuring the yield is easier and less laborious than determining the TKW and counting tillers per plant or kernels per tiller, so that a higher heritability for yield is a favourable outcome for the breeder in terms of labour.

Perspectives for selection strategies for barley adapted to organic farming systems

The question of what is the more suitable selection environment for varieties adapted to organic farming systems is raised not only for technical breeding reasons but also for economic reasons due to the costs incurred due to extra selection fields.

Varieties in organic farming should have an adaptability to variable, organically managed and mostly low-input conditions and direct selection in organic conditions is recommended by many breeders (e.g. Wolfe et al. 2008; Przystalski et al. 2008; Murphy et al. 2008; Reid et al. 2009). Reid et al. (2009) demonstrated for spring wheat, that selection of genotypes for organic farming under conventional conditions does not result in the same genotypes being selected for each system for all traits. They believed that selection of genotypes for organic production systems should be done under organic conditions. Following that reasoning, one could argue that in spite of relatively low heritability the organic O1 site with a fairly stable and comparatively high yield level could be an appropriate environment for selection of genotypes for organic farming. Unstable farm conditions as in O2 are not suitable to select barley for organic farming; more replicates and repetitions across multiple organic farms could be useful and increase heritability, but it would also significantly increase costs.

Another strategy departing from a focus on how conventional breeding can also serve organic farming could be to choose the most suitable conventional conditions. In our trials, the correlations for GY between sites showed that O1 and O2 had comparatively higher correlations with conventional medium input C1 conditions than with the high input site C2 and between both organic sites. Also similar ranking of varieties between the these sites for GY, as well as the higher heritability for yield in the medium-input site C1, can lead to the conclusion that it could be possible to conduct a sufficiently effective selection for GY for organic farming purposes under the conventional medium input C1 conditions. However, our trials also showed that to ensure yield stability under organic conditions additional testing of genotypes under various organic conditions is necessary. Due to different management practices and different levels of soil fertility among organic farms, such tests will help to make decisions which genotype is stable for GY and the most appropriate for cultivation under organic conditions.

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