Euphytica 133: 185–200, 2003.

A methodological study on participatory barley breeding II. Response to selection

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Received 23 September 2002; accepted 9 May 2003

Key words: barley, farmer participation, genotype by environment interaction, *Hordeum vulgare*, participatory plant breeding, PPB

Summary

Farmer participation is increasingly seen as a key to develop technologies which are more relevant to farmers' communities. In plant breeding, farmer participation is seen as key to increase the probability of adoption of new varieties. This paper addresses the issue of selection efficiency in participatory plant breeding by testing the effect of selection environment and of who did the selection in one cropping season (1997) on the performance of the selected lines in the following cropping season (1998). Selection environment had a larger effect on response to selection than who did the selection, confirming the importance of decentralized selection. Selections made by the breeder and the farmers in 1997, differed in 1998 for a number of traits, but seldom for grain yield. When the difference for grain yield was significant, breeder's selection was more effective on station, while farmers' selection was more effective in farmers' fields. The results of this study indicate that it is possible to organize a plant breeding program with the objective of adapting crops to a multitude of both physical and socio-economic environments: such a breeding program will, at the same time, increase productivity and stability, enhance biodiversity and produce environmentally friendly cultivars.

Introduction

In recent years there has been an increasing consensus that users' participation in technology development is an important factor to increase the probability of success for the technology. While social scientists usually advocate farmers' participation in technology development on the basis of equity, biological scientists consider farmers' participation as one way to increase the probability and the speed of adoption.

Most participatory work has been devoted to plant breeding, partly because varieties are among the easiest technologies to change, and partly because farmer participation is relatively easier to organize in plant breeding, either as Participatory Variety Selection (PVS) or as Participatory Plant Breeding (PPB) than in other areas of agricultural research.

One limitation of the current PPB and PVS work is that most of the institutions promoting farmer participation are not those responsible for plant breeding, and most of the practitioners of either PVS or PPB are predominantly non-breeders. The first consequence is that there are several definitions of participatory plant breeding (Soleri at al., 2002; Joshi et al., 2002): in this paper we define PPB as a collaborative process, where the professional plant breeders and the farmers (usually several) share decisions in most of the steps of the plant breeding cycle. The interaction between the farmers and the breeders ranges between two extremes, which have been defined as farmer-led and breeder-led types of participation (McGuire et al., 1999). These two types of PPB do not necessarily have an ideological connotation, because they could represent different stages in the same PPB program, or because the same professional plant breeder can be involved in both types of PPB depending on the country, the crop or the farmers' community.

The second consequence is that rigorous studies on various methodological issues of the biological aspects of farmer participation are limited. In addition, the fact that few institutional plant breeders practice PPB has generated the belief that there are two types of plant breeding, participatory and non-participatory, which are often seen as equivalent to non-formal and formal breeding, respectively.

We have argued the obvious, i.e. that participatory plant breeding is based on the same genetic principles of non-participatory plant breeding, and therefore it is not a different type of plant breeding at least in terms of biological theory (van Eeuwijk et al., 2001; Ceccarelli and Grando, 2002). Therefore, low heritability, unsuitability of the germplasm, wrong choice of the selection environment, inappropriate selection methods, strong genotype × environment interactions, setting wrong breeding objectives, all have a negative effect on selection efficiency and effectiveness no matter whether plant breeding is participatory or non-participatory.

In a previous paper (Ceccarelli et al., 2000) we presented the results of an experiment on PPB conducted in 1997 on barley with the objectives of comparing breeder and farmers' selections in research stations and farmers' fields, of identifying the selection criteria used by farmers and breeders, and of assessing the feasibility of implementing a PPB program. In this paper we address the question of selection efficiency by testing the effect of the selection environment and of who did the selection in 1997, on the performance of the breeding material in the following cropping season.

Materials and methods

The material used consisted of the barley lines and populations (entries), which were selected, by either the farmers or the breeder in the nine farmers' fields and in the two research stations (Tel Hadya representing a favorable environment, and Breda representing a stress environment) in Syria described by Ceccarelli et al. (2000). Based on the selection conducted in the cropping season 1997/98, entries were classified on a) who selected them and b) where they were selected. For each of the nine farmers' fields, this resulted in the following six groups of entries:

a. selected by each farmer in his own field
b. selected by each farmer in Tel Hadya (TH)
c. selected by each farmer in Breda (BR)
d. selected by the breeder in each of the farmer's fields (FF)
e. selected by the breeder in Tel Hadya
f. selected by the breeder in Breda

The first four groups were specific to each of the nine farmers' fields, although a number of entries were common to more than one farmers' field.

With the selected entries, and avoiding duplications within the same trials, we prepared a specific trial for each of the nine farmers' fields. The entries in the last two groups (e. and f.) were common to all trials. Each trial was unreplicated with one systematic check planted either every ten or 20 plots. The cultivar used as systematic check was chosen in consultation with the farmers, and was either the local landrace or an improved cultivar or both, depending on the farmers' field. The plots were laid down in four strips of an equal number of plots each; each plot was identified by a number on a plastic label held by a wooden peg as already done in 1997. In one farmer's field (Al Bab), where the farmer had introduced a forage legume crop in the rotation (common vetch, *Vicia sativa*), the trial was planted twice, once after barley and once after vetch. All ten trials were also planted at the two research stations, using the same layout as in the farmer field.

The total number of entries tested was 1348, of which 196 were genetically different as a consequence of the large diversity of selection criteria used in 1997. The planting dates and the details of each trial are shown in Table 1. In total 95 entries were common to all trials, either because they belonged to groups e. and f., or because all the farmers selected them, or because the breeder selected them in all farmers' fields. Plot size was 8 rows 20 cm apart and 7.5 m long (12 m^2). The decision on the agronomic management of the trial was left to each farmer. The application of nitrogen in each of the farmers' fields varied from zero to182 kg/ha, while the application of P_2O_5 varied from zero to 97 kg/ha. In all the farmers' fields, the material was evaluated under rainfed conditions.

The following characters were recorded at the two research stations and in each farmer field on a sample of 2.4 m^2 from each plot:

- grain yield (GY in kg/ha)
- total biological yield (BY in kg/ha)
- harvest index (HI)
- plant height (PH in cm excluding the spike)
- kernel weight (KW)

Table 1. Composition and planting dates of the 1997/98 trials

Location (code)	Planting dates	Nr. of entries	Nr. of checks	Layout	Check
Ibbin (01)	14.11.97	134	14	37 × 4	Rihane-03
Ebla (02)	13.11.97	141	11	38 × 4	Rihane-03
Tel Brak (03)	8.11.97	115	17	33 × 4	Tadmor
Jurn El-Aswad (04)	7.11.97	136	12	37 × 4	Tadmor
Baylonan (05)	7.11.97	136	12	37 × 4	Zanbaka
Al Bab (06BB and 06BV)	10.11.97	129	15	36 × 4	Sara
Melabya (07)	8.11.97	148	12	40 × 4	Zanbaka
Bari Sharki (08)	12.11.97	140	12	38 × 4	Zanbaka
Suran (09)	11.12.97	140	16	39 × 4	Arta
Total		1348			

Other traits recorded at only one or both research stations were:

- growth habit (GH, as a visual score from 1 = erect to 5 = prostrate) at Tel Hadya
- growth vigor (GV, as a visual score from 1 = good to 5 = poor) at Tel Hadya
- cold damage (CD, as a visual score from 1 = no damage to 5 = maximum damage) at Tel Hadya
- lodging resistance (LDG, as a visual score from 1 = resistant; 9 = susceptible) at Tel Hadya
- number of tillers per m^2 (calculated from the number of tillers on 2 m of one representative row) at Tel Hadya and Breda (TN)
- days to heading (DH, as number of days from emergence to heading) at Tel Hadya.

We have adapted various spatial models from those used by Sarker et al. (2001) and a method of selection of best model based on Akaike Information Criterion (AIC) implemented by Singh et al. (2003) using Genstat codes (Genstat 5 Committee, 1997). Spatial analysis of unreplicated trials has also been carried out in Gilmour (1992) and Gilmour et al. (1998). Using the deviance values obtained from the Genstat, the criterion can be defined as AICD = deviance + twice the number of linear and non-linear variance components of the models, where the deviance is minus twice the REML log-likelihood ignoring a constant depending on the fixed terms. Thus AICD values can be used to compare models, 'smallest deviance is the best', with the same set of fixed effects.

To represent various spatial patterns in the field trials of these unreplicated trials with rectangular layouts, we used the Models 1–9 (Table 2) arising as factorial combinations of:

Table 2. The spatial models used for the analysis of the quantitative data from the field trials

Model No.	Trend	Errors	Model abbreviation
1		I	CrdId
2		AR	CrdAR
3		ARAR	CrdARAR
4	Linear	I	CrdLId
5	Linear	AR	CrdAR
6	Linear	ARAR	CrdARAR
7	LCS	I	CrdLCSId
8	LCS	AR	CrdLCSAR
9	LCS	ARAR	CrdLCSARAR

Crd: Completely randomized design. I: independent plot errors. Linear: fixed linear trend in column number. LCS: fixed linear trend in column number and random cubic spline in column number. AR: first order auto-regressive errors along rows; ARAR: first order auto-regressive error along rows and along columns.

1. three ways of accounting trends in column direction – a) with a linear-trend, b) with a linear trend and random cubic smoothing spline (CS), and c) without any trend, and
2. three structures for plot errors – a) first-order auto-regressive errors in columns (AR), b) first-order auto-regressive errors in columns and in rows (ARAR), and c) independent errors (I) indicating no spatial errors.

The Genstat programs described in Singh et al., 2003 were customized with no block structure fitted. For the model selection using AIC, the genotype effects were assumed as fixed to account for the full degrees of freedom due to genotypes and leaving minimal degrees of freedom for the residuals.

Selection of the best model

For a given trial and a response variable selected, the program fitted all the nine models (Table 2) and calculated a number of statistics including AIC values in terms of the deviance (AICD) and the probability of chi-square greater than the Wald statistic to test the significance of the linear trend in column numbers. Best of the Models 4–9 (each of these has a linear-trend in columns) was selected using the lowest AICD value. If the linear-trend for this best model was significant ($p < 0.05$) then the selected model was the 'best' of the nine models, else the best of Models 1–3 was chosen using the lowest AICD values as the 'best' of the nine models.

For a selected spatial model, heritability of the traits from the entries and response to selection were computed assuming entries as random and the best linear unbiased predictor (BLUP) estimates.

The BLUPs were used to calculate the correlation coefficients between grain yield measured in different farmers' fields, using the data of the 95 entries which were common to all farmers' fields.

Response to selection was measured in two ways. Firstly, we compared the grain yield (using the BLUP's) of the selected entries with the grain yield of the improved check or the local check, or both, depending on the farmers' field. We considered as entries responding to selection those with a grain yield higher than the checks. This is justified since after only one cycle of selection large changes in mean values are not expected. The selection efficiency of farmers and breeder was estimated by the percentage of entries responding to selection that were selected by either the farmers or the breeder in each of the farmer fields. The percentage was also weighted by the total number of entries selected by each participant.

Secondly, the entries were classified according to the six possible combinations of who made the selection (farmers or breeder) and where (Tel Hadya, Breda and farmer field) in 1997. The means of the BLUP's of the six groups were then used to analyze the main effects of the selection environment and of who did the selection, the interaction effect, and to compare farmers' and breeder selections at each individual location. The main effect of the selection environment (research station vs. farmer field) was measured, for each trait by the contrast:

a. (Mean of BS and FS) – (Mean of BF and FF)

where BS and FS are the entries selected by the breeder and the farmer on station, while BF and FF are the entries selected by the breeder and the farmer in a given farmer field. This contrast was analyzed for both Tel Hadya and Breda, each compared with every farmers' field and for every character.

The main effect of who did the selection (breeder vs. farmer) was measured by the contrast:

b. (Mean of BS and BF) – (Mean of FS and FF)

This contrast was analyzed for each trait and for Tel Hadya, Breda and the nine farmers' fields.

The interaction between the main effects a) and b), indicating whether the difference between farmers' and breeder's selections differs between experiment station and farmers' fields, was measured by the contrast:

c. (Mean of FF and BS) – (Mean of BF and FS).

This contrast was analyzed for Tel Hadya, Breda and for each farmer's field.

Eventually, the entries selected by the farmers and the breeder in 1997 in the two research stations and in the farmers' fields, were compared in 1998 in each of the three locations.

The spatially corrected BLUP estimates for the test entries were used for comparing the selections using the above contrasts. The variances of the contrasts were derived from the variances between the estimates of the test entries within the groups and considered more appropriate than those derived from error-variances based on the check entries.

All contrasts were tested for significance using t-test for groups of unequal size, conducted with AGROBASE after testing the homogeneity of variances within the groups of genotypes.

The contrasts described above measure not only the direct response to selection, but also the correlated response to selection for those traits that in 1998 were measured in a location different from where the selection was conducted in 1997.

Genotype × Environment (GE) Interactions were analyzed for grain yield by clustering and ordination procedures on environmentally standardized data (DeLacy et al., 1996) using the software GEBEI (Watson et al., 1996).

Table 3. Rainfall (recorded by farmers through rain-gauges), and mean and standard error of grain yield (GY in kg/ha), total biological yield (BY in kg/ha), harvest index (HI), plant height (PH in cm) and kernel weight (KW in g) in nine farmers' fields and in two research stations (Breda and Tel Hadya). The data are based on the 95 entries common to all trials

Location (code)		Rainfall	GY	BY	HI	PH	KW
Ebla (02)	Mean	368	2813	7145	0.40	85.9	35.3
	s.e.		26	113	0.001	0.93	0.28
Tel Brak (03)	Mean	298	692	1663	0.41	40.5	34.3
	s.e		19	36	0.00	0.50	0.12
Jurn El-Aswad	Mean	202	755	2648	0.27	29.0	32.3
(04)	s.e.		21	40	0.01	0.70	0.28
Baylonan (05)	Mean	200	827	3037	0.27	37.6	29.3
	s.e.		21	51	0.003	0.64	0.18
Al Bab (06BB)	Mean	269	1101	4105	0.26	42.9	33.8
	s.e.		2	17	0.00	0.64	0.20
Al Bab (06BV)	Mean	269	2521	7634	0.33	54.8	30.6
	s.e.		100	195	0.00	1.10	0.33
Melabya (07)	Mean	167	426	1715	0.25	23.0	31.1
	s.e.		10	28	0.007	0.33	0.30
Bari Sharki (08)	Mean	316	1787	6069	0.28	62.9	27.7
	s.e.		41	0.01	0.003	0.91	0.14
Suran (09)	Mean	329	2186	5101	0.43	52.0	41.7
	s.e.		38	51	0.004	0.77	0.20
Breda (BR)	Mean	229	942	2450	0.40	36.4	35.0
	s.e.		18	72	0.009	0.55	0.15
Tel Hadya (TH)	Mean	411	3143	8260	0.39	77.4	42.2
	s.e.		41	171	0.010	0.55	0.12

[a] At Ibbin the crop was damaged by a hail storm and was not harvested.
[b] At Al Bab the trial was planted both after barley (BB) and after common vetch (BV).

Table 4. Phenotypic correlation coefficients between grain yield of 95 barley entries in nine farmers' fields (see codes in Table 1) and in two research stations (BR = Breda and TH = Tel Hadya)

Locations	02	03	04	05	06BB	07	08	09	06BV	TH
02	1.000									
03	0.001	1.000								
04	0.031	–0.012	1.000							
05	0.005	0.088	0.121	1.000						
06BB	0.184	0.191	0.307**	0.147	1.000					
07	0.035	0.065	0.093	0.090	0.047	1.000				
08	0.380**	–0.291**	–0.107	–0.050	0.162	–0.062	1.000			
09	0.184	–0.238**	0.126	0.164	0.076	0.061	0.215*	1.000		
06BV	0.054	–0.079	–0.032	0.081	0.159	–0.127	0.352**	0.198	1.000	
TH	0.459**	–0.231**	0.044	0.120	0.200	–0.064	0.422**	0.451**	0.197	1.000
BR	0.083	0.172	0.124	0.409**	0.119	0.211*	–0.142	0.177	0.174	0.165

* Level of significance: r = ± .202 (p <0.05); r = ± .263 (p <0.01).

Table 5. Total number of lines out-yielding the local check and the best check in eight farmers' fields, and number, percentage of the total, and percentage of selected lines (% of sel.) by the breeder and the farmer, respectively

Location			Selected by the breeder			Selected by the farmer		
		Total (T)	n	% of T	% of sel	n	% of T	% of sel
2	> Local Check (A.Aswad)	136	65	0.48	1	46	0.34	0.96
	> Best Check (Rihane-03)	2	1	0.50	0.02	1	0.5	0.02
3	> Local Check (A.Aswad)	11	5	0.45	0.07	4	0.36	0.17
	> Best Check (Rihane-03)	4	2	0.50	0.03	2	0.50	0.09
4	> Local Check (A.Aswad)	105	61	0.58	0.86	20	0.19	0.91
	> Best Check (Tadmor)	72	45	0.63	0.63	12	0.17	0.55
5	> Local Check (A.Aswad)	44	27	0.61	0.33	4	0.09	0.80
	> Best Check (Arta)	7	3	0.43	0.04	1	0.14	0.20
6BB	> Local Check (A.Abiad)	44	22	0.50	0.31	3	0.07	0.27
	> Best Check (Rihane-03)	29	22	0.76	0.31	2	0.07	0.18
6BV	> Local Check (A.Abiad)	64	35	0.55	0.50	6	0.09	0.60
	> Best Check (Rihane-03)	19	11	0.58	0.16	2	0.11	0.18
7	> Local Check (A.Aswad)	8	4	0.50	0.06	0	0.00	0.00
	> Best Check (Zanbaka)	2	1	0.50	0.02	0	0.00	0.00
8	> Local Check (A.Abiad)	64	34	0.53	0.38	2	0.03	0.15
	> Best Check (Arta)	26	26	1.00	0.29	0	0.00	0.00
	–	–	–	–	–	–	–	–
9	> Best Check (Arta)[a]	19	12	0.63	0.13	0	0.00	0.00

[a] In this village the farmers did not want to include the local landrace as check.

Results

There were large differences in average grain yield (from about 400 kg/ha in Melabya to more than 3 t/ha in Tel Hadya), biological yield (from less than 2 t/ha in Tel Brack and Melabya to more than 8 t/ha in Tel Hadya), harvest index (from 0.25 in Melabya to 0.4 and more in Ebla, Suran, Breda and Tel Hadya), plant height (from just more than 20 cm in Melabya to more than 80 cm in Ebla) and in kernel weight (from less than 30 g in Bylounan and Bari Sharky to more than 40 g in Tel Hadya and Suran) (Table 3). This was partly due to the different levels of inputs and partly to the large differences in total rainfall, which ranged from less than 200 mm in Melabya to more than 400 mm in Tel Hadya. Farmers' field 01, not shown in Table 3 because no data were recorded due to a hailstorm shortly before harvesting, was also high yielding because of its high rainfall and high soil fertility.

The correlation coefficients between grain yield measured in the eight farmers' fields and the two research stations (Table 4), were generally low, and even when significant they indicated that only a maximum of 21% of variation in grain yield in one location (Ebla) was explained by the variation in grain yield in another location (Tel Hadya). The highest positive correlation coefficients were found between the highest yielding farmers' fields (Ebla, Bari Sharky, Tel Hadya, and Suran), indicating a certain degree of coincidence in the performance of the barley entries in these farmers' fields. However, the correlation between the yield at Ebla and the yield at Suran was significant only at $P < 0.1$. In Al Bab, the grain yield in the trial planted after vetch was positively correlated with the yield at Bari Sharky, while the grain yield of the trial planted after barley was positively correlated with the grain yield at Jurn El-Aswad. The correlation coefficients between low yielding locations were generally lower than correlation coefficients between high yielding farmers' fields, and only two were significant (between grain yield in Breda and grain yield in Bylounan and Melabya). This trend, already observed in 1997, indicates that low yielding locations differ more among themselves than high yielding locations. Correlation coefficients between low yielding and high yielding locations were either negative and significant, like those between Tel Brack, Bari Sharky, Suran, and Tel Hadya, or non-significant. In general, the picture presented by the correlation coefficients was confirmed by the two-way hierarchical ANOVA on the environmentally standardized data which showed that

Table 6. Effect[c] of the 1997 selection environments on different traits in 1998: Tel Hadya vs. farmers fields

Trait[a]	Selection at Tel Hadya vs. Selection on Farmer Field 01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	– **	– *	– **	– **	=	n.s.	– **	n.s.
CDTH	n.s.	n.s.	n.s.	+ *	+ **	+ **	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	+ **	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	n.s.	+ **	n.s.	=	n.s.	n.s.	n.s.
LDGTH	n.s.	n.s.	– **	– *	– **	– **	=	– **	– **	n.s.
PHBR	n.s.	n.s.	– *	– **	– **	– **	=	– **	– **	n.s.
PHTH	n.s.	n.s.	– *	– **	– *	n.s.	=	– **	– **	n.s.
PHFF	n.a.	n.s.	– **	– **	– **	n.s.	– **	– **	– **	n.s.
TNTH	n.s.	n.s.	n.s.	– **	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	– *
GYTH	n.s.	n.s.	n.s.	n.s.	+ **	+ **	=	+ **	+ **	n.s.
BYTH	n.s.	n.s.	n.s.	– *	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	+ *	&	+ **	+ *	=	+ **	+ *	&
GYBR	n.s.	n.s.	n.s.	&	n.s.	– **	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	– **	n.s.	&.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	&.	n.s.	&.	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	– *	n.s.	n.s.	n.s.	n.s.	n.s.	+ **	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	+ **	n.s.
KWTH	n.s.	+ *	n.s.	+ **	+ **	+ **	=	n.s.	+ *	n.s.
KWBR	n.s.	+ *	n.s.	n.s.	+ **	+ *	=	n.s.	+ *	n.s.
KWFF	n.a.	+ *	n.s.	&	n.s.	+ *	+ *	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that Tel Hadya had the largest or the smallest value, respectively;
* $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

81% of the total sum of squares was due to G × E interactions.

Response to selection

The number of lines that performed better than the best check varied from a minimum of two (farmers' fields 02 and 07) to a maximum of 72 in farmers' field 04 (Table 5). The number of lines that performed better than the local check was always higher, ranging from a minimum of eight in farmers' field 07 to a maximum of 136 in farmers' field 02. On average, the number of lines out-yielding the local check in the highest yielding farmers' fields (02, 06V, 08 and 09) was more than double the number of lines out-yielding the local check in the lowest yielding farmers' fields (03, 04, 05, 06B and 07). This is not surprising because the local check was the local landrace, which is very susceptible to lodging under favorable growing conditions. Conversely, the average number of lines out-yielding the best check was nearly the same regardless of the yield level of the farmers' field.

Among the lines that performed better than the best check, the number selected by the breeder was, with one exception, higher than the number selected by the farmers, the exception being farmers' field 02, where both selected one of the two lines out-yielding the best check.

Among the lines out-yielding the local check, the breeder always selected a larger number than the farmers. However, when the number of lines out-yielding either the local or the best check was weighted by the total number of lines selected by each participant, the difference between farmers' and breeder's effectiveness is much lower. In fact, for lines out-yielding the best check, the breeder selected a higher proportion in five farmers' fields, the farmers selected the highest proportion in three farmers' fields, and in one farmers'

Table 7. Effect[c] of the 1997 selection environments on different traits in 1998: Breda vs. farmer's fields

Trait[a]	Selection at Breda vs. Selection on Farmer Field									
	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	+ **	+ **	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
CDTH	– **	– **	n.a.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
GVTH	– **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
LDGTH	n.s.	+ **	n.s.	n.s.	n.s.	– *	=	n.s.	n.s.	n.s.
PHBR	+ **	+ **	n.s.	n.s.	n.s.	– *	=	n.s.	n.s.	n.s.
PHTH	+ **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	– **	n.s.
PHFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	– **	n.s.	n.s.	n.s.
TNTH	+ **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
GYTH	n.s.	– **	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	+ *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	– **	– *	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	&
GYBR	+ *	+ *	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	&	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.
KWTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWBR	n.s.	+ *	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWFF	n.a.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that Breda had the largest or the smallest value, respectively; * $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

field farmers and breeder selected the same proportion. For lines out-yielding the local check, the farmers and the breeder each selected a higher proportion in four farmers' fields.

Main effect of selection environment

The environment where selection was conducted in 1997 had a significant effect on a number of traits measured in 1998. In general, the greater the similarity between the selection environment of 1997 and the testing environment of 1998, the more similar were the selections. For example, selections made at Tel Hadya (Table 6) differed significantly more often from those in low yielding farmers fields (03, 04, 05 and 07) than from those in high yielding farmers fields (01, 02, 08 and 09). However, there were also several significant differences between selections made at Tel Hadya and those made in Bari Sharky (08), even though the yield level of this farmer field was high. By contrast, selections made at Breda (Table 7) differed more frequently from those in the two highest yielding farmers' fields (01 and 02) than from those in low yielding farmers' fields. Again there was an exception, however, namely farmers' field 08.

When the comparison was made between Tel Hadya and the farmers' fields (Table 6), the traits most often and more consistently affected by the selection environment were the following:

growth habit (Tel Hadya selections were more erect than those in five farmers' fields);

lodging resistance (Tel Hadya selections were more resistant than those in six farmers fields);

plant height regardless of where it was measured (Tel Hadya selections were shorter than those in five farmers fields when it was measured at Tel Hadya, and in six occasions when it was measured at Breda or in the farmer fields);

Table 8. Effect[c] of Breeder selection vs. Farmer selection across environments in 1997 (Tel Hadya and Farmer' Field) on different traits measured in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	+ *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
CDTH	n.s.	n.s.	n.a.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	– *	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
LDGTH	– *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHBR	+ *	+ *	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHTH	n.s.	n.s.	n.s.	+ *	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TNTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
GYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	n.s.	n.s.	n.s.	+ *	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	&
GYBR	+ *	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.
KWTH	+ **	+ *	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWBR	+ **	+ *	n.s.	– *	– **	n.s.	=	n.s.	n.s.	n.s.
KWFF	n.a.	+ *	n.s.	&	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that breeder's selections had the largest or the smallest value, respectively;
* $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

kernel weight (Tel Hadya selections had larger kernels than a number of farmers' fields selections that varied depending where the trait was measured);
cold damage (Tel Hadya selections were more cold susceptible than those in three farmers' fields);
grain yield and harvest index measured at Tel Hadya (Tel Hadya selection yielded more and had a larger harvest index than farmers' fields selections in four cases, namely farmers' fields 05, 06BB, 07 and 08). By contrast, the selection environment affected grain yield at Breda only once (Tel Hadya selections yielded significantly less than selections in 06B) and twice in farmers' fields; in the first, grain yield at Bari Sharky (08) was significantly lower in Bari Sharky selections than in Tel Hadya selections, and in the second, Tel Brack (03) selections yielded significantly more than Tel Hadya selections.

When the comparison was made between the selections made in Breda and those made in the farmers' fields (Table 7), only a few characters were affected by the selection environment, and out of 20 significant differences, 16 were found in two of the highest yielding farmers' fields, namely Ibbin (01) and Ebla (02). Compared with the selections made in these two farmers' fields, selections made in Breda were more prostrate, more cold tolerant, taller and higher yielding at Breda, and with a lower harvest index at Tel Hadya.

Grain yield in farmers' fields was not affected by whether the selection was conducted in Breda on in the farmers' fields. However, grain yield at Breda was higher in Breda selections than in the selection made in two high yielding farmers' fields (01 and 02). Grain yield in Tel Hadya was generally not affected by whether the selection was done in Breda or in the farmers' fields. The only exception was that the selections made in one of the high yielding farmers' fields (02) yielded significantly more than Breda selections.

Table 9. Effect[c] of Breeder selection vs. Farmer Selection across environments in 1997 (Breda and Farmer' Field) on different traits measured in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	n.s.	– *	n.s.	n.s.	=	n.s.	n.s.	n.s.
CDTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	n.s.	+ *	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
LDGTH	n.s.	n.s.	– *	n.s.	– **	n.s.	=	n.s.	n.s.	n.s.
PHBR	+ *	+ *	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHTH	– *	n.s.	n.s.	n.s.	– *	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TNTH	– *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	– *	n.s.	&	n.s.	n.s.	=	n.s.	– *	n.s.
GYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	+ *	n.s.	n.s.	&	– *	n.s.	=	n.s.	n.s.	&
GYBR	+ *	+ *	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	– **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	– **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.
KWTH	n.s.	+ *	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWBR	n.s.	+ *	n.s.	n.s.	n.s.	n.s.	=	+ *	n.s.	n.s.
KWFF	n.a.	+ **	n.s.	&	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that breeder's selections had the largest or the smallest value, respectively;
* $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

Main effect of who did the selection

When farmers' selections across research station and farmers' fields were compared with those of the breeder, the results were slightly different depending on whether the research station was Tel Hadya (Table 8) or Breda (Table 9). For the former, differences were significant for only a few traits and mostly when the comparison was between the high yielding farmers' fields 01, 02 and the low yielding farmers' field 04. The trait for which significant differences were found more often was 1000 kernel weight. Selections made by the breeder in Tel Hadya and farmers' fields 1 and 2 had significantly larger kernels at both Tel Hadya and Breda than selections made by farmers across the same farmers' fields. By contrast, selections made at Tel Hadya and farmers' field 04 and Tel Hadya and farmers' field 05 by the breeder had significantly smaller kernels than farmers' selections. On only two occasions was yield affected significantly by who did the selection, and in both (grain yield in Breda and biomass yield in Tel Hadya) breeder's selections yielded more than farmers' selections. When the comparison between farmers' and breeder selections was made using Breda as the research station (Table 9), a slightly larger number of differences were significant, and they were found mostly when the comparison was made in farmers' fields 01, 02, 03 and 05. When the differences were significant, breeder's selections were more erect, more lodging resistant, taller in Breda but shorter in Tel Hadya, tillering less, and with larger kernels. In only a few instances were significant differences found for either grain yield or biomass. Breeder's selections in Breda and either farmers' fields 01 and 02 had a higher grain yield in Breda than farmers' selections. Conversely, farmers' selections in Breda and in farmers' field 03 had a higher grain and biomass yield than breeder's selections in the same farmers' fields. Grain yield and biomass yield in farmers' fields was affected by who did the selection only once, when selections

Table 10. Interaction effect[c] between environment of selection and who did the selection in 1997 (Tel Hadya and Farmer' Field) on different traits measured in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	**	n.s.	**	n.s.	=	**	n.s.	n.s.
CDTH	n.s.	*	n.s.	n.s.	**	n.s.	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	n.s.	**	n.s.	=	n.s.	n.s.	n.s.
LDGTH	n.s.	n.s.	n.s.	n.s.	**	n.s.	=	n.s.	**	n.s.
PHBR	n.s.	*	n.s.	*	**	– *	=	n.s.	*	n.s.
PHTH	n.s.	n.s.	n.s.	n.s.	**	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	– *	**	**	n.s.	n.s.	**	n.s.	n.s.
TNTH	n.s.	n.s.	n.s.	*	n.s.	n.s.	=	n.s.	*	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	*	n.s.	n.s.
GYTH	n.s.	n.s.	n.s.	n.s.	**	n.s.	=	n.s.	*	n.s.
BYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	*	&	**	n.s.	=	n.s.	n.s.	&
GYBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.
KWTH	n.s.	*	n.s.	n.s.	*	n.s.	=	n.s.	n.s.	n.s.
KWBR	n.s.	*	n.s.	n.s.	*	n.s.	=	n.s.	*	n.s.
KWFF	n.a.	*	n.s.	&	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] * $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

made by the farmer from Tel Brack out-yielded those made by the breeder.

Interaction effects

There were several significant interactions between selection environment and who did the selection (Tables 10 and 11). When Tel Hadya was used in the contrast as research station (Table 10), most of the significant interactions were found with farmers' field 05. The traits where the interaction effects were significant were plant height in Breda and in the farmers' fields, growth habit and kernel weight in Breda. When Breda was used as research station (Table 11), most of the significant interactions were found with farmers' field 03. The traits where the interaction effects were significant were plant height and kernel weight in the farmers' fields, growth habit, kernel weight in Breda, and grain yield, biomass yield and harvest index in the farmers' fields. The presence of significant interactions between the environment of selection and who did the selection indicates the presence of significant differences in the contrasts between breeder and farmers' selections within individual farmers' fields: the results of these contrasts are presented in the following section.

Comparison between breeder and farmers in individual locations

The entries selected at Tel Hadya in 1997 by the breeder and the farmers differed only in few traits when tested in 1998 (Table 12). With the exception of days to heading, these differences were not associated with either specific locations or specific traits. Farmers' selections were earlier than breeder's selection in the three instances in which the differences were significant. Only once was grain yield affected; the grain yield in Breda of the selections made by the farmer from farmers' field 01 was significantly higher ($P < 0.05$) than the selections made by the breeder in Tel Hadya.

Table 11. Interaction effect[c] between environment of selection and who did the selection in 1997 (Breda and Farmer' Field) on different traits measured in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	*	n.s.	n.s.
CDTH	n.s.	*	n.a.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	*	n.s.	n.s.
DHTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
LDGTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHBR	n.s.	n.s.	*	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	**	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.
TNTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	n.s.	**	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
GYTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	*	&	n.s.	n.s.	=	n.s.	n.s.	&
GYBR	n.s.	n.s.	*	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	*	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	**	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	*	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	*	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	**	n.s.	n.s.	&	**	n.s.	n.s.	n.s.
KWTH	n.s.	n.s.	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWBR	n.s.	*	**	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWFF	n.a.	*	**	&	&	n.s.	**	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] * $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

Entries selected at Breda in 1997 by the breeder and the farmers differed more often than the Tel Hadya selection (Table 13). Significant differences were observed for all farmers except for the farmer from Al Bab (06). Significant differences were found for lodging resistance, plant height, days to heading, tillering in Breda and kernel weight. Breeder's selections were usually more lodging resistant with one exception (farmer from farmers' field 09), were shorter (with the exception of the selections made by the farmer from farmers' field 02), were earlier, and had less tillers and larger kernels. Grain yield or biomass were seldom affected, and when significant differences were observed, breeder's selections out-yielded selections by the farmer from farmers' field 02 in Breda, while farmers' selections (from farmers' field 03) out-yielded breeder's selections in one farmer's field both in grain and in biomass yield.

There were more significant differences among the breeders and farmers selections made in the farmers' fields than those found at the two research stations (Table 14). There was a large variability in the signs of the differences depending on the particular farmer being considered. The most consistent differences were found for kernel weight, which was always higher in the breeder's selections, growth habit (generally more prostrate in breeder's selections), growth vigor (higher in farmers' selections), lodging resistance (higher in breeder's selections), and plant height (generally shorter in breeder's selections). The differences between breeder's selections and farmers' selections were significant on three occasions for grain yield at Tel Hadya and twice for grain yield at Breda, with breeder's selections yielding significantly more than farmers' selections throughout. For comparison, grain yield in farmers' fields was never affected by who did the selection.

Table 12. Effect[c] of Breeder selection vs. Farmer Selection in Tel Hadya in 1997 on different traits in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
CDTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	+ *	n.s.	+ **	=	+ *	n.s.	n.s.
LDGTH	– **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHBR	+ **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHTH	n.s.	n.s.	n.s.	– **	n.s.	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
TNTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	– *	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	– *	n.s.	n.s.
GYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
GYBR	– *	n.s.	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.
KWTH	+ **	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
KWBR	+ **	n.s.	n.s.	n.s.	– *	n.s.	=	n.s.	n.s.	n.s.
KWFF	n.a.	n.s.	n.s.	&	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that breeder's selections had the largest or the smallest value, respectively;
* $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

Discussion

The results of this study confirm the large effect of the selection environment on response to selection, which was found in previous studies (Ceccarelli et al., 1998). The entries selected at the two research stations, which represented a favorable and a stress selection environment, were similar to those made in farmers' fields representing the same physical environment, and were different from the selections made in farmers' fields representing a contrasting environment.

The effect of the selection environment was particularly evident on plant height and lodging resistance, when the selections made in a high yielding environment such as the research station at Tel Hadya were compared with those made in lower yielding farmers fields. Almost always selections from Tel Hadya were shorter and more lodging resistant than those from low-yielding farmers fields. These are key traits in winter cereals, for which almost invariably plant breeding has gone in the same direction as the selection at Tel Hadya, even though short plants and lodging resistance are not necessarily desirable attributes when the crop is grown in marginal environments.

The effect of selection environment was much larger than the effect of who did the selection, confirming the importance of decentralized selection (defined as selection conducted in the target environment) where the crop is grown in a wide range of physical environments, as in barley, and when the breeding objective is to adapt the crop to each of the environments in which it is grown.

Breeder and farmers' selections differed for a number of agronomic traits more often in farmer fields than on the research stations, suggesting that when farmers' selection on station (defined as centralized-participatory plant breeding) might be of less value than farmers' selection in their own fields.

Analysis of the 1998 data confirmed the farmers' preference (and the effectiveness of selection) for early

Table 13. Effect[c] of Breeder selection vs. Farmer Selection in Breda in 1997 on different traits in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	n.s.	n.s.	n.s.	– *	n.s.	n.s.	=	n.s.	n.s.	n.s.
CDTH	n.s.	n.s.	n.a.	n.s.	n.s.	n.s.	=	n.s.	n.s.	– *
GVTH	+ *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
DHTH	n.s.	n.s.	n.s.	– **	n.s.	n.s.	=	– *	n.s.	n.s.
LDGTH	n.s.	n.s.	– *	n.s.	– **	n.s.	=	n.s.	– *	+ *
PHBR	– *	+ *	n.s.	n.s.	– *	n.s.	=	n.s.	n.s.	n.s.
PHTH	– *	n.s.	n.s.	n.s.	– **	n.s.	=	n.s.	n.s.	n.s.
PHFF	n.a.	n.s.	– *	n.s.	– **	n.s.	n.s.	n.s.	n.s.	n.s.
TNTH	– *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	– *	n.s.	&	n.s.	n.s.	=	n.s.	– *	n.s.
GYTH	+ *	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	+ *	n.s.	n.s.	&	+ **	n.s.	=	n.s.	n.s.	n.s.
GYBR	n.s.	+ *	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	n.s.	n.s.	n.s.
GYFF	n.a.	n.s.	– **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	– **	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	+ **	– *	n.s.	n.s.	& .	n.s.	n.s.	n.s.	n.s.
KWTH	n.s.	+ *	n.s.	n.s.	+ **	n.s.	=	n.s.	n.s.	n.s.
KWBR	n.s.	n.s.	n.s.	n.s.	+ **	n.s.	=	n.s.	n.s.	n.s.
KWFF	n.a.	n.s.	n.s.	&	+ *	n.s.	n.s.	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that breeder's selections had the largest or the smallest value, respectively; * $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

vigor and taller plants under moisture stress already observed during the selection phase (Ceccarelli et al., 2000). Even though both farmers and breeder selected for large kernels, breeder's selection was much more effective for this trait than farmers' selection.

Breeder and farmers' selections differed rarely for grain yield. Based on the few significant differences, breeder's selection was more effective on station, while farmers' selection was more effective in farmers' fields. It should be borne in mind, however, that the majority of differences for either grain or biomass yield were not significant.

Even if the selection efficiency of the breeder and the farmers, measured as response to selection for grain yield, was not dramatically different, decentralized farmer selection could be more cost effective than decentralized breeder selection for at least three reasons. First, breeder and farmers' selection may differ for traits that although independent of grain yield are important for farmers' adoption. An example of this is the variety Zanbaka which has been adopted by farmers in areas represented by location nr 5 principally for its superior height under severe drought. Secondly, even assuming equal efficiency, decentralized farmer selection has the advantage of addressing a larger number of target environments than decentralized breeder selection. Thirdly, decentralized farmer selection is capable of adjusting to changes in farmers' preferences, which may be independent of the physical environment.

Eventually, the experiments conducted in 1998 confirmed the ability of farmers to handle a large number of lines, also observed in other countries (Ceccarelli et al., 2001), and their interest in selection, as indicated by the increased number of farmers participating in the selection program. These experiments also revealed that the quality of participation is likely to improve with time as shown by their interest to know more about the origin and pedigree of both good and

Table 14. Effect[c] of Breeder selection vs. Farmer Selection in the farmers' fields in 1997 on different traits in 1998

Trait[a]	01	02	03	04	05	06BB	06BV[b]	07	08	09
GHTH	+ **	+ *	n.s.	– *	n.s.	n.s.	=	+ **	n.s.	n.s.
CDTH	– *	– *	n.a.	n.s.	+ **	+ *	=	n.s.	n.s.	n.s.
GVTH	n.s.	n.s.	n.s.	n.s.	n.s.	+ **	=	+ *	+ **	n.s.
DHTH	n.s.	– *	– **	n.s.	n.s.	n.s.	=	+ **	+ *	n.s.
LDGTH	n.s.	n.s.	n.s.	n.s.	n.s.	– *	=	– **	n.s.	n.s.
PHBR	n.s.	+ *	n.s.	n.s.	n.s.	– *	=	– **	– *	n.s.
PHTH	n.s.	n.s.	n.s.	n.s.	n.s.	– **	=	n.s.	– *	n.s.
PHFF	n.a.	n.s.	n.s.	n.s.	n.s.	– *	– *	n.s.	+ *	– *
TNTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
TNBR	n.s.	n.s.	n.s.	&	n.s.	n.s.	=	n.s.+ *	n.s.	
GYTH	n.s.	n.s.	n.s.	n.s.	n.s.	+ **	=	+ **	+ *	n.s.
BYTH	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	=	n.s.	n.s.	n.s.
HITH	n.s.	n.s.	n.s.	&	n.s.	+ *	=	n.s.	n.s.	&
GYBR	+ *	+ *	n.s.	&	n.s.	n.s.	=	n.s.	n.s.	n.s.
BYBR	n.s.	n.s.	n.s.	– *	n.s.	n.s.	=	n.s.	n.s.	n.s.
HIBR	n.s.	n.s.	n.s.	n.s.	n.s.	&	=	+ **	n.s.	n.s.
GYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
BYFF	n.a.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
HIFF	n.a.	n.s.	n.s.	n.s.	n.s.	&	n.s.	n.s.+ *	n.s.	
KWTH	n.s.	+ *	n.s.	n.s.	n.s.	+ **	=	n.s.	n.s.	n.s.
KWBR	+ *	+ **	n.s.	n.s.	n.s.	+ *	=	+ *	+ *	n.s.
KWFF	n.a.	?+ **	n.s.	&	n.s.	+ *	+ *	n.s.	n.s.	n.s.

[a] abbreviations are given in Materials and Methods.
[b] the value is the same as indicated for 06BB.
[c] + and – indicate that breeder's selections had the largest or the smallest value, respectively; * $p < 0.05$; ** $p < 0.01$; n.s. = non significant; n.a. = not available.
& = zero heritability.

bad performing entries and to relate performance in one year with performance in the previous year.

The results presented in this and the previous paper (Ceccarelli et al., 2000) suggest that it is possible to organize a plant breeding program in a way that addresses not only those plant characteristics that maximize yield and stability over time in a given physical environment, but also the preferences of the users, by developing varieties which are specifically adapted to the different physical and socio-economic environments. Such an objective can be achieved by using a decentralized participatory mode, which needs to be extended also to the seed production aspects. A breeding program organized according to these principles will have the advantages of producing environmentally friendly varieties and of maintaining or even enhancing biodiversity.

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