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A methodological study on participatory barley breeding I. Selection phase

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Summary

Decentralized selection, defined as selection in the target environment, has been used to emphasize favorable interactions when significant genotype by environment interactions exist. However, crop breeding based on decentralized selection can still miss its objectives if it does not utilize the farmers' knowledge of the crops and the environment, and it may fail to fit crops to the specific needs and uses of farmers' communities unless it becomes participatory. One cycle of decentralized participatory selection was conducted in eleven locations in Syria. 208 barley entries (fixed lines and segregating populations) were planted unreplicated in two research stations and in the fields of nine Syrian (host) farmers, where they were managed (except planting) by the farmers themselves. Visual selection was conducted by a breeder at all locations and by the host farmers on their own fields and on both stations. In five farm locations, there was also a one-time group selection by neighboring farmers. Host farmers were able to handle the large number of entries making observations during the cropping season using different scoring methods. They did not use the performance of entries on station for their final selection and used a higher selection pressure than the breeder. In their own fields, they selected about one tenth the number of entries selected by the breeder, while on station the farmers selected, on average, about half the number of lines selected by the breeder. For some broad attributes, such as modern germplasm versus landraces, selection was mostly driven by environmental effects. Selection for other attributes was partly environmentally driven and partly based on individual farmers preferences. Selection preferences were similar for fixed or segregating populations. There was wider diversity among farmers' selections in their own fields than among farmers' selections on research stations and among breeder's selections, irrespective of where the selection was conducted. Larger kernels, higher grain yield and biomass, and taller plants (particularly in environmentally stressed locations) were the characteristics most frequently used as selection criteria by both breeder and farmers. Entries selected by the farmers yielded as much, and in one case significantly more, than those selected by the breeder. Decentralized-participatory selection was significantly more efficient in identifying the highest yielding entries in farmers' fields than any other type of selection. There was also evidence suggesting that the breeder was more efficient in selecting higher yielding entries in the research station in a high rainfall area, while the farmers were more efficient in selecting under stress conditions. The results suggest that farmers can handle selection choices among a large number of lines, and because farmers' selections are at least as high yielding as breeder's selections, it is possible to transfer the responsibility of selection to farmers in their fields.

Introduction

Genotype by environment (GxE) interaction is one of the major factors limiting the efficiency of breeding

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programs. Plant breeders can deal with GxE interactions in three ways (Eisemann et al., 1990) which are to *ignore*, to *avoid* or to *exploit* them. Where GxE interactions are significantly large, it is not possible to ignore them and the two remaining strategies are (1) to avoid them by selecting cultivars that are broadly adapted to the entire range of target environments, or (2) to exploit them by selecting different cultivars, each specifically adapted to a subset of target environments (Ceccarelli, 1989). Selection for specific adaptation is particularly important in breeding crops predominantly grown in unfavorable conditions, because unfavorable environments tend to be more different from each other than favorable environments (Ceccarelli & Grando, 1997) and tend to produce repeatable cross-over interactions with favorable environments (Ceccarelli, 1989, 1996).

Selecting for specific adaptation has the advantage of adapting cultivars to the physical environment where they are meant to be cultivated, and hence is more sustainable than other strategies which rely on modifying the environment to fit new cultivars adapted to more favorable conditions. Selection theory shows that selection for specific adaptation is more efficient when based on decentralized selection (Falconer, 1981; Simmonds, 1991), defined as selection in the early stages of a breeding program conducted in the target environment(s). However, the most serious limitation of decentralized selection for specific adaptation to unfavorable environments is in the large number of potential target environments. Moreover, the number of target environments is often increased by different uses of the crop associated with quality traits, which are neutral in terms of adaptation to the physical environment. Clearly, selection for specific adaptation to unfavorable conditions targets a larger sample of environments than selection for favorable environments. Consequently the number of selection sites needs to be larger.

The participation of farmers in the very early stages of selection offers a solution to the problem of fitting the crop to a multitude of both target environments and users' preferences (Ceccarelli et al., 1996; Kornegay et al., 1996). Although decentralized selection and farmers' participation may be construed as unrelated, the acceptance of the former as a breeding strategy almost inevitably leads to the acceptance of the latter as a tactical necessity. Therefore, there are sound scientific and practical reasons for farmer participation to increase the efficiency and the effectiveness of the breeding program (functional participation), even though farmer participation is often advocated mainly on the basis of equity (Ashby, 1997).

The idea of farmers participation in technology development, including plant breeding, is neither new nor revolutionary (Rhoades & Booth, 1982; Sperling et al., 1993; Farrington, 1996). It should be recalled that for 10,000 years women and men consciously have been molding the phenotype (and so the genotype) of hundreds of annual and perennial plant species as one of their many routine activities in the normal course of making a living (Harlan, 1992). This traditional form of plant breeding by farmers produced hundreds of distinct varieties (Duvick, 1996), each adapted to the environmental and social conditions of particular farmers or communities.

Recently developed participatory approaches in crop improvement programs have often taken the form of participatory varietal selection (PVS), defined as farmers making their choices among the final (or nearly final) products of a crop improvement program (Witcombe & Joshi, 1996), a process now becoming more important in international crop improvement programs. In the majority of cases, PVS takes the form of selection among a limited number of finished lines during on-farm trials or demonstrations.

In contrast to PVS, participatory plant breeding (PPB) cannot be as easily described or defined. In general, it consists in sharing the responsibility of selection with the users when the amount of genetic variability is at its maximum. In a self-pollinated cereal this could be an F_2 generation, and the selection can be either between F_2's (as described in this paper) or within F_2's (as described by Sthapit et al., 1996) or a combination of the two in a classic pedigree or bulk-pedigree or other methods. Because the way of handling the early generations of a breeding program varies with the mating system, with the crop and with the breeder, PPB can take several forms. In any case, the key is the very early stage in the selection process at which farmers become participants.

This paper compares farmers' and breeder's selections on station and on farmers fields using a large number of genotypes within a range of environments, most of which are harsh and unfavorable for high yields. We address some fundamental questions associated with PPB, such as farmers' ability to recognize and select within a widely variable population, efficiency of farmers' selection, compatibility of farmers' and professional breeders' selection criteria, and feasibility of transferring selection responsibilities to farmers.

Materials and methods

The project area

The research area is the northern part of the Fertile Crescent within Syria which receives between 350 mm and 200 mm average annual precipitation, and stretches in a wide arc from Hama province in the southwest to Hassake in the northeast. The area encompasses a range of agroecological conditions, from high to low-potential environments for cereal production. Barley is the main winter cereal. It is planted in the fall, usually after the first rain (mid-October to mid-December) and harvested in May–June. It covers over 2 million hectares with little use of modern or improved varieties. At the wettest end of the area (350 mm of annual rainfall) and on fertile soils, farmers can obtain up to 5 t ha^{-1} of grain in a good season by using fertilizer. In contrast, at the driest end (200 mm of annual rainfall), soils are generally poor, input levels are low, and grain yields vary from nothing to around 1.5 t ha^{-1}. National average barley grain yields are low at 0.65 t ha^{-1} and are stagnant.

Barley is the principal feed crop for sheep in Syria, being used as: a) grain, chopped straw and stubble grazing in years with adequate rainfall for harvest; b) grazing of the standing crop at maturity in dry years when low yields do not justify harvesting; and c) winter green grazing before stem elongation, under all conditions.

Syrian barley landraces are exclusively two-row types, and known as either Arabi Abiad (white-seeded), common in slightly better environments (250 to 350 mm) or Arabi Aswad (black-seeded), common in harsher enviromnents ($<$ 250 mm). Considerable phenotypic and genotypic heterogeneity exists both among landraces collected in different farmers' fields (even if designated by the same name) and among individual plants within the same farmer's field (Ceccarelli et al., 1987; van Leur et al., 1989; Weltzien & Fischbeck, 1990; Ceccarelli et al., 1995; Ceccarelli & Grando, 1998). Farmers in dry areas consider that grain and straw quality of the black-seeded landrace is better than the white-seeded one. However, this has never been tested either in the field or under laboratory conditions and the relationships between desirable qualities and specific use purposes are unclear.

The breeding material

The material consisted of 208 barley lines and populations (entries): 50 fixed lines unrelated to Syrian landraces, 50 segregating populations (F_3 bulks) from crosses between fixed lines unrelated to Syrian landraces, 50 lines derived from Syrian landraces, 50 segregating populations (F_3 bulks) from crosses in which at least one parent was a Syrian landrace, and 8 farmers' cultivars (from seed purchased from eight of the nine host farmers, as one of them grows an improved cultivar already included in the trial).

The 200 entries were deliberately chosen to test farmers' and breeder's preferences for different attributes and/or characteristics. The entries could be classified for four contrasts: 1) modern germplasm (100) vs. landraces (108); 2) fixed lines (100) vs. segregating populations (108); 3) two rowed (158) vs. six-rowed (50); 4) white seed (161) vs. black seed (28), or segregating (mixed) for seed color (19). The entries were planted by research staff with a plot drill, in November 1996, in nine farmers' fields and in two ICARDA's research stations, Tel Hadya and Breda (Table 1). The two research stations represent two distinct production environments. Tel Hadya (average annual precipitation 336 mm) is a typical high-input favorable environment with a wide choice of crops, while Breda (average annual precipitation 260 mm) is a typical low-input risky environment, with barley the most common rainfed crop and with limited choice of crops and cropping systems.

Unreplicated plots of 8 rows at 20 cm distance and 7.5 m long (12 m^2) were laid down in four strips of 52 plots each in farmers' fields and research stations, except in one case (Sauran) where they were arranged in eight strips of 26 plots each. Each plot was identified by numbered plastic labels held by a wooden peg. The agronomic management of the trial (area 0.25 ha) before and after the planting was left to each farmer. The material was grown under rainfed conditions.

Each farmer was given a field book in which he recorded daily precipitation (measured through a rain gauge) and the evaluative plot observations. The quantitative scoring method most farmers preferred was a numeric scale (highest = best, lowest = worst). Some used qualitative scoring such as ticking, or classifying the plots as 'bad', 'medium', 'good', 'very good', and 'excellent'. Eventually farmers used a mixture of quantitative scores for some traits and qualitative descriptors for others. Farmers used the earlier observations at the time of the final selection to assign the final score.

The following types of selection were performed:

a) Individual selection by each participating (host) farmer alone on his own field (*decentralized, in-*

dividual farmer selection): each farmer decided which traits to score for, when, and how often. Each farmer did his final selection by visually inspecting the seed of those entries which received the best score during the last selection before harvesting. Farmers based their selection solely on the performance of the lines in their own field, and did not use the performance of the lines in Breda and Tel Hadya although this information was available to them.

b) Selection by each participating farmer in Breda and Tel Hadya (*centralized, farmer's selection*). A researcher assisted the farmer to record both quantitative and qualitative data. It was done only once, in 2 consecutive days, when the crop was at full heading in Tel Hadya and at dough stage in Breda.

c) Selection by the senior barley breeder of DASR (Directorate of Agricultural and Scientific Research) of the Ministry of Agriculture and Agrarian Reform in Syria, in each of the nine farmers' fields (*decentralized, breeder's selection*) as well as in Breda and Tel Hadya (*centralized, breeder's selection*). This was done over 10 days when the crop was close to maturity and without knowing the selections made by the farmers. The final selection was based on visual seed inspection for those entries which received the best score at the visual selection just before harvesting. Eventually, the breeder selected two groups of entries, one for high-rainfall and one for low-rainfall areas. The first group was based on the scores given in Tel Hadya and in locations 1, 2 and 9, the second on the scores given in Breda and in locations 3, 4, 5, 6, 7 and 8.

d) Group selection by neighboring farmers at five of the nine farm locations (*decentralized, farmers groups selection*). In each of these locations a different group of eight farmers (nine in two locations) did a one-time visual selection, with a score from 0 (worst) to 4 (best), with a researcher recording quantitative and qualitative data. Finally, each farmer was asked to identify and rank the best 15 entries. Group selections were done when the crop was close to full maturity.

Neither the breeder nor the farmers had access to the actual yield data or other objective measurements, and therefore the entire process simulates, except for the plot size, the visual selection during the very early stages of a breeding program. Selection was exclusively between entries.

In each farmer's field research staff recorded plant height before harvesting and discussed with the farmer the sampling procedure to obtain a representative sample of 2.4 m^2 on which the following characters were recorded: grain yield; total biological yield (biomass); harvest index; spike length (on a sample of 10 spikes); number of kernels per spike (on a sample of 10 spikes) and kernel weight.

We measured the following additional characteristics in both research stations (unless otherwise indicated): early growth vigor (1 poor, 5 good); growth habit (1 erect, 5 prostrate); plant color (measured only in Tel Hadya on intact leaves in the field using a portable chlorophyll meter); cold damage (1 none, 5 maximum) in Tel Hadya only; lodging (1 none, 5 complete) in Tel Hadya only; number of tillers per m^2; days from emergence to heading in Tel Hadya only.

Selection scores were reduced to matrices of 1, 0 (selected or discarded), giving 1 to all those entries which a farmer scored in his two highest categories.

The frequency of fixed lines and of segregating populations, of modern and landraces, of six-row and two-row and of different seed color types selected by each farmer and by the breeder in farmers' fields and in Breda and Tel Hadya (Table 3), and by the groups of farmers in farmers' fields were analyzed, using a heterogeneity G-test (Sokal & Rohlf, 1981), which compares the observed frequencies of different types being selected (by the breeder or by the farmer, on farm or on station, by different farmers within the same group) with those expected based on the frequency with which they occurred in the sample of 208 entries. The test was conducted on the individual selections done by the farmers and by the breeder to test their preferences. The test was used also to test whether the results of the individual selections are homogeneous in the eleven locations (Breda, Tel Hadya, farmers fields), whether the total frequencies deviate significantly from those expected based on random selection, and eventually to test the overall agreement between observed and expected frequencies.

The similarity of selection done in different environments by the breeder and by the individual farmers, as well as by the groups of farmers, was evaluated for the following comparisons: (1) farmers and breeder in the farmer fields; (2) farmers in their fields and the breeder in the research stations; (3) breeder in the research stations and in the farmers' fields; (4) farmers in the research stations and in their fields; (5) breeder and the farmers in the research stations; (6) breeder

Table 1. Rainfall, average grain yield, total biomass, harvest index and plant height of 208 barley entries in nine farmers' fields and Breda and Tel Hadya (two research stations)

Location (code)		Rainfall (mm)	Grain yield (kg ha^{-1})	Biomass (kg ha^{-1})	Harvest index	Plant height[a] (cm)
lbbin (1)	Mean	436	3248	8600	0.37	102
	s.e.[b]		81	147	0.005	0.6
Ebla (2)	Mean	460	2857	8000	0.36	98
	s.e.		58	113	0.005	0.7
Tel Brak (3)	Mean	278	3685	7661	0.48	88
	s.e.		69	101	0.006	0.9
Jurn El-Aswad (4)	Mean	284	1415	7259	0.20	45
	s.e.		51	228	0.005	0.7
Baylonan (5)	Mean	193	280	2599	0.11	46
	s.e.		13	60	0.004	0.7
Al Bab (6)	Mean	350	376	1514	0.24	33
	s.e.		15	39	0.009	0.5
Melabya (7)	Mean	241	713	2733	0.26	–
	s.e.		29	103	0.005	–
Bari Sharki (8)	Mean	248	1017	4534	0.22	52
	s.e.		36	163	0.006	0.7
Sauran (9)	Mean	303	2515	7117	0.36	69
	s.e.		46	101	0.006	0.9
Breda (BR)	Mean	233	811	2689	0.31	44
	s.e.		18	51	0.005	0.6
Tel Hadya (TH)	Mean	434	4495	12336	0.36	96
	s.e.		63	110	0.003	0.7

[a] Melabya was not sampled.
[b] Standard error.

in the farmers' fields and the farmers in the research stations.

We used four different methods, viz. 1) simple tabulation and comparison of lines selected in the different environments by the breeder and the farmers, 2) calculation of simple correlation coefficients, 3) calculation of percent of lines selected in common (in different environments or by different selectors), and 4) the use of the similarity analysis based on the Dice coefficient (Czekanowski, 1917). The different methods gave results in close agreement with each other and therefore we only show the results obtained with the similarity analysis. The dendograms of the various combinations of environments of selection and selectors were obtained by the unweighted pair group method with arithmetic average (UPGMA) cluster analysis. These analysis were done using the program NTSYS-PC version 1.80 (Numerical Taxonomy System, Applied Biostatistics, N.Y.).

To identify the actual selection criteria used by the farmers and by the breeder, we used the difference between the mean of the lines selected by the breeder or by the farmers in either the farmers' fields or the experiment stations and the mean of the initial population of 208 lines tested with a t-test for groups of unequal size.

As a measure of effectiveness of selection, we considered the frequency with which the top yielding 20 entries (approximately 10% of the total) were included among the farmers' and the breeder's selections in each farmers' field and in the two research stations. After arcsine transformation, the frequencies were analyzed by factorial ANOVA.

Results

There were large differences in average grain yield, biomass, harvest index, and plant height between the nine farmers' fields and the two research stations (Table 1). The highest yield was obtained in Tel Hadya, with nearly 4.5 t ha^{-1} of grain and over 12 t ha^{-1} of total biomass. The two most stressed sites

Table 2. Simple phenotypic correlation coefficients between grain yield in nine locations (indicated by the codes of Table 1) and two research stations, Breda (BR) and Tel Hadya (TH)

Location	1	2	3	4	5	6	7	8	9	BR
2	0.49**									
3	0.11	0.31**								
4	–0.27**	0.08	0.10							
5	–0.05	–0.01	0.11	–0.03						
6	–0.26**	0.07	0.11	0.19**	0.05					
7	–0.10	0.07	0.25**	0.09	0.00	0.28**				
8	0.07	0.13	–0.06	–0.03	–0.14*	–0.06	–0.12			
9	0.19**	0.29**	0.03	–0.05	0.11	0.06	–0.13	0.00		
BR	0.04	0.10	0.15*	0.07	0.16*	0.07	–0.11	0.08	0.21**	
TH	0.59**	0.45**	0.29**	–0.15*	0.07	–0.17*	–0.05	–0.02	0.28**	0.19**

* $p < 0.05$; ** $p < 0.01$.

were farmers' fields in drier areas, with less than 0.5 t ha^{-1} of grain, a very short crop and a very low harvest index.

The phenotypic correlation coefficients between grain yield of all the 208 entries measured in the different locations and the two research stations (Table 2) were generally low. Twenty out of the 55 correlation coefficients were significant and five of these were negative. The highest positive correlation coefficients were found between Tel Hadya and the three highest yielding farmer locations; by contrast, most correlations between the high yielding locations and the low-yielding locations and some correlation coefficients between low-yielding locations were negative.

Selection between types of germplasm

The breeder selected significantly more lines than the farmers in all locations (Table 3), presumably as a consequence of a different selection procedure.

The results of the G-test for goodness of fit, (summarized in Table 4) reveal that on station the breeder selected the same proportions of fixed lines and segregating populations, while on farmers' fields he showed a preference for segregating populations. Farmers had different preferences, although the total number of selected fixed lines and segregating populations was the same. In farmers' fields, only the selections of one farmer deviated significantly ($p < 0.05$) from the expected ratio between fixed lines and segregating populations. Although there are some specific preferences, in the majority of cases there were no significant differences between fixed lines and segregating populations, and this is also confirmed by the results of the group selection.

In the case of modern germplasm and landraces, breeder's selection was strongly affected by the location, with modern breeding material preferred in Tel Hadya, and landraces preferred in Breda. In farmers' fields, the breeder selected significantly more modern germplasm in two of the highest yielding locations (Ibbin and Ebla) and more landraces in all the others, but only in two cases the G-test was significant. Therefore, the preference of the breeder changed with the location, but there was no indication of an overall preference for one type of germplasm or the other. Farmers selected more landraces than improved germplasm in Breda, whereas at wetter Tel Hadya station eight farmers selected more modern germplasm than landraces (like the breeder). In farmers' fields, two farmers (from two of the highest-yielding locations) selected more modern germplasm and four (from low-yielding locations) more landraces. Both the test for heterogeneity, the pooled test and the total were significant (data not shown), indicating that this set of selections, no matter how they are grouped, deviate strongly from the expectation based on random selection. The strong preference for landraces in farmers' fields is also evident from the results of group selection, with only one farmer preferring modern breeding material.

The selections made by the breeder and by the majority of the farmers indicate a strong and nearly unanimous preference for two-row types in Breda. In Tel Hadya, the two farmers from two favorable locations selected more six-row than two-row, four farmers selected more two-row types, and the breeder did not show any preference. In farmers' fields, the breeder had a strong preference for two-row types in every

Table 3. Breeder's and farmers' selections[a] in each of the nine locations

Location	Selected by	Type of germplasm[b]									
		Total	Fix	Seg	Mod	Land	6R	2R	W	M	B
lbbin	Farmer	11	6	5	11	0	16	2	7	0	0
	Breeder	73	38	32	53	19	28	37	39	0	53
Ebla	Farmer	11	8	2	9	2	12	3	6	0	5
	Breeder	64	32	29	40	22	14	36	32	11	39
Tel Brak	Farmer	13	7	6	3	9	0	8	4	4	32
	Breeder	74	27	45	34	37	14	42	37	26	36
Jum El-Aswad	Farmer	9	2	7	0	8	0	6	5	0	5
	Breeder	71	26	43	28	40	12	41	34	16	50
Baylonan	Farmer	6	4	2	0	6	0	4	0	4	26
	Breeder	82	38	41	29	49	16	47	34	63	57
Al Bab	Farmer	11	6	5	0	10	0	7	4	7	11
	Breeder	71	22	47	22	45	2	44	30	63	36
Melabya	Farmer	10	5	5	3	7	2	6	4	4	11
	Breeder	66	25	39	24	39	6	40	29	32	50
Bari Sharki	Farmer	14	4	10	3	10	0	9	8	4	5
	Breeder	91	27	62	37	50	12	54	44	47	39
Sauran	Farmer	10	2	8	5	5	0	6	6	4	0
	Breeder	105	41	61	51	50	20	60	48	74	50

[a] Except for the totals, the other data are the percent of the total number of lines of that group in the 208 entries.
[b] Fixed (Fix) or segregating (Seg), modern (Mod) or landraces (Land), six- (6R) or two-row (2R), white-seeded (W), black-seeded (B) or mixed for seed color (M).

location except Ibbin where the difference between the frequency of two-row and six-row was not significant. The two farmers from two favorable locations selected more six-row types similarly to what they did in Tel Hadya, while other four farmers selected only two-row types. The farmers involved in group selection also had a strong preference for two-row types. The overall picture is a general preference for two-row types with few exceptions represented by farmers in favorable conditions.

We did not observe a strong preference for seed color even in the case of the selection in farmers' fields, where farmers inspected the seed before making their final selection. However, in those cases where the G-test was significant in Breda and in farmers' fields, it was caused by a preference for black-seeded types. This was the case of the two sites, Tel Brak and Baylonan, located in areas where farmers have a strong preference for black-seeded barley. The preference for black seeded types also appears in the selections of the farmers groups, where 7 of the 11 significant differences in favor of the black seeded types come from the group of farmers selecting in Bylounan. In Tel Hadya and Breda the farmers did not see dry seed. The breeder did not show, overall, any preference for seed color.

The results suggest that, when the germplasm is classified into broad categories, for some contrasts such as modern and landraces, the selection seems to be mostly environmentally driven, i.e. the role of the selection environment is more important than the role of who does the selection. In other words decentralization seems to play a more important role than participation. For other categories, such as two-row and six-row types there is a much more uniform preference across target environments and the selection environment plays a less important role, even though six rows were systematically preferred by two farmers in high rainfall environments.

In the case of fixed lines and segregating populations, there was no specific preference. For seed color, a trait often reported by farmers as important, the preference was not as strong and uniform as expected, and there was a predominance of situations where the frequencies of selection of the different seed colors did not deviate significantly from a random preference. In those cases where a clear preference was expressed it

Table 4. Number of times, or thick (√) in the case of the breeder's selection on station, the G-test was significant or not significant (n.s.) when applied to the frequency of selection of four types of germplasm (fixed or segregating, modern or landraces, six-row or two-row, white-seeded, black-seeded or mixed for seed color) done by a breeder and farmers in farmers fields and research stations

Selection done by	Location[a]	Fixed	Segregating	n.s.	Modern	Landraces	n.s.	Two-row	Six-row	n.s.	White	Mixed	Black	n.s.
Breeder	TH			√	√					√	√			
	BR			√			√	√						√
	FF		5	4	2	2	5	8		1	1			8
Farmers	TH	2	2	5	8		1	4	2	3	1			8
	BR	3	1	5		6	3	7		2			3	6
	FF	1		8	2	4	3	5	2	2			2	7
Groups	FF	5	6	30	1	28	12	28		13	2	4	11	24

[a] TH = Tel Hadya; BR = Breda; FF = Farmer field.

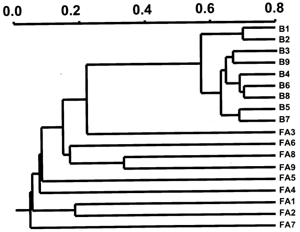

Figure 1. Dendogram based on cluster analysis of the selections of the nine host farmers and of the breeder in farmers' fields (FA = farmer, B = breeder). Individual farm locations are indicated with the location code used in Table 1.

was more often for the black seeded than for the white seeded types.

Selection of individual lines

1. Selection by farmers and breeder on farm

Figure 1 shows the dendogram of the nine host farmers and of the breeder based on cluster analysis of their selections in the nine farmers' fields. There was a high degree of similarity among the selections done by the breeder in the various farmers' fields, with Dice coefficients always higher than 0.57, and a much lower degree of similarity among the selections done by the farmers in their fields, with Dice coefficient always lower than 0.33. Also there was little similarity between the selections done by the breeder and the farmer in the same field. This is certainly a reflection of how selection was done and of the large difference in the number of entries selected by the breeder and the farmers (Table 3). The large dissimilarity between the lines selected by farmers in the different locations should result in a higher diversity left in the breeding material after one cycle of selection done by the farmers than after one cycle of selection done by the breeder. These data show that at the level of individual line selection, decentralized breeding can give different results depending on whether it is done by farmers or the breeder. This does not contradict the evidence presented earlier about the environmentally driven selection in the case of landraces and modern germplasm. Even though there was agreement on which type of germplasm performed better in a given

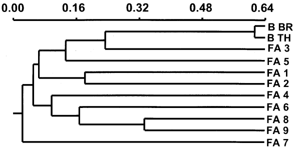

Figure 2. Dendogram based on cluster analysis of breeder's selections in Tel Hadya (B TH) and Breda (B BR) and of farmers' (F) selections in their own fields. Individual farm locations are indicated with the location code used in Table 1.

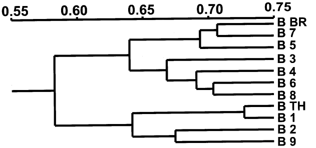

Figure 3. Dendogram based on cluster analysis of breeder's (B) selections in farmers' fields, in Tel Hadya (TH) and Breda (BR). Individual farm locations are indicated with the location code used in Table 1.

environment, the actual lines selected within that type of germplasm were different.

2. Selection by farmers in their fields and by the breeder in the research stations

There was much more similarity between the lines selected by the breeder in Breda and Tel Hadya than between these and the lines selected by the farmers in their fields (Figure 2). This would suggest that either Tel Hadya and Breda do not represent any of the environments sampled with the nine locations, or that the selection criteria used by the breeder are very different from those used by any of the farmers, or a combination of the two. It underlines that the breeder may identify on station lines which are very different from those preferred by the farmers in their fields.

3. Selection by the breeder in the research stations and in farmers fields

There was large similarity between the selection done by the breeder on station and on farm (Figure 3) with similarity coefficients equal or greater than 0.58. Selections made in Tel Hadya tend to cluster together with the selections at some of the other high yielding locations such as Ibbin, Ebla and Sauran. Selections

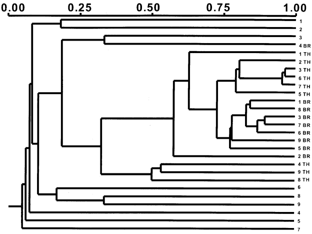

Figure 4. Dendogram based on cluster analysis of the selections of the nine host farmers in Breda (BR), in Tel Hadya (TH) and in their own field. Individual farmers are indicated with the location code used in Table 1.

made in Breda, by contrast, tend to cluster together with most of the low yielding locations. Among those is included Tel Brak which, as mentioned earlier, is the only high yielding location where the black seeded landrace is preferred to the white seeded landrace. This comparison emphasizes both the need for decentralized selection and its limits.

4. Selection by farmers in research stations and in their fields

When we compared farmers' selections in Tel Hadya, in Breda and in their own fields (Figure 4), the similarity among the selections done in Breda was greater than among the selections done in Tel Hadya, while, as already shown in Figures 1 and 2, there was little similarity among the selections from farmers' fields. In Breda, with the exception of the farmer from Jurn El-Aswad (code 4), most of the farmers' selections tend to cluster together. In Tel Hadya, there was similarity between the selections done by six of the nine farmers (1, 2, 3, 5, 6, and 7) while farmers 4, 8 and 9 seem to be less similar among themselves and with the others.

The lowest degree of similarity was found among the selections done by the farmers in their own fields. The Dice coefficients were always very low and it was not possible to identify a single cluster, either between selections in different farmers' fields, or between selections in farmers' fields and either Breda or Tel Hadya.

The low similarity between the lines selected by the individual farmers in their fields is confirmed by the fact that none of the lines selected by all the farmers in Breda was in common with the lines selected

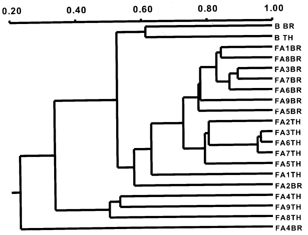

Figure 5. Dendogram based on cluster analysis of the selections of the nine host farmers and of the breeder in Tel Hadya and in Breda (FA = farmer, B = breeder, TH = Tel Hadya, BR = Breda). Individual farmers are indicated with the location code used in Table 1.

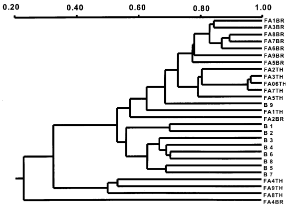

Figure 6. Dendogram based on cluster analysis of farmers' selections in Tel Hadya and in Breda and of breeder's selections in the farmers' fields (FA = farmer, B = breeder, TH = Tel Hadya, BR = Breda). Individual farmers are indicated with the location code used in Table 1.

by all the farmers in Tel Hadya. The majority of the lines selected by every farmer in Breda were landraces while the number of white and black seeded types was nearly the same.

The lines selected by every farmer at Tel Hadya were all two-row, the majority were improved with white seed and only two were landraces with black seed.

5. Selection by the breeder and the farmers in the research stations

Selections on research stations tend to be much more similar than selections in farmers' fields (Figure 5). Most of the farmers' selections in Breda (except for the two farmers from Ebla and Jurn El-Aswad) clustered together with similarity coefficients around 0.8. The farmers' selections in Tel Hadya formed one cluster with high similarity coefficients including six farmers, while the selections made by the other three were less clearly associated.

Breeder's selections in Breda and Tel Hadya were more similar than expected, given the differences between the two research stations. Most similarity coefficients relative to breeder and farmers selections are considerably higher than those shown in Figure 2. (selection by farmers and breeder in the farmer fields) and of the same order of magnitude of the similarity coefficients of breeder's selections in Breda. The breeding material selected by farmers on station (particularly in the dry research station) appears more similar than the breeding material selected by farmers in their fields. This shows once again the influence of the environment in making the selections more or less similar, and hence the advantages of decentralized selection.

6. Selection by the breeder in the farmers' fields and by the farmers in the research stations

The dendogram resulting from the diversity coefficients between the selections made by the breeder in the farmers' fields and those made by the farmers in the research stations (Figure 6) shows two main clusters representing the farmers' selections in Breda, which includes all farmers except two (Ebla and Jurn El-Aswad), and the breeder's selections in farmers' fields, respectively. The selections of six farmers in Tel Hadya (1, 2, 3, 5, 6, 7) clustered together with most of the farmers' selections in Breda, while the remaining three did not show any particular pattern.

When the same similarity analysis was applied to the group selection, the results indicated that the selections of the host farmers did not show any particular similarity or dissimilarity pattern which makes them distinct from those of the other farmers. This would suggest that the relationships between centralized and decentralized selection, and between the selection done by the farmer and by the breeder, were unaffected by the choice of a particular farmer as host farmer, at least in five of the nine locations.

In total 42 different lines were ranked among the best 15 in the five locations. The majority (38, or 90%) were ranked among the best 15 only in one or two locations. Those ranked among the best 15 more often, were either derived from crosses with Syrian landraces or were the local varieties (purchased from the participating farmers) used in the trials.

Table 5. Actual selection criteria used by farmers and breeder

Farmer	Farmers' field	Tall plants, large kernels, high grain yield and high biomass
	Tel Hadya	Lodging resistance, large kernels, high grain yield and high biomass
	Breda	Good early growth vigor, high tillering, tall plants, large kernels, high grain yield
Breeder	Farmers' field	Long spikes, tall plants, large kernels, high grain yield and high biomass
	Tel Hadya	Dark leaf color, lodging resistance, large kernels, high grain yield and high biomass
	Breda	Large kernels and high grain yield

Table 6. Grain yield and total biomass of the lines selected by the farmers and by the breeder in each of the nine farmers' fields

Location	Grain yield (kg ha^{-1})			Biomass (kg ha^{-1})		
	Farmer	Breeder	Δ^a	Farmer	Breeder	Δ^a
lbbin	4615***	3971***	n.s.	10687**	9686***	n.s.
Ebla	3498*	3199**	n.s.	8743	8233	n.s.
Tel Brak	4235	4020*	n.s.	8729*	8036	n.s.
Jurn El-Aswad	2049*	1724**	n.s.	10535**	8429*	n.s.
Baylonan	454*	324	n.s.	3198	2816	n.s.
Al Bab	649***	488***	***	2272***	1787***	***
Melabya	915	920***	n.s.	4127**	3246*	n.s.
Bari Sharki	1366*	1129	n.s.	5276	4708	n.s.
Sauran	2561	2654	n.s.	6796	7257	n.s.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ relative to the comparisons with the population mean.
[a] comparison between breeder's and farmers' selections based on t-test for samples of unequal size.

Actual selection criteria

Actual selection criteria (as opposed to declared selection criteria) were considered to be those traits for which the mean of the selected lines differed significantly ($p < 0.05$) from the mean of the population of 208 lines. Arbitrarily, we decided that a trait was used as an actual selection criteria if at least four farmers (or in four farmers fields in the case of breeder's selections), the mean of that trait in the selected lines was significantly different from the mean of the original population. The criteria actually used for selection by at least four out of nine farmers and by the breeder are summarized in Table 5.

Characters not included in the list are not necessarily unimportant to either the farmer or the breeder. A number of traits could have been changed only slightly in one cycle of selection and therefore they may have remained undetected in this analysis.

Both grain yield and total biomass were the selection criteria most commonly used by both the breeder and the farmer together with kernel size. The most remarkable result (Table 6) was that farmers were effective in identifying high yielding entries both in their fields (the lines selected in 6 out of the 9 locations had a significantly higher average grain yield than the population mean) and even more so in the experiment stations (the lines selected by all the nine farmers in Tel Hadya and by eight of the nine farmers in Breda

Table 7. Plant height (cm) of the lines selected by the farmers and by the breeder in each of the nine farmers' fields

Location	Population	Farmer	Breeder	Δ^a
Ibbin	102	105	102	n.s.
Ebla	98	107**	97	***
Tel Brak	88	85	86	n.s.
Jurn El-Aswad	45	57***	48*	*
Baylonan	46	48	50**	n.s.
Al Bab	33	43***	36***	**
Bari Sharki	52	62***	55*	**
Sauran	69	67	69	n.s.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ relative to the comparisons with the population mean.
[a] difference between breeder's and farmer's selections based on t-test for samples of unequal size.

Table 8. Frequency[a] of the top yielding 20 lines in each of the 9 farmers fields among the selections made by the breeder and the farmers in farmers' fields and research stations

Location	Selection done by					
	Farmer in his field	Breeder in farmer field	Farmer in Tel Hadya	Farmer in Breda	Breeder in Tel Hadya	Breeder in Breda
1	36	21	18	3	16	11
2	18	17	12	14	17	9
3	31	19	2	9	7	11
4	33	23	5	39	11	19
5	33	15	0	13	13	9
6	82	18	9	18	7	15
7	30	15	10	7	9	9
8	36	17	7	11	9	11
9	0	11	19	20	13	8
Means[b]	33.3 a	17.2 b	9.1 c	15.0 bc	11.3 bc	11.1 bc

[a] calculated on the number of selected entries.
[b] means followed by the same letter(s) are not significantly ($p < 0.05$) different.

had a significantly higher average grain yield than the population mean). The higher effectiveness on station could be explained by the higher precision of the trials, but one should also remember that modalities of selection were not the same. The breeder's selections were also significantly higher yielding than the population mean in 6 out of the 9 farmers fields and in the two experiment stations. The lines selected by the farmers and by the breeder in the 9 farm locations never differed significantly in grain yield with the exception of Al Bab, where farmers' selections yielded significantly ($p < 0.001$) more grain and more biomass than breeder's selections.

Farmers' and breeder's selections were taller than the population mean (Table 7) in the farm locations where the crop was very short (Jurn El-Aswad, Al Bab and Bari Sharki) with the farmers' selections even taller, significantly, than the breeder's selections in these dry locations. Thus plant height may be considered as one of the traits for which both decentralized selection and farmer selection are important.

Effectiveness of selection for grain yield

The farmers were remarkably successful in identifying the highest yielding lines in their fields with the only exception of the farmer from Sauran (Table 8). The breeder was able to identify a higher number of high yielding lines by selecting a total number of entries which was much higher than the farmer (see Table 3), hence the lower percentage as compared with farmers.

The effectiveness of selection done by farmers in their fields was significantly ($p < 0.05$) the highest, followed by the selection done by the breeder in farmer fields. This gives a measure of the advantage of farmer participation over decentralized-non participatory selection. The selection done by the farmers in Tel Hadya had the lowest effectiveness, significantly lower than selection done on farmers' fields, but not different from selection done on station by the breeder.

The frequency of the 20 highest yielding entries among the breeder's and farmers selections in Tel Hadya was significantly ($p < 0.05$) lower than the frequency of the 20 highest yielding entries among the breeder's and farmers selections in Breda (Table 9). The higher effectiveness in Breda, where the differences between entries were much more obvious at the time the selection was made, is more evident in the farmers' selections than in the breeder's selections.

In the five locations where we conducted group selection there were various levels of selection efficiency, as defined earlier (Table 10). The frequency of the 20 highest yielding entries among the farmers' selections was the highest in Al Bab followed by the other 3 low-yielding locations (4, 5 and 8). Sauran, which was the only high yielding locations where group selection was conducted, had the lowest frequency of the 20 highest yielding entries included among the selections. The host farmer in Sauran, who in the final selection did not select any of the 20 top yielding entries (Table 8), included 12.5% of them in his visual selection done at the time of the group selection.

Table 9. Frequency of the top yielding 20 lines in the two research stations among the selections made by the 9 farmers and by the breeder in the research stations

Location	Selection done by										Means[a]
	1	2	3	4	5	6	7	8	9	Breeder	
Tel Hadya	6	12	8	14	8	11	14	15	10	14	11.1 b
Breda	22	38	21	22	13	21	21	32	15	16	22.1 a

[a] means followed by the same letter(s) are not significantly ($p < 0.05$) different.

The data indicate that, in general, farmers' ability to identify the highest yielding lines is higher in stressful environments than in relatively favorable environments.

Discussion

Before drawing any conclusion from the work presented in this paper, it must be clear that what has been described is not yet participatory plant breeding but an experiment on participatory plant breeding. As such, the main conclusion of this work is that formal plant breeding has nothing to loose and much to gain from farmers' participation.

In fact, one cycle of selection conducted by farmers in their own fields, with no assistance from researchers, has resulted in a wider diversity of selected lines in comparison with breeder's selections, has captured the advantages of decentralized selection together with those associated with users' perception, and has identified a proportion of the highest yielding entries comparable (or greater) with that of the breeder. In terms of efficiency, the farmers were able to select visually for high yield, particularly under stress conditions, both in their fields and at a research station. The selection criteria used by the farmers were neither new, nor unusual or unexpected.

The experiment has also revealed that the farmers in the project area have reacted enthusiastically, and in some cases they have requested to extend the experiment to other crops even though they received no compensation for the additional work required by the participation. This would suggest that the main obstacle to implement participatory plant breeding is the breeder's attitude rather than the farmers' interest or skills.

The major limitation to generalizing information of the type presented in this paper is that it is affected by the personality of the individual participants, and this applies to the farmers as well as to the breeder. In our experiment, the use of group selection seems to exclude any large bias associated with the host farmers, at least in those locations where both individual and group selection could be compared. However, the bias associated with the selection done by an individual breeder is inevitable in experiments on participatory plant breeding and is the same type of bias which affects formal breeding programs. In fact, a breeding program on any given crop is typically conducted by either one professional breeder with a number of technical assistants, or by a team of professional breeders all following the dogmas of the 'prima donna' of the team. The strategies, methodologies and techniques used in formal breeding programs are therefore very individual in nature and, as a consequence, all attempts to compare farmers and breeders selection have to live with this bias.

Table 10. Frequency of the top yielding 20 lines among the selections made by the farmers during group selection in five farmers' fields

Farmer	Selection done in				
	4	5	6	8	9
1 (Host)	24	20	20	14	13
2	26	12	39	20	8
3	16	16	22	22	17
4	16	16	50	13	5
5	2	24	40	23	11
6	25	16	27	18	16
7	19	17	36	20	10
8	14	18	50	31	6
9	–	–	–	21	–
Mean[a]	19.9 b	17.2 b	35.5 a	20.3 b	10.7 c

[a] means followed by the same letter(s) are not significantly ($p < 0.05$) different.

Comparison with other participatory plant breeding work is also difficult because the way in which farmers respond to the possibility of making choices vary with the crop, its uses and with the cultural and social environment. This will make it difficult to build a 'generalized methodology for PPB'. However, one conclusion which seems common to other PPB work (see for example Sthapit et al., 1996) is that breeder's selection, both on station and in farmers fields leads to more uniform breeding material than farmers' selection in farmers fields, but not to higher yields.

This work demonstrated that it is possible to organize a plant breeding program in a way that includes farmers as major actors in the selection, testing and multiplication of new cultivars. After all, participatory plant breeding recognizes that regardless of whether the breeder likes it or not, are the farmers who ultimately decide whether or not to adopt a new variety, and reduces the chances of developing cultivars that for reasons unknown or overlooked by the breeder are not acceptable to farmers. Participatory plant breeding may be the only possible type of breeding for crops grown in remote regions, for crops for which a high level of diversity is required within the same farm, or for those considered as minor crops and therefore neglected by formal breeding.

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