Decentralized-Participatory Plant Breeding: Adapting Crops to Environments and Clients

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Introduction

In recent years there has been an increasing interest towards participatory research in general, and towards participatory plant breeding in particular. Following the early work of Rhoades and Booth (1982), scientists have become increasingly aware that users' participation in technology development may increase considerably the probability of success for the technology.

In the case of plant breeding, the concept of participation is often associated with the concept of decentralization, defined as selection (not testing) in the target environment(s), and decentralized-participatory plant breeding has been proposed as a strategy to reach those areas and those farmers which have been so far bypassed by the benefits of the so called “formal breeding” by exploiting specific adaptation not only to various physical environments but also to various users (Ceccarelli et al., 1996).

Social scientists have been the first to experiment with various methodologies of participatory research, while in general biological scientists have been slower in accepting this innovative way of conducting research. Even now, in the case of participatory plant breeding (PPB), who either experiment it or practice it. Therefore, the main objective of this paper is to discuss decentralized-participatory plant breeding from a plant breeding, rather than from a social science perspective.

Wide vs Specific Adaptation

A fundamental problem in plant breeding is the relationship between selection and target environment. As Falconer (1952) pointed out, direct selection (i.e. selection in the target environment) is always the most efficient. In the case of indirect selection, selection efficiency decreases as the selection environment becomes increasingly different from the target environment, and Genotype by Environment (GE) interactions limit the efficiency of breeding programs. Plant breeders can either avoid GE interactions by selecting material that is broadly adapted to a range of target environments, or exploit them by selecting a range of material, each adapted to a specific target environment (Ceccarelli, 1989).

The issue of selection for broad and specific adaptation has been debated since the early twenties (Hayes, 1923; Engledow, 1925) and it is still highly controversial. Among the causes of the controversy is the confusion between adaptation over time and adaptation over space, even though the distinction is of fundamental importance. It can be argued that wide adaptation over time (also defined as stability) is much more important to farmers than wide adaptation over space. The latter is, for obvious reasons, the major concern of seed producer. Other two causes of the controversy are the range of environmental variation sampled and the type of genetic (or breeding) material being used, and most of the studies comparing the two strategies are biased either because they use a narrow range of environments, or because breeding material selected for specific adaptation is not included.

One of the most recent examples of using a narrow range of environments is on two-row barley in Canada (Atlin et al., 2000) where the ratio between the lowest (nearly 3 t/ha) and the highest yielding environment is 1.8, and where, not surprisingly, no crossover interaction was found. On the other hand, most of the studies supporting the concept of breeding for wide adaptation, counting on the so called “spillover effect” in marginal environments from selection conducted in optimal or sub-optimal environments, are based on comparisons between modern varieties (MV) and farmer varieties (FV). Since few breeding programs have conducted enough breeding cycles under marginal conditions to achieve measurable gains, studies comparing MV selected for favorable environments and MV selected for unfavorable environments are few. These invariably show repeatable crossover interactions (Ceccarelli, 1996).

Breeding for specific adaptation is particularly important in the case of crops predominantly grown in unfavorable conditions, because unfavorable environments tend to be more different from each other than favorable environments (Ceccarelli and Grando, 1997). Furthermore, unfavorable environments tend to produce repeatable cross-over interactions (Ceccarelli, 1989; 1996). Breeding for specific adaptation to unfavorable conditions is often considered an undesirable breeding objective because it is usually associated with a reduction of potential yield under favorable conditions. This issue has to be considered in its social dimension and in relation to the difference between adaptation over space vs. adaptation over time: for example Australian farmers prefer maximizing yield in favorable years, while for North African and Near East farmers yield in very poor years is more important.

Selecting for specific adaptation also has the advantage of adapting cultivars to the physical environment, and hence is more sustainable than other strategies which rely on changing the environment to fit new cultivars adapted to more favorable conditions. When crossover GE interactions are present, selection for specific adaptation has to be based on decentralized selection (Falconer, 1981; Simmonds, 1991). 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 increases if we consider that environment is not only climate, soil, agronomic practices, farming system, etc., but also people leaving in that physical environment, their perception of risk associated with yield variation over time, their uses of the crop, and the consequent importance of quality traits even if neutral in terms of adaptation to the physical environment. Clearly, selection for specific adaptation to unfavorable conditions needs a larger sample of selection environments than selection for favorable environments.

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, 2000). Although decentralized selection and farmers' participation are unrelated concepts, the acceptance of the former as a breeding strategy almost inevitably leads to the acceptance of the latter as a tactical necessity. It is worth mentioning that, although farmer participation is often advocated on the basis of equity, there are sound scientific and practical reasons for farmer involvement to increase the efficiency and the effectiveness of the breeding program. It is also expected that decentralized-participatory plant breeding could be particularly effective in those situations where seed is supplied by the informal seed system as it is the case for several crops in marginal environments.

The idea of farmers participation in technology development, including plant breeding, is neither new nor revolutionary (Rhoades and 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.

Participatory Selection and Participatory Breeding

The majority of the participatory plant breeding work published on referee journals would be better defined as participatory variety selection (PVS) (Witcombe and Joshi, 1996). In PVS, farmers either select between a limited (generally between 10 and 30) number of varieties on station, and then grow in their fields those they selected, or are given a number of varieties (also between 10 and 30, but sometimes just one) to test in their own fields. PVS has been very successful both in facilitating adoption by poor farmers in marginal environments, not previously reached by formal plant breeding, and in understanding farmers' preferences (Maurya et al., 1988; Sperling et al., 1993; Joshi and Witcombe, 1996). However, PVS lacks the cyclic nature of plant breeding with a continuos flow of genetic material from one stage to next, and it is not clear from the literature on PVS whether, how and when a farmer or a farmer community who have practiced PVS, will have another chance of participating in variety selection. Therefore, many examples of PVS are a linear process and could be described as sporadic, episodic or occasional participation. Also, to be successful, PVS has to assume that at least some of the varieties produced by a centralized-non participatory breeding program are adapted to the target environment and meet farmers' requirements.

The best examples of participatory selection conducted for a number of cycles and starting from early segregating populations, are those reported by Sthapit et al. (1996) on rice, by Kornegay et al. (1996) on common bean, and by Ceccarelli et al. (2000) on barley. These are closer to PPB because farmers are exposed to breeding material at a much earlier stage than in PVS and for a number of cycles of selection, but they are not yet PPB. In fact, even in these cases, the difference with a participatory plant breeding program is that farmers are not exposed to a continuous flow of germplasm, but only to a initial "flush" of segregating populations from which to select.

An important and obvious point to make is 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. In fact, low heritability, unsuitability of the germplasm, wrong choice of the selection environment, inappropriate selection methods, strong genotype x environment interactions, setting wrong objectives, all have a negative effect on selection efficiency and effectiveness no matter whether plant breeding is participatory or non participatory. However, the belief that participatory plant breeding is different from formal breeding is well rooted, and because most participatory work is sporadic, episodic or occasional, there is a substantial discussion on the issue of breeding methods for participatory plant breeding. Successful participatory plant breeding does not need special breeding methods (see also the point made above), but it is certainly true that some breeding methods are more suitable than others to be used in participatory plant breeding. It should also be remembered that farmers' skills almost inevitably improve in the course of a truly participatory plant breeding, and therefore there may be a need to adjust the breeding method as the participatory breeding program proceeds.

Eventually, one more point to make is that the fact that plant breeding has been historically unable to reach small and poor farmers in marginal environments as efficiently and as effectively as in the case of favorable environments (Zeigler, 1997) is not necessarily due to lack of participation, but often to the use of the wrong selection environment(s).

Issues in Participatory Plant Breeding

Nearly 50 examples of programs defined as "participatory plant breeding" with a variable degree of involvement of formal breeding programs and farmers have been recently described by Weltzien/Smith et al. (1999). They cover crops such as maize, chickpea, cowpea, beans, potatoes, rice, barley, pearl millet, sorghum and cassava, in Asia, Africa, Central and South America and in a variety of conditions, from the dry desert margins to high rainfall conditions, and from the lowlands to high altitudes. Many of these programs are relatively new, having started within the last 10 years, and have been working on a small scale. The degree of participation varies from mere consultation to addressing issues or problems identified by farmers.

The International Center for Agricultural Research in the Dry Areas (ICARDA) is involved in a number of participatory barley breeding programs in Syria, Egypt, Jordan, Tunisia, Morocco and Eritrea and in one program on both barley and lentil in Yemen.

The results and information generated from both PVS and PPB experiments on various crops will be used to discuss some issues that are particularly relevant to plant breeders, namely:

1. Which type of breeding material and how much material farmers can handle
2. What is more important: decentralization or participation?
3. Is farmers' selection effective?
4. Are farmers' and breeder's selection criteria different?
5. Is decentralized-participatory plant breeding effective in enhancing/conserving biodiversity?
6. Is decentralized-participatory plant breeding effective in increasing/speeding-up adoption?

Quantity and type of breeding material

The amount of breeding material that can be evaluated in decentralized-participatory breeding programs is important to achieve some of the main objectives, particularly the adaptation to the physical, production and social environment, the enhanced adoption rate and the maintenance of biodiversity. Too many so called participatory programs are based on a very small number of fixed or nearly fixed lines, and it is not clear what is the difference between them and the final stages of variety testing conducted by any private or public formal breeding program.

There is a widespread and untested assumption that farmers are not able to examine, express a judgement and translate that judgement in a quantitative score on a large number of breeding lines. As shown in **Table 1**, the assumption on the amount of material that farmers are able to handle needs to be verified in each project, and the program should be designed accordingly. Similarly, plot size can be very different, and can also be very small, as in the case of Yemen where the breeding trials have to be accommodated within the limited space of the terraces. The cases quoted in Table 1 are all based on early segregating populations (F_2 or F_3 bulks) indicating that participation of farmers is feasible even at such an early stage of a breeding program.

Table 1. No. of villages, no. of lines, plot size used in different farmer selection projects conducted by ICARDA and number of farmers involved.

Country	No. of villages	No. of lines	plot size (m^2)	No. of farmers/village
Syria phase 1	9	208	12	5-9
Syria phase 2	8	200-400	12	6-11
Yemen	3	100	3	15-20
Morocco	6	30-210	4.5	6-15
Tunisia	6	25-210	4.5	10-20
Eritrea	3	155	3	10-12
Egypt	8	60	6	5

Comparison between decentralization and participation

Although the comparison between decentralization and participation is a crucial issue, only in very few cases this comparison has been made possible by conducting selection both on station and in farmers fields by both the breeder and the farmers. Results obtained in Syria and Yemen (**Table 2**) show that decentralization has the largest effect, as a consequence of large GE interactions of crossover type, and that in some cases participation adds a further gain in efficiency.

Table 2. Effectiveness (measured by the % of high yielding lines included among the selections) of different selection strategies in barley and lentil.

Type of Selection	Barley in Syria[1]	Lentil in Yemen
Decentralized - participatory	33.3a	32.8a
Decentralized - non participatory	17.2b	26.6ab
Centralized - participatory	11.3 bc	19.6bc
Centralized- non participatory	9.1 c	21.0bc

[1]Ceccarelli et al., 2000

Efficiency of farmer selection

One of the most classical data set on the efficiency of farmers' selection is the case of beans in Rwanda described by Sperling et al. (1993). As shown in **Table 3**, the varieties selected by farmers on station out yielded the locally grown mixtures 64 -89% of the time with yield increases up to 38%. By contrast, the breeders selections out yielded the local mixtures about 50% of the time but with considerably smaller yield increases.

Table 3. On-farm performance of varieties of bush bean selected from on-station trials by farmers and of varieties selected by breeders in Rwanda: A and B represent two cropping seasons (modified from Sperling et al., 1993).

Year	Number of trials	% of trials where new variety out yielded local mixture	Yield increase (%) of new variety over local mixture
		Farmer Selection	
1989A	11	73 ns	3.9 ns
1989B	19	89 **	33.4**
1990A	36	64 ns	12.9 ns
1990B	18	83 **	38.0**
		Breeder Selection	
1987A	131	51 ns	6.7 *
1988A	204	50 ns	2.6 ns
1988B	204	50 ns	7.6 *

*, ** differences significant at P < 0.05 and P < 0.01, respectively; ns, not significant

Similarly, in the case of barley in Morocco, farmers seem to be as able as the breeder in identifying the highest yielding entries both in term of grain yield and in terms of straw yield (**Table 4**).

Table 4. Farmer and Breeder's efficiencya in selecting early segregating populations of barley in Morocco.

Selection done by	Attribute	Farmers' Field				Research Stations	
		S. Boumahdi	Chemaia	Oued Zem	Zhiliga	Merchouch	J. Shaim
		Experiment 1 (30 lines in 2 replications)					
Farmer	Grain	0.20	0.21	0.33	0.30	0.25	0.20
Breeder	Grain	0.17	0.18	0.31	0.29	0.18	0.38
Farmer	Straw	0.18	0.28	0.24	0.23	0.22	0.17

Breeder	Straw	0.42	0.27	0.25	0.24	0.18	0.38
				Experiment 1 (50 lines in 2 replications)			
Farmer	Grain	0.16	-	-	0.29	0.50	0.14
Breeder	Grain	0.21	-	-	0.26	0.29	0.20
Farmer	Straw	0.34	-	-	0.30	0.07	-
Breeder	Straw	0.21	-	-	0.29	0.25	-

[a]Efficiency is expressed as the ratio between the number of high yielding lines (in parenthesis the efficiency of selection for straw yield) and the total number of lines selected.

Farmers' selection criteria

A common inefficiency in formal breeding programs is the selection and the release of varieties that do not meet farmers' requirements and needs, and that therefore are not adopted, particularly but not only, in the more marginal conditions.

Information about farmers' selection criteria is one of the most common outputs of PPB programs and some of the most common features emerging from various crops and various countries are the following:

1. usually farmers are interested in a wider range of traits or of combinations of traits than breeders expected. These are related to adaptation to various growing conditions but also to marketability. A typical example is provided by barley in the dry areas of Syria where farmers prefer genotypes which are tall even under severe drought (they can be harvested by combine even in dry years), with a soft straw (this is considered associated with palatability for sheep) and with black seed (the darker is the seed, the higher is the price).
2. although farmers nearly always rank yield as their most important selection criterion, they in fact select for several other traits above a minimum acceptable yield.
3. farmers' selection criteria vary according to the environment. An example is provided by pearl millet in India where poor farmers in poor growing conditions select for high tillering and small panicle size, while better-off farmers in better growing conditions select for low tillering and larger panicle size. In Syria, farmers in dry areas select tall barley varieties with soft straw and black seed in their farm, but short (lodging resistant) varieties on station (**Table 5**). The work on barley in Syria has shown that the environment affects much less the breeder's selection criteria as indicated by the similarity coefficients among the selections made by the same breeder in nine fields with mean yields ranging from less than 300 kg/ha to nearly 3700 kg/ha **(Fig. 1**). The figure also confirms the large differences between breeder's and farmers' selections in the same environment.

Fig. 1. Dendogram based on cluster analysis of the selections of nine farmers and of a breeder in farmers' fields (FA= farmer, B= breeder). Individual farm locations are indicated with numbers from 1 to 9. (From Ceccarelli et al., 2000).

Table 5. Tall or short? Plant height (cm) of barley lines selected by the breeder and the farmer in a research station (favorable environment) and in a farmer's field in a dry area, compared with the population mean with a t-test for samples of unequal size.

Selected by	**Selected at**	
	Research Station	Farmer field
Farmer	71.1*	45.1***
Breeder	71.8*	42.8*
Pop. Mean	77.5	39.6

*, *** differences significant at P < 0.05 and P < 0.001, respectively.

Effects of PPB on Biodiversity

One of the most common outcome of PPB program is that different farmers in different communities select different varieties (as shown for barley in Fig. 1), and there are examples (rice in Nepal, bean in Rwanda, and cassava in Colombia) of substantial increases in the number of different varieties grown by communities after one cycle of PVS program.

It is not easy to distinguish in the literature the effect of PPB and PVS on different levels of biodiversity, namely diversity within the same farm (more than one variety of the same crop in the same field), diversity within a community or an area (different farmers growing different varieties), and it is even more difficult to understand whether PPB can affect the choice between uniform and heterogeneous breeding material.

In barley, we found that decentralized-participatory selection may lead to the same decrease of diversity as centralized-non participatory selection. In our project in Syria, the initial population of 208 entries included 48% modern lines and 52 landraces. Two cycles of selection on station led to disappearance of the landraces (**Fig. 2**), but the same effect was observed in a farmer field located in area similar to the research station. By contrast, two cycles of selection in a dry site led to the opposite result, namely the disappearance of the modern germplasm. This data seem to suggest that farmer's selection may have the same effect on narrowing the biodiversity available in the original breeding material, but because different farmers select different material, the biodiversity over the total area is maintained or even increased.

Fig. 2. Change in the frequency of modern and landraces after two cycles of centralized-non participatory selection in a research station (favorable conditions) and two cycles of decentralized-participatory selection in a high rainfall (wet site) and in a low rainfall (dry site) location.

Selection conducted only in the stations not only could lead to discard lines performing well elsewhere, but also affects the total number of lines preserved after each cycle of selection. As shown in **Table 6**, the percent of lines after one cycle of decentralized - participatory selection is always among the highest; the major effect in the case on barley in Yemen is clearly the selection environment, with decentralized selection retaining more than twice the number of lines compared with the number retained by selection on station. However, in the other two cases, farmers' selection led to a larger percent of lines selected even on station (centralized-participatory selection), presumably as an effect of individual differences and of the different types required in the areas where the farmers are coming from. It is interesting to note that these effects where not due to the total number of selected lines, as the farmers always selected a lower number of lines than the breeder (Ceccarelli et al., 2000).

Table 6. Entries selected with four different strategies of selection in Syria on barley and in Yemen on barley and lentil in percent of the original population size.

Strategy of selection	Barley in Syria	Barley in Yemen	Lentil in Yemen
Centralized - non participatory	0.34	0.20	0.22
Centralized - participatory	0.61	0.24	0.40
Decentralized - non participatory	0.79	0.52	0.46
Decentralized - participatory	0.74	0.50	0.56

Effects of PPB on adoption

Although PPB and PVS programs are relatively recent, there are already some examples of impact. For examples there are cases where varieties preferred by farmers were identified in environments where no improved varieties have ever been available to farmers, such as the rice variety combining the frost tolerance of a landrace with the higher yield of a modern variety which has been adopted in the mountains of Nepal. A bean variety combining disease resistance with a desirable coat color has been adopted in northeastern Brazil before the variety could be formally recommended. Other examples are provided by rainfed rice varieties in India, potatoes in Ecuador, maize in Ethiopia, and, surprisingly, irrigated wheat and rice in Gujarat, in India, demonstrating that even in the areas where formal plant breeding has been particularly successful, farmer participation can identify desirable varieties at an earlier stage than in conventional breeding.

One of the best example of fast adoption through farmers' participation in variety testing (PVS), is the spreading of the rice variety Kalinga III in India. Seed of this variety, which has neither been recommended nor released, was initially made available to farmers in three villages in Rajasthan in 1993 through a farmer-managed participatory research trial. By 1997 in one of the villages 65% of the area was planted with Kalinga III, while the lowest adoption was about 20% of the area. The variety also spread to other villages (**Table 7**) with very high rates of spread, and with the number of villages growing Kalinga III increased by a factor of 2.3 to 7.0.

Table 7. Ratea of spread of the rice variety Kalinga III from the three initial villages where the seed was distributed (modified from Witcombe et al., 1999).

Spread	Rate of increase in number of villages		
	1994-1995	1995-1996	1996-1997
From first harvest	4.7	2.3	2.5
From second harvest	-	7.0	3.0

[a] factor by which the number of villages increase (for example 2 is a doubling in number)

There are other examples of very rapid adoption of new varieties by participating farmers. Much of the success depends obviously on seed availability and also on the reaction of the formal system to allow varieties (or breeding lines) to bypass the official channels.

Conclusions

Most of the data on different types of farmer participation in selection suggest that there is little to lose and much to gain by involving farmers, and more generally the users, in the process of plant breeding.

Decentralized-participatory plant breeding should not be seen as "an alternative" type of plant breeding somewhat opposed to the formal plant breeding, but rather as an approach to specifically address situations such as marginal environments where GE interactions are repeatable and large, precluding the adaptation of one or few varieties, or where there is a variety of different requirements (quality, crop duration, management, etc). One specific advantage of decentralized participatory plant breeding is to rapidly adapt the crops to a changing agronomic management. Eventually, PPB could 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 crops locally important but globally considered as minor crops and therefore neglected by formal breeding.

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