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Decentralized-participatory plant breeding: an example of demand driven research

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Abstract It is widely recognized that conventional plant breeding has been more beneficial to farmers in high-potential environments or those who can profitably modify their environment to suit new cultivars, than to the poorest farmers who cannot afford to modify their environment through the application of additional inputs and cannot risk the replacement of their traditional, well known and reliable varieties. As a consequence, low yields, crop failures, malnutrition, famine, and eventually poverty still affect a large proportion of humanity. Participatory plant breeding (PPB) is seen by several scientists as a way to overcome the limitations of conventional breeding by offering farmers the possibility to choose, in their own environment, which varieties suit better their needs and conditions. PPB exploits the potential gains of breeding for specific adaptation through decentralized selection, defined as selection in the target environment, and is the ultimate conceptual consequence of a positive interpretation of genotype × environment interactions. The paper describes a model of PPB developed by The International Center for Agricultural Research in the Dry Areas and used successfully in several countries in West Asia and North Africa. Genetic variability is generated by breeders, selection is conducted jointly by breeders, farmers, and extension specialists in a number of target environments, and the best selections are used in further cycles of recombination and selection. Technically, the process is similar to conventional breeding, with three main differences. Testing and selection take place on-farm rather than on-station, key decisions are taken jointly by farmers and the breeder, and the process can be independently implemented at a large number of locations. The model also incorporates seed production. Farmers handle the initial phases, multiplying promising breeding material in village-based seed production systems. The PPB model is flexible; it can generate populations, pure lines, and eventually mixtures of pure lines in self-pollinated crops; as well as hybrids, populations, and synthetics in cross-pollinated crops. PPB has several advantages. New varieties reach the release phase much faster than in conventional breeding, and are better suited to farmers' needs and willingness to invest in inputs and management. Release and seed multiplication activities concentrate on varieties known to be farmer-acceptable. These advantages are particularly relevant to developing countries where large investments in plant breeding

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have not yielded returns, and many "improved" varieties developed through conventional breeding are not adopted by farmers. PPB also ensures that biodiversity is maintained or increased because different varieties are selected at different locations. In addition to the economical benefits, participatory research has a number of psychological, moral, and ethical benefits, which are the consequence of a progressive empowerment of the farmers' communities; these benefits affect sectors of their life beyond the agricultural aspects. In conclusion, PPB, as a case of demand driven research, gives voice to farmers, including those who have been traditionally the most marginalized such as the women, and elevates local knowledge to the role of science.

Keywords Decentralized selection · Genotype × environment interaction · Biodiversity

Introduction

Agricultural research has led to dramatic improvements in food supplies and crop productivity in many areas. But in marginal environments in developing countries, with high-poverty levels, the impacts have been far below expectations. This lack of impact could be due to the way many research programs are developed and implemented.

1. The research agenda is usually decided unilaterally by the scientists and is not discussed with the users.
2. Research programs are usually organized by discipline or by commodity, without an integrated approach. Even "interdisciplinary" research does not reflect the integration that exists at farm level.
3. There is a disproportion/unbalance between the large amount of technologies generated by agricultural scientists and the relatively small number of them actually adopted and used by the farmers.

When one looks at these characteristics as applied to plant breeding programs, most scientists would agree that:

1. Plant breeding has not been very successful in marginal environments and for poor farmers.
2. It still takes a long time (about 15 years) to release a new variety.
3. Many varieties are officially released, but few are adopted by farmers; by contrast farmers often grow varieties, which were not officially released.
4. Even when new varieties are acceptable to farmers, their seed is either not available or too expensive.
5. There is a widespread perception of a decrease of biodiversity associated with conventional plant breeding.

Participatory research in general, defined as a type of research in which users are involved in the design—and not merely in the final testing—of a new technology, is now seen by many as a way to address these problems. PPB in particular, is defined as a form of plant breeding in which farmers, as well as other partners, such as extension staff, seed producers, traders, NGOs, etc., participate in the development of a new variety. The objective is to produce varieties, which are adapted not only to the physical but also to the socio-economic environment in which they are utilized.

The objective of this paper is to illustrate some of the characteristics of PPB using examples from projects implemented by the International Center for Agricultural Research in the Dry Areas (ICARDA) in a number of countries.

Genotype × Environment Interactions And Breeding Strategies

Plant breeding is a complex process and in the majority of cases, the only notable exception being the breeding programs in Australia (Eglinton and Coventry, personal communication), only rarely takes place in farmers' fields. Most of the process takes place in one, or more often in a number of research stations, and all the decisions are taken by the breeders and collaborating scientists.

One of the main consequences is that a large amount of breeding material is discarded before knowing whether it could have been useful in the real conditions of farmers' fields, and the one which is selected is likely to perform well in environments similar to the research stations, but not in environments which are very different. This is because of Genotype × Environment (GE) interactions that, when they cause a change of ranking between genotypes in different environments (crossover interaction), are one of the major factors limiting the efficiency of breeding programs for more diverse marginal environments. An example of crossover GE interactions between research stations and farmers fields is given in Fig. 1. In both cases there was much more similarity between research stations than between farmers fields, and low or negative correlations between research stations and farmers fields.

In general, when different lines or cultivars of a given crop are evaluated in a sufficiently wide range of environments, GE interactions of crossover type seem to be very common (Ceccarelli et al. 2001) and we have argued (Ceccarelli 1989) that for crops grown in environments poorly represented by the research stations, this often results in discarding useful breeding materials. Figure 2 illustrates the dangers of discarding potentially useful material. The five highest yielding barley lines in a farmer's field in Senafe (Eritrea) out yielded the local check by 27–30%, but when tested on station, four showed a substantial *disadvantage* and one showed only a marginal advantage.

Significant GE interactions cannot be ignored. The alternatives are to avoid them by selecting material that is broadly adapted to the entire range of target environments, or to exploit them by selecting a range of materials, each adapted to a specific environment (Ceccarelli 1989). To select between these alternatives will require separate analysis of the two components of GE interactions, namely Genotype × Year (GY) and Genotype × Location (GL), the first of which is largely unpredictable, while the second, if repeatable over time, identifies distinct target environments (Annicchiarico et al. 2005, 2006).

Selection for specific adaptation to each target environment is particularly important in crops that are grown predominantly in unfavorable conditions, because unfavorable environments can be very different from each other, while favorable environments tend to be somewhat similar (Ceccarelli and Grando 1997). For example in Fig. 3, total GE was nearly 90% in the two dry locations (left), but less than 50% in the two high-rainfall locations.

In selecting for specific adaptation, we obtain cultivars that are adapted to the environments where they will be grown. This is more sustainable than other strategies which rely on modifying the environment to fit new cultivars adapted to more favorable conditions (Ceccarelli and Grando 2002).

The similarity between research stations observed in Fig. 1 and between high-rainfall

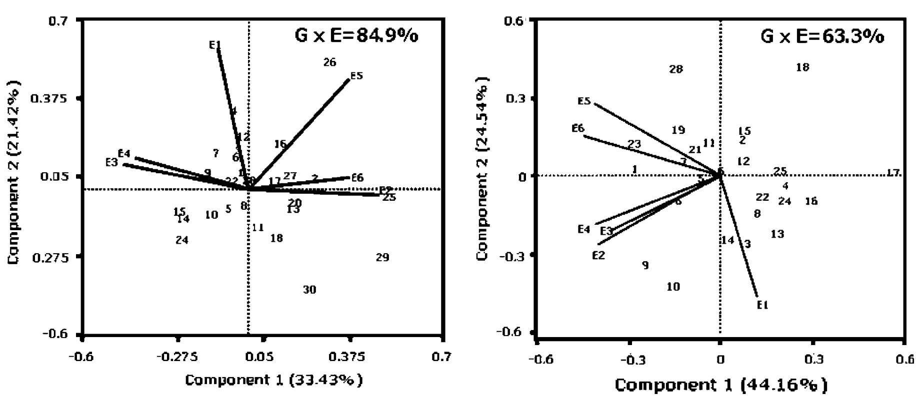

Fig. 1 *Left*: biplots of 30 barley genotypes grown at six locations in Morocco; two research stations (E3, E4) and four farmers' fields (E1, E2, E5, E6). *Right*: biplots of 25 barley genotypes grown at six locations in Tunisia; two research stations (E5, E6) and four farmers' fields (E1–E4). Genotypes are indicated by numbers and locations by vectors

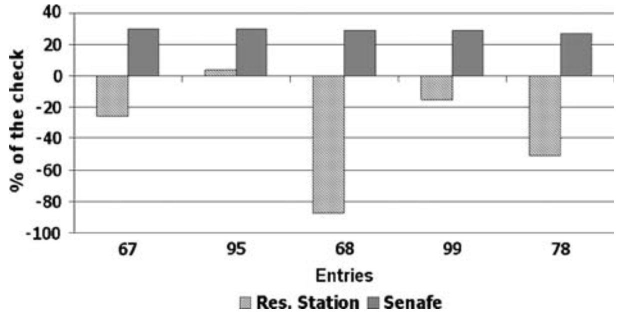

Fig. 2 Percentage yield superiority/disadvantage over local check of five barley lines at two locations in Eritrea: a farmer's field in Senafe and Halhale (40 km south of Asmara) research station

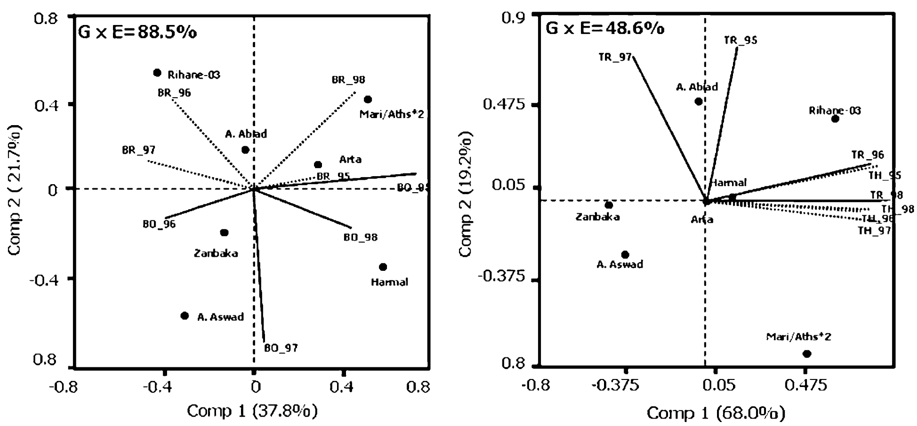

Fig. 3 Biplots of grain yield of seven barley cultivars grown for 4 years (1995–1998) in two dry locations, Bouider (*BO*) and Breda (*BR*) with a grand mean of 1.3 t/ha (*left*) and in two relatively wet locations, Tel Hadya (*TH*) and Terbol (*TR*) with a grand mean of 3.5 t/ha (*right*). Genotypes are indicated by numbers and locations by vectors

locations and years observed in Fig. 3 are likely to be also associated with the larger use of inputs (fertilizers, weed control, etc.,) common to both research stations and high-rainfall areas, which tend to smooth differences between locations and years.

Selection for specific adaptation, also known as decentralized selection, is based on direct selection in the target environment (Simmonds 1991). Selection theory shows that this approach is more efficient than breeding for wide adaptation because it exploits the larger heritabilities within each specific target environment (Annicchiarico et al. 2005). One serious limitation is the large number of potential target environments, differentiated not only in terms of climate but also in terms of farming objectives (sale versus household consumption), access to inputs, market opportunities, etc. Consequently a large number of selection sites will be needed, especially in unfavorable 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 1996).

Defining Decentralized-Participatory Plant Breeding

Although plant breeding programs differ from each other depending on the crop, on the facilities and on the breeder, they all have in common some major stages that Schnell (1982) has defined as ''generation of variability,'' ''selection,'' and ''testing of experimental cultivars.'' The process is illustrated in Fig. 4 (left) in the case of a self-pollinated crop.

A decentralized-participatory plant breeding (PPB) program (Fig. 4, right) is exactly the same process with three differences: (1) most of the process takes place in farmers' fields, (2) the decisions are taken jointly by the farmers and the breeder, and (3) the process can be implemented at a number of locations involving a large number of farmers evaluating different breeding materials.

In the following sections we describe a model of PPB that can be applied to self-pollinated crops. From a breeding point of view, this is only one of the several methods, which can be used, but it is based on three main concepts, which can be generalized to any PPB program:

1. The trials are grown in farmers' fields using farmer's agronomic practices (to avoid the GE interactions between research stations and farmers' fields).
2. Selection is conducted jointly by breeders and farmers in farmers' fields, so that farmers participate in all key decisions.
3. The traditional linear sequence Scientist ➡ Extension ➡ Farmers is replaced by a team approach with Scientists, Extension Staff, and Farmers participating in all major steps of variety development.

The model we will describe uses a bulk-pedigree method which consists of three cycles of selection between populations (cross-evaluation) followed, but not necessarily, by selection within superior cross (Ceccarelli and Grando 2005).

A Model of Decentralized-Participatory Plant Breeding

The model

The model of PPB we use in a number of countries has been described in details elsewhere (Ceccarelli and Grando 2005; Mangione et al. 2006). Crosses are made and the F_1 and F_2 generations grown on station. The bulks are then yield-tested on farmers' fields for 4 years (Fig. 5).

The activities in farmers' fields begin with the yield testing of early segregating populations in trials called Farmers Initial Trials (FIT), which are unreplicated yield trials of early segregating populations with systematic checks. The number of entries varies from about 50 in Egypt, to 75 in Eritrea and Algeria, to 160 in Jordan and Syria, and the total number of plots varies from 60 in Egypt, to 100 in Eritrea and Algeria and to 200 in Jordan and Syria. Plot size varies from 2 to 12 m^2.

Breeding materials are selected from the FIT, using the process described in the next section, and tested for a second year in Farmer Advanced Trials (FAT). The number of entries and checks varies from village to village and from year to year. Plot size is 10–45 m^2 depending on the country. There are multiple FATs within each village (the number depends on how many

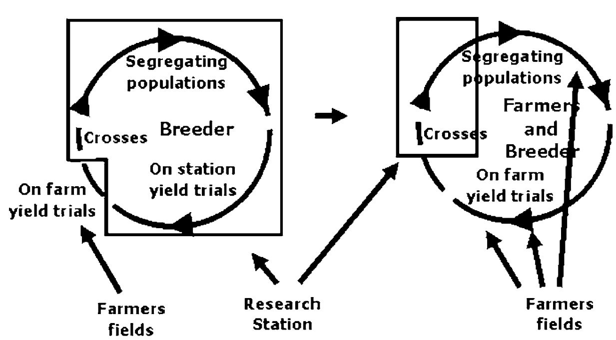

Fig. 4 Conventional plant breeding is a cyclic process that takes place largely within one or more research stations (*left*) with the breeder taking all decisions; decentralized-participatory plant breeding is the same process, but takes place mostly in farmers' fields (*right*) and the decisions are taken jointly by farmers and breeders

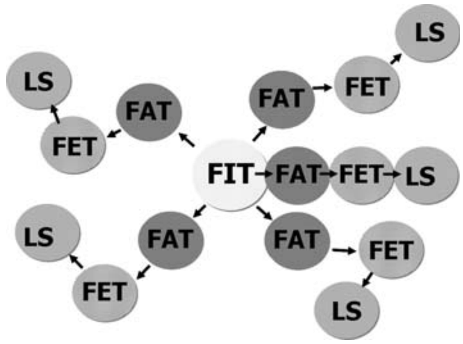

Fig. 5 A model of participatory plant breeding in one village: from the farmer initial yield trial (*FIT*), grown by one farmer, participatory selection identifies the lines grown in the farmers advanced yield trials (*FAT*) by more farmers (5 in the figure). The process is repeated to identify lines grown in farmer elite trials (*FET*) and in the initial adoption stage (*LS* or large scale trials). The model takes 4 years for the full implementation

farmers volunteer), all testing the same entries—-but under different soil types and management levels, because each farmer decides the rotation, seed rate, soil type (choice of field), amount, and time of fertilizer application, etc. During selection farmers exchange information about the agronomic management of the trials, and rely greatly on this information while selecting entries. Thus, breeding materials are being characterized for their responses to environmental or agronomic factors, early in the selection process.

The entries selected from the FAT are tested in the Farmer Elite Trials (FET), with a plot size twice as large as the FAT. After one more cycle of selection, farmers select a limited number of lines (usually less than five) which are planted on large scale (LS) in unreplicated plots (a few thousand m^2) as a first step in the adoption process.

The PPB trials (FIT, FAT, and FET) are identical to the Multi Environment Trials (MET) in a conventional breeding program with crucial advantages. Even when the MET are conducted in farmers' fields, as in Australia, there are still at least two major differences. (1) The primary objective of MET is to sample target physical environments, while PPB trials are meant to sample both physical and socio-economic environments including different types of users. (2) MET data are usually analyzed to estimate or predict the genotypic value of each line across all locations, while in PPB trials the emphasis is on estimating or predicting the genotypic value of each line over time in a given location.

Farmers' selection and data collection

At the time of selection, farmers are provided with field books to register both qualitative and quantitative observations. Farmers' preferences are usually recorded from 0 (discarded) to 4 (most preferred). Between 10 and 30 farmers participate, including (in some countries) women. In the case of illiterate participants scientists (or literate farmers) assist in recording the scores. Breeders collect quantitative data on a number of traits indicated by farmers as important selection criteria—growth vigor, plant height, spike length, grain size, tillering, grain yield, biomass yield, harvest index, resistance to lodging and to diseases and pests, cold damage, etc,—similar to yield trials in a conventional breeding program.

The data are processed as described under statistical analysis. The final decision of which lines to retain for the following season is taken jointly by breeders and farmers at a special meeting and is based on both quantitative data and visual scores.

In parallel to the model shown in Fig. 5, and in countries where varieties of self-pollinated crops can be released only if genetically uniform, pure line selection within selected bulks is conducted on station. The head rows will be promoted to a screening nursery only if the corresponding bulks are selected to the next stage. The process is repeated until there is enough seed to include the lines (as F_7) in the yield-testing phase (Ceccarelli and Grando 2005). Thus when the model is fully implemented, the breeding material, which is yield tested includes new bulks as well as pure lines extracted from the best bulks of the previous cycle. If a country has very strict requirements for genetic uniformity, only the pure lines will be considered as candidates for release.

Experimental designs and statistical analysis

For the first-stage FIT, with one host farmer per location, it is convenient to use an unreplicated design with entries arranged in rows and columns, with systematic checks every five or ten entries.

In the second and third level, the trials (FAT and FET) can be designed as α-lattices with two replications or as randomized complete blocks with farmers as replicates, or as standard replicated trials.

The data are subjected to different types of analysis, some of which were developed at ICARDA such as spatial analysis of replicated or unreplicated trials (Singh et al. 2003). Environmentally standardized Best Lineal Unbiased Predictors (BLUPs) obtained from the analysis are then used to analyze GE Interactions using the GGEbiplot software (Weikai et al. 2000).

Thus, PPB trials generate the same amount and quality of data as METs in a conventional breeding program—plus additional information on farmers' preferences usually not available from METs. In recognition of this fact, varieties produced by PPB can be submitted for release (and commercial seed production) in several countries.

Time to variety release

In a typical breeding program, following a classical pedigree method, it normally takes about 15 years to release a variety of a self-pollinated crop. With PPB, the time is reduced by half. However, the comparison is biased because of the difference in the genetic structure of the material being released, i.e., pure lines in one case, populations in the second.

If PPB includes pure line selection within the superior bulks (e.g., in situations where the variety release authorities will not accept populations), the time to variety release in the PPB program is still 3–4 years shorter than the conventional program based on the pedigree method—with the additional advantage that the conventional breeding program does not generate the information on farmers' preferences.

The PPB model is therefore very flexible. It can generate populations, pure lines, and eventually mixtures of pure lines in self-pollinated crops. When applied to cross-pollinated crops, PPB can be used to produce hybrids, populations, and synthetics.

Effect on biodiversity

Another benefit from PPB is an expected increase in crop biodiversity. This is illustrated using data from the 2001–2004 breeding cycle in Syria (Table 1). As indicated earlier, the on-farm component of PPB begins with initial yield trials FIT, progressing through FAT, FET, and finally LS trials. The FIT had an average of 165 genetically different entries per village. Because different germplasm is tested in different villages, the total number of genetically different entries tested in Syria was 412 in the FIT, 238 in the FAT, 51 in the FET, and 19 in LS. The total number of different entries at *the end* of a breeding cycle in farmers fields is higher than the number of lines the Syrian National Program tests at *the beginning* of its on-farm testing which usually ends with one or two recommended varieties across the country.

Variety Release and Seed Production

The potential advantages of PPB—such as faster dissemination of new varieties, higher adoption, and increased biodiversity within the crop—will not be realized unless the seed of the new varieties is available in sufficient amounts to all the farmer community. In many countries, seed is produced only after a variety is officially released. Variety release is decided by a government-appointed committee (the variety release committee) based on a scientific report on the performance, agronomic characteristics, reaction to pests and disease, and quality characteristics of the new variety. Farmers' opinions are not sought. As a result, there are several cases of near-zero adoption of released varieties, and widespread adoption of varieties that have not been released. In these cases, the considerable investment made in developing the new variety and in producing its seed has been wasted.

The PPB addresses this issue directly, by turning the delivery phase of a plant breeding program upside down (Fig. 6). In conventional breeding, the most promising lines are released, their seed is produced under controlled conditions (certified seed); and only then do farmers decide whether or not to adopt the new variety. The entire process is supply-driven; as a conse-

Table 1. Flow of germplasm, selection pressure, number of farmers participating in the selection and number of lines in initial adoption in one cycle of participatory plant breeding on barley in Syria

	FIT	FAT	FET	LS
Entries tested per village	165	17.3	7	3
Trials per village	1	3.2	3.4	2.8
Entries selected per village	17	8	3.5	1–2
No of farmers selecting	9–10	8–9	8–9	8–9
Total no of entries across the country	412	238	51	19

FIT farmer initial trials, *FAT* farmer advanced trials, *FET* farmer elite trials, *LS* large scale trials

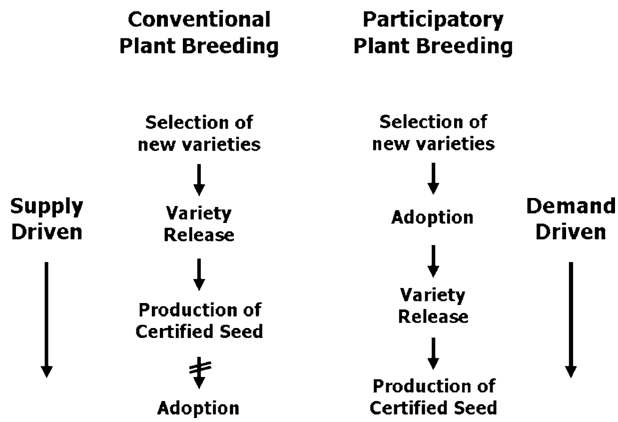

Fig. 6 Conventional plant breeding is typically supply-driven; new varieties are released before knowing whether or not farmers like them. Participatory plant breeding is demand-driven; the delivery phase is driven by the initial adoption by farmers at the end of a full cycle of selection

quence, in many developing countries many varieties are produced and released but only a small fraction of these are adopted. With PPB, decision on which variety to release depend on initial adoption by farmers; the process is demand-driven. This is expected to increase adoption rates—and also reduce production risks, since farmers gain knowledge of the variety's performance as part of the selection process. Last but not least, the institutional investment in seed production is nearly always paid off by farmers' adoption.

Implementation of PPB requires changes both in variety release procedures and in the seed sector. Conventional plant breeding and the formal seed sector have been successful in providing seeds of improved varieties of some important staple or cash crops to farmers in favorable areas. However, the policy, regulatory, technical, and institutional environment under which these institutions operate limits their ability to serve the diverse needs of small-scale farmers in marginal environments and remote parts of developing countries.

The model we are implementing (Fig. 7) is based on integration between the formal and informal seed systems. Seed requirements for PPB trials are 50–100 kg per variety, with 15–30 varieties being tested in each village. This seed is produced in the village and cleaned and treated using locally manufactured equipment: small seed cleaners that can process about 400 kg of seed per hour. For the LS trials, requirements are a few tons per variety per farmer and 2–3 varieties are tested in each village. At this stage seed production is still handled at village level, using locally manufactured larger equipment capable of cleaning and treating 1 t of seed per hour of seed. Production is now supervised by staff of the Seed Organization (a Governmental Body). The procedure for variety release can be initiated at this stage. If initial adoption if followed by wider

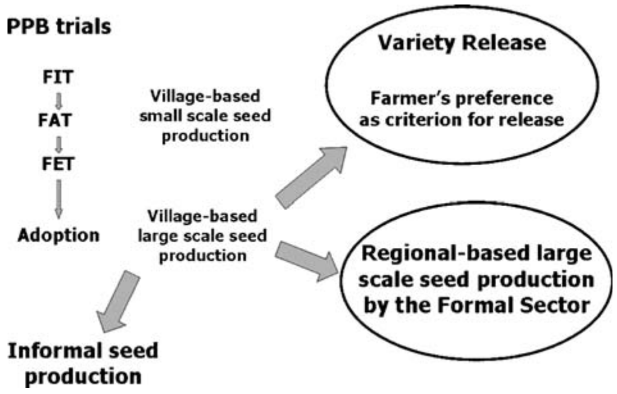

Fig. 7 Linking participatory plant breeding, and variety release, with informal and formal seed production

demand for seed, the variety is released, and the formal seed system can initiate large-scale seed production using as a starting point the few tons of seeds produced in the villages.

In most developing countries, most seed used is produced by the informal seed system. In this situation, the PPB model can provide the informal system with quality seed of improved varieties.

Impact of Participatory Plant Breeding

By the end of 2006 the PPB model was fully implemented in Syria, Jordan, Egypt, and Eritrea, and started in Algeria and Iran (Table 2) on a number of crops. PPB programs based on this model have been also implemented in Tunisia and Morocco (Ceccarelli et al. 2001), and Yemen.

Table 2. Countries where the participatory breeding program is being implemented by ICARDA and national program scientists

Country	Crop (s)	Locations	Trials	Plots
Syria	Barley	24	176	10,020
	Wheat	6	42	710
Jordan	Barley, wheat, chickpea	9	21	2,798
Egypt	Barley	6	20	460
Eritrea	Barley, wheat, hanfetse, chickpea, lentil, faba bean	7	36	1,475
Algeria	Barley	5	5	500
	Durum wheat	2	2	200
Iran	Barley	7	7	700
	Bread wheat	2	2	200

These PPB projects had four main types of impact:

1. *Variety development*: a number of varieties have been already adopted by farmers even though the program is relatively young in breeding terms (Table 3).
2. *Institutional*: in several countries, there is growing interest from policy makers and scientists who recognize PPB's ability to generate quicker and more relevant results.
3. *Farmers' skills and empowerment*: PPB has considerably enriched farmers' knowledge, improved their negotiation capability, and enhanced their dignity (Soleri et al. 2002).
4. *Enhancement of biodiversity*: different varieties have been selected in different areas within the same country, in response to different environmental constraints and users' needs. In Syria, where this type of impact has been measured more carefully, the number of varieties selected after three cycles of selection is 4–5 time higher than the number of varieties entering on-farm trials in the conventional breeding program.

An economic analysis of the PPB barley breeding program in Syria confirmed that PPB increases the benefits to resource poor farmers. The total benefit (i.e., discounted value of research induced benefits to Syrian agriculture) were estimated at US$21.9 million for conventional breeding and US$ 42.7 million to US$113.9 million for three different PPB approaches (Lilja and Aw-Hasaan 2002).

Table 3. Number of varieties selected and adopted by farmers in PPB programs

Country	Crop (s)	Varieties
Syria	Barley	19
Jordan	Barley	1 (submitted)
Egypt	Barley	5
Eritrea	Barley	3
Yemen	Barley	2
	Lentil	2

Using case studies of different crops, Ashby and Lilja (2004) have shown that:

1. The use of participatory approaches improves the acceptability of varieties to disadvantaged farmers by including their preferences as criteria for developing, testing, and releasing new varieties. A survey conducted on over 150 PPB projects showed that (a) PPB improved program effectiveness in targeting the poor, (b) consulting women and involving them in varietal evaluation, led to a better acceptability and faster adoption, and (c) involvement of women farmers in the development of maize seed systems in China resulted in a broadened national maize genetic base, higher maize yields, and stronger women's organizations.
2. PPB improves research efficiency. A study of the PPB program in Syria (Ceccarelli et al. 2000, 2003) found that farmers' selections are as high yielding as breeders' selections. Another study found that by introducing farmer participation at the design stage, the time taken from initial crosses to release was reduced by 3 years. In another example, breeders concluded that it was faster, less expensive, and more reliable to involve farmers directly in the identification of promising accessions for use in the breeding program. Farmer involvement also leads to efficiency gains, e.g., minimizing on varieties which, after release, turn out to be of little or no interest to farmers.
3. PPB accelerates adoption. Participatory approaches resolve adoption bottlenecks caused by low levels of acceptability of new varieties to poor farmers. Table 3 shows some examples. Other examples are Ethiopia, where only 12 out of over 122 released varieties of cereals, legumes, and vegetables were adopted by farmers (Mekib 1997); Brazil, where after years of non-adoption, the implementation of PPB lead to the adoption of several clones of cassava which were both resistant to root rot and highly acceptable to farmers (Fukuda and Saad 2001); and Ghana, conventionally bred maize varieties had poor adoption, while adoption rose to nearly 70% for varieties bred with farmer participation (Morris et al. 1999).

Thus, PPB delivers clear quantifiable benefits. But one impact of PPB (and of participatory research in general), is less tangible—but no less important. When farmers are asked what benefits they obtained from PPB, typical responses in many areas include: their quality of life has improved, they feel happier because they have gone from passive receivers of information to active protagonists, their opinion is valued. As an Eritrean farmer said, "We feel we have taken back science into our own hands".

Conclusions

Results achieved in several countries show, that is, possible to organize a plant breeding program in a way that not only addresses issues of yield, yield stability, and adaptation to environmental conditions, but also user preferences and the socio-economic environment. This can be achieved by using a decentralized participatory approach, from variety selection and testing to seed production. Such an approach will, in addition, maintain or even enhance biodiversity.

The main objections to PPB are usually that: (1) if plant breeders do their job properly there should not be the need for farmer participation, (2) seed companies cannot cope with the multitude of varieties generated by PPB, and (3) PPB varieties do not meet the requirements for official variety release.

All three objections are unfounded.

1. Conventional plant breeding has been successful in favorable environments, or those which can be made favorable (e.g., by the use

of inputs). It has been much less successful in less-favorable areas. Even in areas where it has been successful, there are environmental and biodiversity concerns—heavy use of chemical inputs required by modern varieties, and narrowing of the crop genetic basis. More recently, there is a widespread concern about the use of the improperly called Genetically Modified Organisms (GMOs) which, regardless from other consideration, represent yet another type of top-down technology. For these reasons, it may be useful to explore alternative avenues of plant breeding where the same science can be used in a different way.

2. Seed supply: the capacity of seed companies is not an issue, because for the major food crops—indeed for most crops in developing countries—90% of the seed planted is produced by farmers, not by seed companies. PPB can introduce new varieties directly into the most efficient seed system currently operating.
3. Variety release requirements: this objection assumes that PPB varieties are inevitably genetically heterogeneous, unstable, and not distinct: and therefore not suited for release. There are three points to consider. (a) The majority of cultivars grown in marginal environments are genetically heterogeneous, and in several cases their seed is multiplied officially by the same authorities which refuse permission to release populations. (b) It may be unwise to replace this heterogeneity with genetically uniform material. (c) PPB, like conventional plant breeding, is flexible and can be used to produce varieties with different genetic structure including pure lines and hybrids. On one hand, PPB varieties can fit the current requirements for variety release; on the other hand, given the actual and potential impact of PPB, the current regulatory frameworks for variety release and seed production should be modified to facilitate the official recognition of PPB varieties. This will avoid the emerging danger of parallel breeding systems with the associated variety and seed production.

Thus, the most frequent objections to PPB are unfounded; they ignore the fact that farmers have modified crops for millennia, domesticating wild species, exchanging seed, and introducing new crops and new varieties. In the process they have accumulated a wealth of knowledge that modern science tends to ignore. PPB is one way of recognizing farmers' science and merging it with modern science.

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