Decentralized-participatory plant breeding

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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 could profitably modify their environment to suit new cultivars, than to the poorest farmers who could not afford to modify their environment through the application of additional inputs and could not risk the replacement of their traditional, well-known and reliable varieties. As a consequence, low yields, crop failures, malnutrition, famine, and eventually poverty are still affecting a large proportion of humanity. Participatory plant breeding is seen by several scientists as a way to overcome the limitations of conventional breeding by offering farmers the possibility of deciding which varieties better suit their needs and conditions without exposing the household to any risk. Participatory plant breeding 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 x environment interactions. This article describes a model of participatory plant breeding in which genetic variability is generated by professional breeders, selection is conducted jointly by breeders, extension specialists and farmers in a number of target environments, and the best selections are used by breeders in further cycles of recombination. Farmers handle the first phases of seed multiplication of promising breeding material in village-based seed production systems. The model has the following advantages: (i) varieties reach the release phase earlier than in conventional breeding; (ii) the release and seed multiplication concentrate on varieties known to be acceptable by farmers; (iii) it increases biodiversity because different varieties are selected in different locations; (iv) varieties fit to the agronomic management that farmers are familiar with and can afford and therefore can be beneficial to poor farmers. These advantages are particularly relevant to developing countries where large investments in plant breeding have not resulted in production increases, especially in marginal environments.

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Introduction

Despite the tremendous effects of the Green Revolution, millions of people still go to bed hungry every day, and little has changed in the life of subsistence farmers in many developing countries. Most of these farmers live in the drier parts of the world where water is scarce, so they must depend on rainfall. Because most "improved" crop varieties have been developed for near-optimal conditions of water supply and other inputs they often do not perform well under the subsistence farming conditions.

The outcome of conventional crop breeding is a few varieties, often closely related, which are cultivated over large areas resulting in genetic uniformity which is dangerous in areas prone to disease and pest attack, and with unpredictable climate. The threat that genetic uniformity continues to pose to agriculture has been shown recently by the Fusarium head blight epidemic that has swept some areas of the US, causing economic losses in wheat and barley estimated at US$ 2.5 billion and US$ 400 million, respectively (Windels 2000). This has been associated with the decline in the agro-system diversity (Mercer and Wainwright 2000).

This is also in contrast with the genetic diversity maintained by farmers in stress environments in the form of different crops, different cultivars within the same crop and/or heterogeneous cultivars to retain adaptability, i.e. to maximize adaptation over time, rather than adaptation over space (Martin and Adams 1987). Diversity and heterogeneity serve to disperse or buffer the risk of total crop failure due to environmental variation. Several examples of the presence, the value and the use of diversity in various countries and crops are given by Almekinders and De Boef (2000).

It appears that on one hand, plant breeding has been unable to address the needs of a considerable number of farmers, including the most marginal and the poorest, and on the other hand has created a number of undesirable effects on the environment and on biodiversity. It is now recognized that the shortcomings of centralized plant breeding are related to their inability to address the enormous diversity of environmental conditions and end-users' needs (Morris and Bellon 2004).

Participatory plant breeding (PPB) has been proposed as a solution to the problem of fitting the crop to a multitude of both target environments and users' preferences (Ceccarelli et al. 1996, 1997, 2000). 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 a breeding program (Ceccarelli and Grando 2002).

Implementing a participatory plant breeding program: Migrating a conventional program into farmers' fields and building partnerships

Plant breeding is a cyclic process (Figure 1): each year (or cropping season) a new cycle begins with new crosses, which are largely made using, as parents, material derived from previous cycles.

In the majority of plant breeding programs, the only known exception being Australia, only a small fraction of the entire process takes place in farmers' fields (Figure 1, left): most of the process occurs in one or more often in several, research stations. One of the main consequences is that a large amount of breeding material is discarded without knowing whether it could have been useful in the real conditions of farmers' fields, and the one that is selected, is likely to perform well in environments similar to the research stations and may not perform as well in the fields of the poorest farmers. We have argued that for crops grown in environments poorly represented by the research stations, this often results in discarding useful breeding material (Ceccarelli et al. 1996).

The implementation of a truly decentralized-participatory plant breeding requires the transfer to farmers' fields of part of the breeding materials that are usually grown on station (see for example Figure 1, right) and the transfer to farmers of part of the decisions which are usually taken by the breeder. Therefore, decentralized-participatory plant breeding must, by necessity, involve several farmers or farmers' communities.

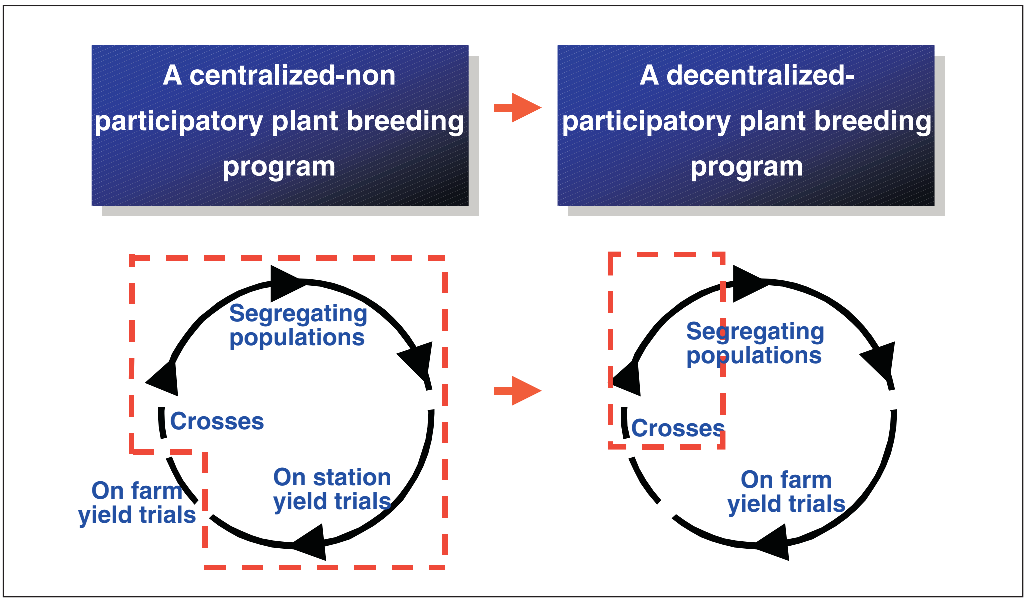

Figure 1. A schematic representation of centralized-non participatory (left) and of decentralized-participatory (right) plant breeding. The dotted lines represent a research station.

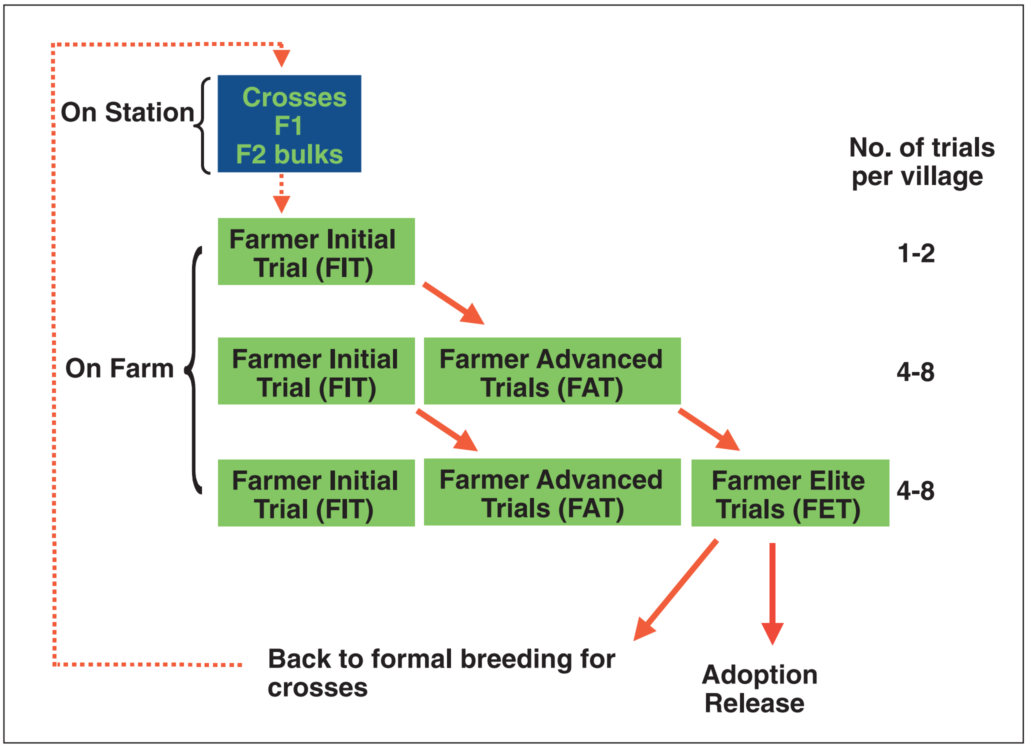

Figure 2. A model of participatory plant breeding implemented with farmers in Syria, Jordan, Egypt, Eritrea, Yemen, Morocco and Tunisia.

The method of plant breeding we use in barley in a number of countries is a bulk-pedigree, in which the crosses are prepared on station, where we also grow the F_1 and the F_2, while in the farmers' fields we yield test the bulks over a period of three years (Figure 2).

The activities in farmers' fields begin with the yield testing of early segregating populations in trials called Farmer Initial Trials (FIT), which are unreplicated trials with 200 plots of 12 m^2: these contains 170 entries plus one or two checks repeated 30 times. The breeding materials selected from the FIT are yield tested for a second year in the Farmer Advanced Trials (FAT) with a number of entries and checks that vary from village to village and from year to year. The plot size in the FAT is 45 m^2 to produce enough seed on farm to plant the selected entries on larger plots in the third stage. The number of FAT in each village depends on how many farmers are willing to grow this type of trial. In each village, the FAT evaluate the same entries. Each farmer decides the rotation, seed rate, soil type, and the amount and time of application of fertilizer. Therefore, the FAT are planted in a variety of field conditions and managements. During selection, farmers exchange information about the agronomic management of the trials, and rely greatly on this information before deciding which entries to select. Therefore, the characterization of the breeding materials for their responses to environmental or agronomic factors starts at an early stage of 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.

All these trials are typically laid down in a symmetric array of rows and columns (for example, four rows and 50 columns). The data are subjected to different types of analyses, some of which were developed at ICARDA, such as the spatial analysis of unreplicated or replicated trials (Singh et al. 2003). The environmentally-standardized Best Lineal Unbiased Predictors (BLUPs) obtained from the analysis are then used to analyze Genotype x Environment interactions (GE) using the GGE-biplot software (Yan et al. 2000).

Large effects due to genotypes x farmers' field interaction were found within the same village, and they seem to be associated with rainfall (Figure 3). In wet locations (such as Mardabsi in Figure 3), GE effects explained ca. 48% of the total variation, while in a dry location (Bylounan in Figure 3) GE effects explained nearly 90% of the total variation.

Figure 3 illustrates one of the advantages of this model of PPB over conventional plant breeding which consists of measuring the repeatability of GE interactions among farmers' fields over time. If two or more farmers consistently discriminate genotypes in the same way, one of the two can be excluded thus leading to an optimization of the number of locations within and across the villages.

By the end of 2003, the model shown in Figure 2 was fully implemented in eight villages and started being implemented in three others, covering the majority of the barley-growing areas in Syria. Each year we have, therefore, about 100 trials and an average of 200 farmers involved in the selection process. PPB programs based on the

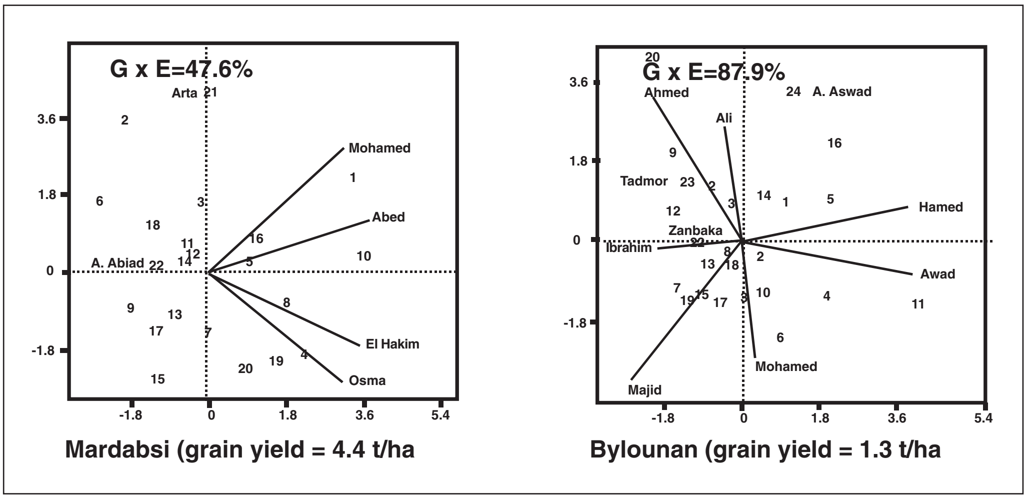

Figure 3. Genotype x Farmers' field within the same village interaction. These analyses will allow optimizing the number of trials within each village.

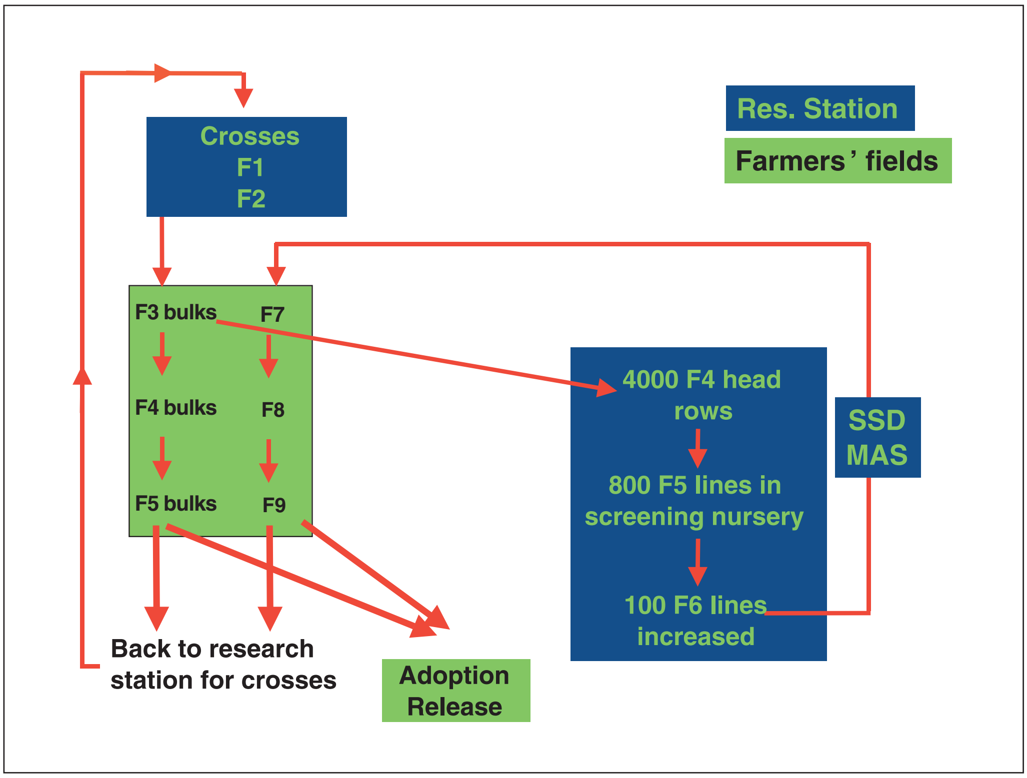

Figure 4. Pure line selection, single seed descent (SSD) and marker-assisted selection (MAS) combined with participatory plant breeding (in blue are the steps in the research station, in green those in farmers' fields).

methodology described above have been implemented in Tunisia and Morocco (Ceccarelli et al. 2001a, 2001a, b), Yemen, Egypt, Jordan and Eritrea (Tekle et al. 2000).

In parallel to the model shown in Figure 2, we conduct pure-line selection within the selected segregating populations (Figure 4) by collecting heads on the selected F_3 bulks on station. The F_4 head rows are promoted to the F_5 screening nursery only if farmers select the corresponding F_4 bulks. The process is repeated in the F_5 and the resulting families, after one generation of increase, return as F_7 in the yield-testing phase. Therefore, 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.

The process of pure line selection shown in Figure 4 can be accelerated by using the same techniques used in single-seed descent and marker-assisted selection: this considerably increases the speed and the precision with which the desirable genotypes are identified.

Institutionalization and scaling up

The work described above has had the merit of developing a network of participating farmers and a methodology for PPB. However, the number of villages and farmers involved is too limited to have an impact at the country level. During 2003 and 2004, we started a process of scaling-up which went through the following steps:

1. A meeting of all the stakeholders (farmers, researchers, extension staff, seed production organizations and policy makers) at the beginning of the process to discuss the various aspects of PPB and the responsibility of each of the stakeholders.
2. The creation of local teams with scientists, extension staff and farmers participating in all major steps of variety development, even though maintaining specific responsibilities. This will replace the traditional linear sequence scientist → extension → farmers by a team approach for scaling-up. This usually does not require organizational changes in the institutions involved.
3. The decentralization of responsibilities to local teams who gradually become responsible for all the regional or provincial activities. Therefore, one important initial component of scaling-up is an extensive training program of the local teams on all aspects of PPB. Initial evidence in Syria would suggest that this decentralization of responsibilities is associated with a considerable reduction in costs.

As a result of these steps, the number of FIT increased from 14 to 28, the number of FAT from 43 to 73 and the number of FET from 25 to 51. As a consequence, there was an increase in the total number of lines tested and in the total number of farmers involved.

Table 1. Effect of one year of scaling-up the program of participatory plant breeding in Syria.

	2003		2004	
Type of trial	Number of trials	Number of lines[a]	Number of trials	Number of lines[a]
FIT	14	200	28	200
FAT	43	23	73	15
FET	25	6	51	8

[a] in the case of the FAT and FET is the average number of lines across villages.

Variety release and seed production

The potential advantages of participatory plant breeding, such as the speed with which new varieties reach the farmers, the increased adoption rate and the increased biodiversity within the crop due to the selection of different varieties in different

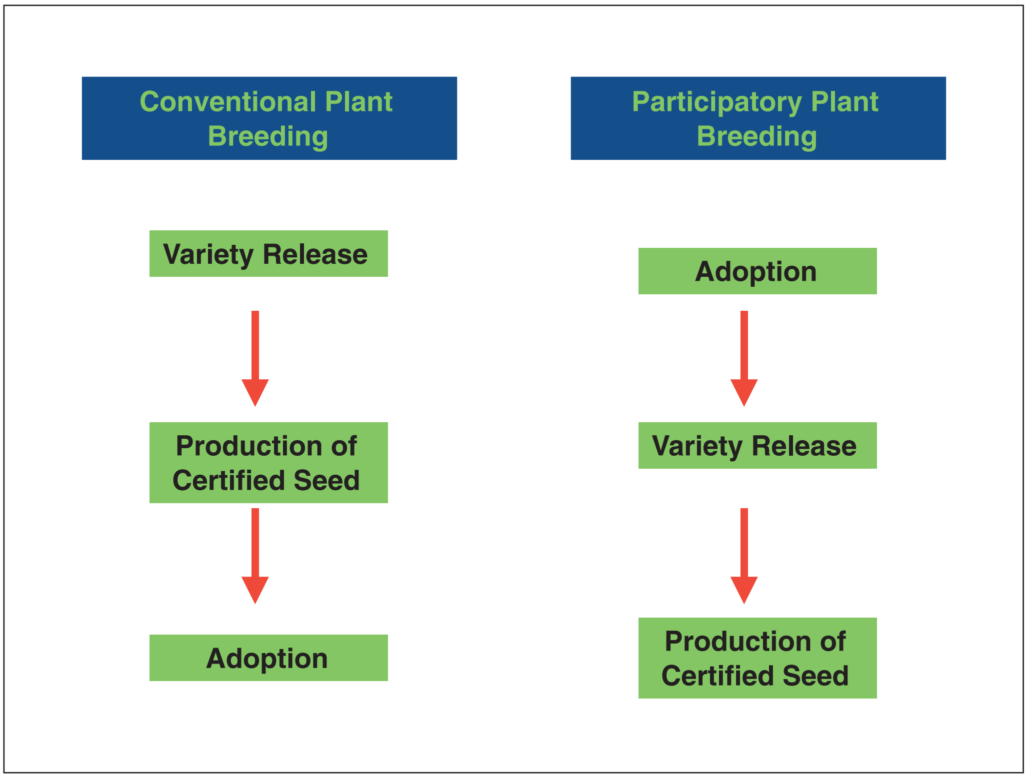

Figure 5. In conventional plant breeding new varieties are released before knowing whether the farmers like them or not. In participatory plant breeding the delivery phase is reversed because the process is driven by the initial adoption by farmers at the end of a full cycle of selection.

areas, will not be achieved if the seed of the new varieties does not become available in sufficient amounts to the whole farmers' community. In many countries this is associated with, and depends on, the official recognition of the new varieties. This process, called variety release, is usually the responsibility of a committee (the variety release committee) nominated by the Minister of Agriculture. The decisions of the committee are based on a scientific report on the performance, agronomic characteristics, reaction to pests and disease, and quality characteristics of the new variety. The farmers' opinion is not requested, and therefore there are several cases of varieties grown by farmers without being released as well as cases of varieties released which have never been grown by any farmer. In these cases, the considerable investment made in developing the new variety and in producing its seed has no benefits.

One of the most important advantages of PPB is associated with reversing the delivery phase of a plant breeding program (Figure 5). In a conventional breeding program, the most promising lines are released as varieties, their seed is produced under controlled conditions (certified seed) and only then do farmers decide whether or not to adopt them. In many developing countries this process results in many varieties being released and only a small fraction being adopted. With PPB, it is the initial farmers' adoption which drives the decision of which variety to release. As a consequence, adoption rates are expected to be higher, and risks are minimized, as intimate knowledge of varietal performance is gained as part of the selection process. Last but not least, the institutional investment in seed production is nearly always paid off by farmers' adoption.

The implementation of a PPB program implies not only a change in the process of variety release but also assumes changes in the seed sector. Conventional plant breeding and the formal seed industry have been successful in providing improved varieties and seeds of some important staple or cash crops to farmers in favorable areas of developing countries. However, the policy, regulatory, technical and institutional environment under which these institutions operate constrained the efficiency of most public sector organizations in providing the diverse needs of the small-scale farmers in marginal environments and remote regions prompting new paradigms in plant breeding and seed supply systems.

The model we are implementing (Figure 6) is based on the integration between the informal and the formal seed systems. During the selection and testing phase (the PPB trials described in Figure 2) the seed required, which varies from 50 to 100 kg for each variety while the number of varieties in each village varies between 15 and 30, is produced in the village and is cleaned and treated with locally-produced equipment. These are small seed cleaners which are able to process about 400

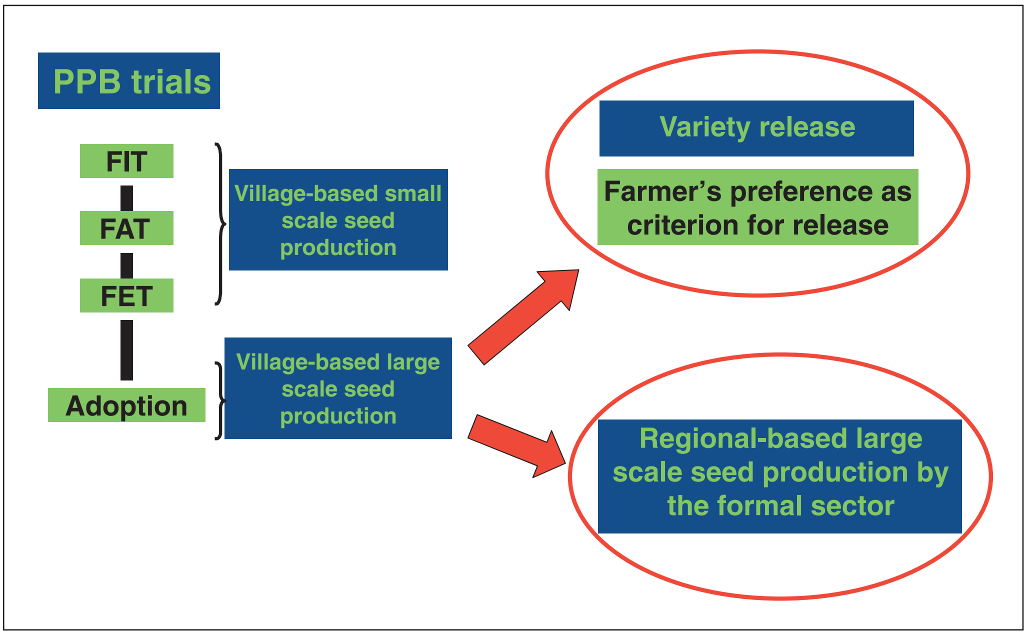

Figure 6. Linking participatory plant breeding and variety release with informal and formal seed production.

kg of seed per hour. After the Farmer Elite Trials, the first initial adoption usually takes place, seed requirement goes up to few tons/farmer and the number of varieties is reduced to two to three in each village. At this stage, seed production is still handled at village level, using locally produced larger equipment capable of cleaning and treating 1.000 kg of seed per hour. In this phase, the staff of the Seed Organization starts supervising the large-scale, village-based seed production. At the same time, the procedure for variety release can be initiated, and if the initial adoption is followed by a wider demand for seed, the variety is released, and the formal seed system can initiate large-scale, regional seed production using as a starting point, the few tons of seeds produced in the villages.

Conclusions

The PPB projects had four main types of impact:

1. **Variety development**: new varieties were spontaneously tested by farmers as early as three years after starting the program. In Syria, several thousand hectares are planted with two varieties and about 30 varieties are under farmers' large-scale testing; in Jordan two varieties are being purified before being submitted for release; in Eritrea two varieties have been multiplied and distributed to farmers; and in Egypt three varieties have been named by farmers and multiplied.
2. **Institutional**: in several countries, the interest of policy makers and scientists in PPB as an approach which is expected to generate quicker and more relevant results has considerably increased
3. **Farmers' skills and empowerment**: the cyclic nature of the PPB programs 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 four to five times higher than the number of varieties entering the on-farm trials in the conventional breeding program.

The results obtained so far (Ceccarelli et al. 2000, 2003; van Eeuwijk et al. 2001) indicate that it is possible to organize a plant breeding program in a way that addresses not only those plant characteristics that maximize yield and stability over time in a given physical environment, but also the preferences of the users, by developing varieties with specific adaptation to the different physical and socio-economic environments. Such an objective can be achieved by using a decentralized participatory model, which needs to be extended also to the seed production aspects. A breeding program organized according to these principles will have the advantages of producing environmentally-friendly varieties and of maintaining or even enhancing biodiversity.

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