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Participatory plant breeding research: Opportunities and challenges for the international crop improvement system

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Summary

This paper describes the current state of international plant breeding research and explains why the centralized global approach to germplasm improvement that was so successful in the past is today being transformed by the incorporation of decentralized local breeding methods designed to better incorporate the perspective of end users into the varietal development process. It describes international breeding efforts for major crops and identifies factors that have contributed to the success of the international breeding system; discusses shortcomings of the global approach to plant breeding and explains why future successes will depend critically on researchers' ability to incorporate the knowledge and preferences of technology users; reviews a number of farmer participatory research methods that are currently being tested by plant breeding programs throughout the developing world; describes synergies that can potentially be achieved by linking centralized global and decentralized local breeding models; and discusses technical, economic, and institutional challenges that will have to be overcome to integrate end user-based participatory approaches into the international plant breeding system.

Abbreviations: CGIAR – Consultative Group for International Agricultural Research; IPR – Intellectual property rights; MVs – Modern varieties; NARS – National agricultural research systems; NGOs – Non governmental organizations; PPB – Participatory plant breeding

Introduction

Modern crop varieties developed by international agricultural research centers supported by the Consultative Group for International Agricultural Research (CGIAR) played a leading role in launching the Green Revolution in world agriculture. Traditionally, CGIAR plant breeding efforts have been based on a centralized global research model under which CGIAR breeders collect germplasm from many different sources, evaluate the germplasm under carefully controlled experimental conditions, and make crosses among superior materials.[1] The best progeny from these crosses are distributed to collaborators in national agricultural research systems (NARSs) for testing. In return for doing the testing, collaborators are free to use the materials in their own breeding programs. This international breeding system has been very successful. It has enabled CGIAR breeders to develop materials that perform well under a wide range of environmental conditions, and it has provided an effective mechanism for distributing these materials worldwide.

Since the first modern varieties (MVs) were released during the late 1960s and early 1970s, the area planted to MVs has continued to expand. This expansion resulted both from growth in area planted to MVs of the original CGIAR mandate crops and from

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[1] Throughout this paper, the term *plant breeders* is used in a broad sense to mean plant breeders and other scientists involved in crop genetic improvement research (plant physiologists, plant pathologists, entomologists, molecular biologists, etc.).

broadening of the CGIAR mandate to include many non-cereal crops, including roots and tubers, legumes, oilseeds, bananas and plantains, and forage crops. While it is clear that MVs developed using CGIAR germplasm have brought benefits to millions of producers and consumers, over time it has become evident that adoption of MVs has lagged in some areas, including many marginal environments of low production potential. Among the factors that have slowed the spread of MVs into marginal environments has been the unsuitability of many MVs for the specialized production and consumption requirements of people who live in these environments.

Faced with evidence that MVs developed for favorable production conditions have not always diffused readily into marginal environments, more and more plant breeders are searching for ways actively to involve end users in the varietal development process. The result has been a surge in interest in participatory plant breeding (PPB) methods designed to incorporate the perspective of farmers[2] – usually by inviting farmers to participate in varietal evaluation activities, but sometimes also by teaching them formal selection techniques. Proponents believe that PPB methods show great promise for making varietal development efforts more responsive to the needs of technology users, particularly members of poor rural households that are not well integrated into the market economy (Almekinders & Elings, 2001; Sperling et al., 2001).

This paper describes the current state of international plant breeding research and explains why the centralized global approach to germplasm improvement that was so successful in the past is today being transformed by the incorporation of decentralized local breeding methods designed to better incorporate the perspective of end users into the varietal development process. The authors are social scientists working for a CGIAR Center that is active in maize and wheat improvement research. While we share with our colleagues who are plant breeders an interest in strengthening the crop improvement work conducted under the international plant breeding system, our disciplinary background leads us to approach the problem from a perspective that is somewhat different from the perspectives of many biophysical scientists. In particular, as social scientists when we talk about the 'efficiency' of alternative breeding strategies, we are more likely to include in our definition of efficiency not only technical and economic dimensions of the breeding process (How long does it take? How much does it cost?), but also considerations of how costs and benefits are distributed among different groups in the population (Who pays? Who profits?), as well as considerations of how the process is being driven (Who decides?). Incorporating these additional dimensions can lead to divergent conclusions about the relative desirability of alternative breeding strategies.

The paper begins by describing international breeding efforts for major crops and identifying factors that have contributed to the success of the international breeding system. Next, it describes shortcomings of the global approach to plant breeding and explains why future successes will depend critically on researchers' ability to incorporate the knowledge and preferences of technology users. It then reviews a number of farmer participatory research methods that are currently being tested by plant breeding programs throughout the developing world. The paper concludes by describing synergies that can potentially be achieved by linking centralized global and decentralized local breeding models and discussing technical, economic, and institutional challenges that will have to be overcome to integrate end user-based participatory approaches into the international plant breeding system.

The current international plant breeding system

Established in 1971, the CGIAR is an association of approximately 60 public and private members that supports a global network of 16 international agricultural research centers (known as Future Harvest Centers). Plant genetic improvement research is a major focus of the CGIAR. Currently nine Future Harvest Centers conduct plant breeding research, and a tenth, the International Plant Genetic Resources Center (IPGRI), holds a mandate to advance the conservation and use of plant genetic diversity for the well-being of present and future generations. The CGIAR breeding programs target crops that are widely produced and consumed by the poor in developing countries, including cereals (rice, wheat, maize, sorghum, pearl millet, barley), pulses (common bean, lentil, chickpea, faba, pigeon pea, cowpea), oilseeds (soybeans,

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[2] For simplicity, throughout this paper we discuss participatory breeding as involving *farmers*. In may developing countries, food crops are produced and consumed within the same household, so participatory breeding schemes will want to focus on production and consumption traits. Often it will be desirable to involve different types of end users, i.e., not only those who produce the crop but also those who process, prepare, and/or consumet it.

groundnut), roots and tubers (cassava, potato, sweet potato, yam, Andean roots and tubers), and bananas and plantains. CGIAR breeding programs also work on selected non-food species that contribute to improving and sustaining the livelihoods of the poor, such as forage crops and trees.

Future Harvest Centers remain at the forefront of international germplasm improvement activities, especially in developing countries, but they do not in and of themselves constitute the global plant breeding system. The success of CGIAR plant breeding programs depends critically on the contribution of thousands of local public plant breeding institutes and university crop science departments, and, increasingly, private seed companies and non-governmental organizations (NGOs). Many of these organizations collaborate actively with Future Harvest Centers, and indeed relationships between the Centers and these organizations can be considered true partnerships.

The impacts of CGIAR breeding programs are well known. Modern varieties developed using improved germplasm from Future Harvest Centers today are grown on millions of hectares throughout the developing world. Widely publicized Green Revolution success stories involving wheat and rice were followed in subsequent years by similar success stories involving many other crops – not only cereals, but also legumes, oilseed, roots and tubers, and bananas and plantains. Over the past four decades, MVs developed using improved germplasm from Future Harvest Centers have fueled important gains in global food production and generated billions of dollars of benefits for producers and consumers (Evenson & Gollin, 2003).

MVs have had an enormous impact in the developing world, but the benefits have not been distributed evenly. Productivity gains associated with adoption of MVs have been concentrated in favorable production environments characterized by fertile soils, adequate and reliable water supplies, ready access to input and output markets, effective extension services, and economic policies that encouraged investment in improved crop production technology. These conditions were present in many original Green Revolution sites, including northwest Mexico, the Punjab regions of India and Pakistan, the Mediterranean coast of Turkey, central Luzon in the Philippines, and southern China.

Critics of the Green Revolution claim that MVs have had little impact in marginal environments, but this is not correct. In the cases of wheat and rice, for example, while it is true that the semi-dwarf MVs that spearheaded the Green Revolution initially made little headway in non-irrigated zones, over the past 25 years most of the expansion in area planted to wheat and rice MVs has occurred in rainfed areas, beginning first in wetter areas and spreading gradually into drier areas (Byerlee, 1994; Lipton & Longhurst, 1989). In many cases, the expansion of wheat and rice MVs into marginal environments has depended on availability of varieties that are suitable for more difficult production conditions and that satisfy the special requirements of people who live in these environments. Development of such varieties usually depends on the presence of a strong local breeding program capable of taking germplasm developed elsewhere and adapting it to local environmental conditions and end-user needs.

The traditional global approach to plant breeding

Advantages of global plant breeding

The extensive diffusion of MVs developed using CGIAR-improved germplasm shows that centralized plant genetic improvement research can be very effective. The global model of international plant breeding in which Future Harvest centers serve as hubs of extended global networks for germplasm improvement and exchange has a number of obvious advantages.

Elimination of redundant activities. Because they operate at the regional or global level, Future Harvest Centers achieve important efficiencies by eliminating activities that would be redundant if performed at the country level. Gene banks are a good example. For crops of global importance, if every country in which the crop is grown were to establish its own gene bank, there would be a large amount of wasteful duplication as the same accessions were collected and maintained in multiple locations. Security considerations dictate that at least two copies of all materials be maintained in separate sites (to provide protection in case of catastrophic loss at one site), but maintenance of multiple copies of the same germplasm at many different sites is unnecessary and inefficient.

Extensive exchange of germplasm. Most plant breeders who work for Future Harvest Centers travel extensively, interact frequently with scientists from public and private breeding programs, and regularly exchange germplasm with colleagues from all over the world. These breeders are well placed to take advantage of progress made elsewhere because they are exposed to large amounts of diverse germplasm. By introgressing exotic materials into their crossing blocks, they can exploit genetic gains made in other locations. Over the long run, genetic gains achieved by CGIAR breeding programs are greatly enhanced by regular introgression of exotic materials.

Multi-locational testing. Thanks to their close links to colleagues in national breeding programs, Future Harvest Centers' plant breeders are able to test experimental germplasm in many different locations around the world. This provides them with an important advantage when selecting superior materials, which are more easily identified with the help of performance data collected in a wide range of production environments. Plant breeders working in national programs generally do not have access to nearly as many testing sites, which complicates the selection task.

Exploitation of technology spillovers. A key to the success of the global breeding system has been its ability to distribute improved germplasm to local breeding programs. International nurseries managed by Future Harvest Centers have proved to be very effective tools for disseminating improved materials. Virtually all NARSs breeding programs and most private seed companies regularly screen CGIAR nursery entries in search of useful germplasm, and many report that CGIAR nurseries represent their single most important source of new breeding materials. Numerous studies have confirmed that the international breeding system based on centralized CGIAR plant breeding programs generates enormous spillover benefits (Byerlee & Traxler, 1996; Maredia & Byerlee, 1999; Traxler & Pingali, 1999).

In summary, CGIAR plant breeding programs have been successful because their large size and global reach allows them to capture important economies of scope and scale. Another factor that has contributed to the success of CGIAR plant breeding programs is that the Future Harvest Centers have been able to attract and retain well-trained, highly motivated scientists and support them with sufficient resources to accomplish the job.

Shortcomings of global plant breeding

While the global model of international plant breeding has many advantages, it also has some shortcomings.

Limited adaptation breeding. CGIAR plant breeding programs do not always have sufficient resources to do extensive local adaptation breeding. Most CGIAR breeding programs identify a core set of priority traits and work to incorporate these traits into a range of diverse germplasm backgrounds, which are then made available to national breeding programs and private companies. Traits that are commonly targeted include high yield potential, tolerance or resistance to major biotic and abiotic stresses, early maturity, fertilizer responsiveness, and food or feed quality. In some cases, CGIAR breeders also develop finished cultivars containing specific combinations of traits desired by particular groups of farmers in well-defined target environments. This so-called 'cultivar development' work is justified when a crop is grown in large, ecologically homogeneous production environments, because successful varieties are likely to diffuse across a large area. More often, however, cultivar development work is left to local breeding programs, especially when a crop is grown in small, ecologically diverse target environments that require distinct varieties. When local breeding programs are weak or inadequately funded, cultivar development work often gets neglected.

Weak links to end users. CGIAR plant breeders often have weak links to the end user. This is partly due to their professional training: plant breeders receive rigorous instruction in the theory and practice of crop improvement and have little exposure to survey methods needed to elicit structured feedback from farmers. While many plant breeders do make a point of frequently visiting farms and talking to farmers about the advantages and disadvantages of different varieties, information about farmers' varietal preferences is often collected in an informal and unsystematic manner from small and potentially non-representative samples of respondents. As a result, what plant breeders consider to be important in a variety may not correspond closely with what the majority of farmers in a target area consider to be important, in which case the breeding program may be selecting for a non-optimal combination of traits.

Inadequate farm-level testing. CGIAR plant breeding programs do not always have resources to test their products at the farm level. On-farm varietal testing tends to be very resource intensive, especially in developing country settings where the breeding program is targeting mainly subsistence-oriented farmers living in remote areas that are poorly served by roads and other forms of infrastructure. For this reason, few CGIAR breeding programs conduct extensive on-farm varietal trials; instead, most base their selection decisions on data generated through on-station trials. This can lead to problems, because research has shown that varieties often perform differently under farmers' management practices than they do under researchers' management practices.

In summary, despite its many advantages, the global model of plant breeding also has shortcomings. These shortcomings relate mainly to the inability of a highly centralized breeding system to address the enormous diversity of environmental conditions and end-user needs. Varietal preferences often vary significantly from location to location, from season to season, and from farmer to farmer, particularly in subsistence-oriented farming systems. Most CGIAR plant breeding programs lack the resources to solicit the diverse varietal preferences of farmers in thousands of different locations, develop distinct varieties for all these locations, and test all of the varieties thoroughly at the farm level. These activities have traditionally been left to national agricultural research systems (NARS), with a mixed record of success. In many large developing countries, public breeding programs have done a good job in adapting cultivars to meet specialized local needs, particularly in the case of major food crops that are economically and politically important (e.g., rice, wheat, maize). However in many small countries, public breeding programs have been less effective. Furthermore, there has been a general lack of investment in breeding for traditional food crops consumed mainly in developing countries, including minor grains (sorghum, pearl millet, finger millet, barley, teff), roots and tubers, plantains and bananas, and pulses.

The emerging local approach to plant breeding

In an effort to overcome some of the limitations of the traditional global approach to plant genetic improvement, researchers in many Future Harvest Centers and some national breeding programs are developing a new approach known as *participatory plant breeding* (PPB). PPB is based on a set of methods that involve close farmer-researcher collaboration to bring about plant genetic improvement within a crop. PPB is expected to produce more benefits than the traditional global breeding model in situations where a highly centralized approach is inappropriate (Weltzien et al., 2000). Situations in which PPB is expected to be particularly advantageous include the following:

- Improvement of crops that are mainly of local interest and hence do not attract the attention of commercial breeding programs.
- Improvement of crops grown in marginal environments characterized by subsistence-oriented agriculture.
- Improvement of crops grown in highly variable environments in which genotype-by-environment interactions preclude widespread use of individual varieties.
- Situations in which end users require uncommon traits.
- Situations in which end users require unusual combinations of common traits.

With PPB, farmers and plant breeders can interact in a number of ways. The various *modes of participation* can be thought of as points along a continuum representing different levels of interaction. Each mode of participation can be characterized in terms of how farmers and plant breeders interact to set objectives, take decisions, share responsibility for decision-making and implementation, and generate products. In practical terms, these four factors affect three key aspects of the breeding process:

1. the *stage of the breeding process* at which farmers interact with breeders,
2. the *location* where selection and testing of germplasm takes place, and
3. the *design and management* of the germplasm evaluation process.

The stage at which farmers interact with breeders can range from very early in the breeding process (e.g., during selection of source materials or when the germplasm being improved still shows a high degree of genetic variability) to very late in the breeding process (e.g., during evaluation of near-finished or finished varieties). Selection and testing of germplasm may take place in experiment station plots, in farmers' fields, or both. By planting breeding materials in several different locations, plant breeders and farmers are able to evaluate varieties under a range of biophysical conditions. The design and management of the germplasm evaluation process can be done by plant breeders alone, by farmers alone, or jointly by both groups. Interactions between the location where selection and testing of germplasm takes place and the design and management of the germplasm evaluation process are particularly important, because they provide breeders and farmers the opportunity to assess genotype-by-environment interactions (with the environment defined to include not only biophysical conditions in the target environment, but also management conditions that are relevant to farmers). It should be pointed out that in the literature on PPB, farmer selection of finished or near-finished varieties is known as *participatory varietal selection*, while farmer selection with unfinished materials with a high degree of genetic variability is known as *participatory plant breeding* (Witcombe et al., 1996). Testing and selecting in different locations representative of the target breeding environment is known as *decentralized breeding* (Ceccarelli et al., 2000). As defined above, *decentralized breeding* can be done without farmer involvement and *participatory varietal selection* and *participatory breeding* do not necessarily imply that they are done in multiple environments (decentralized).

Table 1 presents examples of different modes of participation, ranked from the least amount of farmer participation to the greatest. The examples in Table 1 represent arbitrarily selected points on a continuum characterized by increasing participation by farmers in the breeding process, more frequent communication between farmers and scientists, and growing mutual trust. An actual breeding system may consist of only one of these modes of participation, or of some combination. For example, it is possible to conceive of a breeding system in which varieties are initially improved through formal breeding, then evaluated by farmers, then subjected to further selection by farmers in a community setting, and only then released (Machado & Fernandes, 2001).

For both farmers and breeders, movement along the continuum is not costless. As their participation increases, farmers must invest increasing amounts of time, energy, and resources; they must also provide increasing amounts of intellectual input and draw on increasingly sophisticated analytical skills. For scientists, movement along the continuum similarly entails costs, since traditional ways of organizing breeding programs may have to be modified substantially through the addition of new activities involving farmers.

Advantages of local plant breeding

Local approaches to plant breeding based on participatory methods offer a number of potential advantages compared to the traditional global approach to plant breeding.

Improved local adaptation breeding. PPB methods are well suited for niche breeding, or development of varieties that perform well in specialized environments. Niches can be defined not only by biophysical variables, but also by human preferences and needs. The advantage of PPB methods derives from the strong links that they generate between scientists and end users. By making selection criteria more relevant to end user needs, PPB can reach poor households that have not yet benefited from MVs (Kornegay et al., 1996; Sperling et al., 1993; van Oosterom et al., 1996).

Promotion of genetic diversity. Unlike the current global breeding model, which for the most part has concentrated on developing a limited number of varieties that are stable over time and adapted to a wide range of environments, the breeding model based on PPB methods encourages the maintenance of more diverse, locally adapted plant populations (Berg, 1995; Ceccarelli et al., 1997; Joshi & Witcombe, 1996). To the extent that diverse populations are taken up and grown by farmers, *in-situ* conservation of crop genetic resources is encouraged (Qualset et al., 1997), and genetic diversity is enhanced (Witcombe et al., 2001). PPB methods could, however, lead to loss of genetic diversity if only a few genetically similar plant populations are taken up and grown by farmers, displacing an array of more diverse populations.

Increased breeding efficiency. Returns to investment in plant breeding research will increase if use of PPB methods increases MV adoption levels. Similarly, economic benefits will be created if use of PPB methods accelerates adoption of MVs by reducing the time required to develop new varieties (Pandey & Rajatasserekul, 1999). No matter how excellent the science, if improved germplasm is never adopted, or if it is adopted only after a long lag, the breeding process must be considered inefficient. Although relatively little empirical work has been done to document the speed of PPB compared to conventional breeding, recently evidence has started to emerge suggesting that PPB can lead to earlier adoption of MVs, with no major additional costs (Witcombe et al., 2003).

Empowerment of rural communities. PPB allows rural communities to maintain germplasm they value

Table 1. Modes of participation in participatory plant breeding (PPB)

Mode of participation	Role of plant breeders	Role of farmers	Comments
Farmers are given finished varieties developed by plant breeders	• Set breeding objectives • Select source germplasm • Identify traits for improvement • Determine breeding methodology • Establish testing procedures • Evaluate finished cultivars on station	• Decide only whether or not to adopt the product	• Traditional breeding • Little direct interaction between farmers and breeders • Breeders knowledge of what farmers' want is not based on organized and direct interaction with farmers
Farmers provide source germplasm on which breeding process is based	• Collect and characterize source germplasm • Identify traits for improvement • Determine breeding methodology • Establish testing procedures • Evaluate finished cultivars on station • Basis for developing new varieties	• Provide source germplasm • Part of target population	• Source germplasm comes from farmers in target population, rather than gene bank • Well adapted material, hopefully with many traits farmers value • Tenuous relationship between farmers and breeders • Breeding process solely in the hands of breeders
Farmers identify traits to be improved and suggest selection criteria	• Set breeding objectives • Select source germplasm • Determine breeding methodology • Establish testing procedures • Evaluate finished cultivars on station	• Identify traits for improvement	• Better targeted varieties • Varieties more likely to respond to farmers' needs and constraints
Farmers evaluate finished varieties on station or in scientists-managed on-farm trials and help select varieties to distribute	• Set breeding objectives • Select source germplasm • Identify traits for improvement • Determine breeding methodology • Establish testing procedures • Finished cultivars evaluated on station or in farmers' fields but under breeders' management	• Actively participate in testing procedures • Identify finished or near finished varieties that are interesting to them	• Farmers may be able to select for traits that they cannot easily describe in words • Decision-making and responsibility for selection of germplasm shared between breeders and farmers • If varieties are planted on-farm in several different locations, breeders and farmers can evaluate them under a range of biophysical conditions

Table 1. Continued

Mode of participation	Role of plant breeders	Role of farmers	Comments
Farmers evaluate unfinished materials (lines, families, landraces) on station or in scientists-managed on-farm trials and select materials for further improvement	• Help set breeding objectives • May select source germplasm • Help identify traits for improvement • Determine breeding methodology • Establish testing procedures • Finished cultivars evaluated on station or in farmers' fields	• Identify interesting materials that still show a high degree of genetic variability for further improvement • Help to set the breeding objectives • Identify traits for improvement	• May lead to more diverse set of materials to be improved • Provides good idea of genotype-by-environment interactions if done in farmers' fields
Farmers conduct germplasm evaluation trials in their own fields and using their own management practices	• Help set breeding objectives • May select source germplasm • Help identify which traits will be targeted for improvement • Determine breeding methodology	• Farmers actively participate in testing procedures • Testing is done in farmers' fields and under their management • Identify near or finished varieties or interesting materials that still show a high degree of genetic variability for further improvement • Help to set breeding objectives • Identify traits for improvement	• Materials could be finished varieties or unfinished materials in different stages of improvement • Provides a very good idea of genotype-by-environment interactions • Explicitly incorporates farmers' needs, interests, and constraints • Strong organized interaction between breeders and farmers • Sharing of decision-making, responsibilities, and activities
Farmers are trained in 'scientific' breeding methods	• Train farmers in scientific breeding methods so they can: (1) maintain valued traits in their varieties, (2) modify existing traits, and/or (3) introduce new traits.	• Set breeding objectives • Select source germplasm • Identify traits for improvement • Determine breeding methodology • Establish testing procedures • Testing done on farmers' fields	• Trained farmers are able to carry out breeding process on their own, possibly with help from scientists

Source: Authors.

and enables them to participate in the development of new varieties that suit their needs. PPB methods thus can empower groups that traditionally have been left out of the development process (McGuire et al., 1999).

Shortcomings of local plant breeding

While PPB has many potential advantages, it also has several potential shortcomings.

High overall cost for breeding programs. One advantage of PPB methods is that they can generate varieties targeted to specific niches. This advantage may come at a cost, however: the recommendation domain for each individual variety will often be limited. Although varieties developed for specific niches may be capable of spreading to other distant and different environments (Joshi et al., 2001), in many cases they are unlikely to spread as readily as varieties that have specifically been developed to have wide adaptation. For this reason, PPB methods are well suited for village-level work involving small numbers of farmers, but it is not clear that it will always be feasible to scale them up to involve large numbers of farmers, especially when these farmers are distributed over a wide area. Scaling up PPB methods for work at the regional, national, or international level could require large investments in resources.

High cost for participating farmers. Unlike traditional approaches to plant breeding in which most work is done by scientists, farmers participating in PPB have to invest resources – their time and intellectual capital, and sometimes traditional production inputs such as land, labor, and capital. The amount of resources farmers must invest increases in proportion to their degree of participation. This may be a particular problem for poor farmers, who by definition have few resources to contribute. Poor farmers therefore may be unwilling or unable to participate in PPB schemes because participation tends to be relatively costlier for them.

Additional training needed for scientists. Scientists require specialized skills that are not normally taught in traditional plant breeding programs to be proficient at using PPB methods. These specialized skills require additional training. At a time when many NARSs are downsizing, this additional training will not always be readily forthcoming. Currently there is limited local capacity within most NARSs for carrying out PPB, and prospects are limited for quick improvement. Unfortunately, it also seems unlikely that such training will be provided by the private sector, because while PPB is particularly well suited to serve the needs of farmers located in marginal areas of high environmental variability, these areas offer limited commercial incentives for private firms.

Linking the old with the new

The global approach that has traditionally characterized international plant breeding efforts and emerging new local approaches epitomized by the PPB movement both have strengths and weaknesses. In future, the international plant breeding system will be greatly strengthened if the new local approaches can be combined with the existing global approach in ways that exploit the advantages of both while eliminating or at least reducing their respective disadvantages. For this to happen, three types of challenges will have to be overcome: technical, economic, and institutional.

Technical challenges

If emerging local approaches to plant breeding are to gain wider acceptance, data generated by these approaches will have to be credible. Because many methods being developed in PPB are still evolving, data generated using these methods lack credibility in certain circles. Some ‘old school’ plant breeders think that participatory methods are so informal that data generated using these methods are not amenable to rigorous statistical analysis. Justified or not, attitudes such as this diminish the professional standing of breeders who use PPB and act as a disincentive to adoption of PPB methods. Recent papers that analyze PPB issues in the context of accepted plant breeding theory (e.g., Atlin et al., 2001; Witcombe & Virk, 2001) or draw on experience gained through formal plant breeding research to strengthen PPB methods (e.g. Bänziger & Cooper, 2001; van Eeuwijk et al., 2001) are adding credibility to PPB approaches. Unfortunately, however, the credibility problem extends beyond the plant breeding profession. Regulatory authorities in many countries are still not willing to consider data generated using participatory methods when they evaluate varieties for registration and release. Seed company representatives may also be reluctant to market varieties generated through PPB. Even farmers who have evaluated the performance of varieties grown in researcher-managed trials are skeptical that their own rankings will hold up when the same varieties are grown under farmer management.

One of the main advantages of PPB is that it provides a means of assessing so-called ‘subjective’ traits. In food crops these include taste, aroma, appearance, texture, and other characteristics that determine the suitability of a particular variety for culinary use. These traits are difficult to measure quantitatively because they are a function of human perceptions. This poses a major problem for plant breeders, because before they can select for a trait, it must be well identified and subject to measurement. Depending on the context, the concern of the plant breeder may be to improve these ‘subjective’ traits, or simply to maintain them while other traits are being improved. In either case, however, the breeder will need to be able to identify these subjective traits and evaluate them. Identification and evaluation of subjective traits requires close collaboration between plant breeders, social scientists, and farmers. Social scientists traditionally have played a minor role in plant breeding, but when it comes to identifying subjective traits their contribution is fundamental, because they specialize in the study of human perceptions and preferences.

Not all social scientists are experts in this field. Much methodological work still needs to be done in developing efficient and reliable methods for eliciting and analyzing end-user preferences. Bellon (2001) has reviewed methods being developed by PPB practitioners to help in identifying and analyzing subjective traits. Focus group interviews and matrix ranking techniques can be useful for eliciting and prioritizing traits of importance to selected groups of end users. Since these methods rely on group interviews, however, the data they generate generally cannot be used to analyze variability in the preferences of individual group members. Also, while group interviews often help to build consensus among members, consensus building can hide important differences of opinions between individuals. Partly for this reason, group interviews are increasingly being complemented by systematic elicitation of scores or rankings from individuals as a way to capture intra-group variability in knowledge and preferences. If respondents are selected using valid sampling methods, these scores or ratings can be analyzed in a statistically rigorous way (Coe, 2002).

To achieve better integration of global and local approaches to plant breeding, data generated by PPB methods will have to be recognized as valid not only by supporters of participatory breeding, but also by skeptics. The technical challenge facing the PPB movement is to develop varietal evaluation methods capable of generating credible data of widespread acceptability. Efforts are currently underway to refine specialized trial designs that can generate different types of data tailored to specific needs of different groups of users. Following Franzel at al. (2001), it is possible to distinguish three types of varietal evaluation trials distinguished in terms of objectives, design, and manner of implementation. Type 1 trials, whose objective is to assess the biophysical properties of different materials, are researcher-designed and researcher-managed. Type 2 trials, which are designed to elicit farmer perceptions about different materials, are researcher-designed and farmer-managed. Type 3 trials, whose objective is to determine the acceptability of different materials and/or promote farmer innovation, are farmer-designed and farmer-managed. Depending on the research objectives, these different trial types can be combined. For example, the ‘Mother-Baby" varietal evaluation system combines Type 1 and Type 2 trials in different locations within the same target area (CIMMYT, 2000; Snapp, 2002). The Mother-Baby system has become popular in recent years, even though its technical and economic merits remain unproven. Some breeders think that the Mother-Baby system provides a cost-effective approach for generating data that are credible to all involved in the plant breeding process.

Economic challenges

In a world of limited resources, research must be cost-effective. Managers of plant breeding programs must determine how global and local approaches can be combined in ways that make sense economically. Intuition suggests that it would not be efficient for the international plant breeding system to consist *only* of global breeding programs or *only* of local breeding programs; rather, efficiency could be improved by adopting some combination of the two. But what combination? In economic terms, the challenge is to allocate resources in such a way that global and local breeding programs generate similar benefits at the margin. This promises to be difficult, because relatively little is known about the economics of plant breeding. Numerous case studies have estimated the returns to investment in conventional plant breeding programs, but the results tend to be specific to a particular location, organization, and crop. Much less empirical work has been done to assess the returns to investment in PPB programs, which is not surprising given that participatory breeding methods are still new. The few existing studies indicate that PPB can generate significant benefits – not only direct benefits resulting from faster and more extensive adoption of MVs, but also indirect benefits resulting from farmers' participation in the breeding process (Lilja & Hassan, 2003; Witcombe et al., 2003). Economic evaluation of PPB continues to be hampered by methodological problems. Although widely accepted methods are available for estimating the benefits resulting from yield increases (Morris and Heisey, 2003), the same is not true when it comes to estimating the benefits resulting from improvement of 'subjective' traits, one of the key advantages associated with PPB approaches. This is not to say that methods for evaluating subjective traits do not exist; they do (Agbola et al., 2002; Baidu-Forson et al., 1997). However these methods have not been applied to the evaluation of PPB programs.

A major challenge will be to generate improved knowledge about the economics of plant breeding so that the integration of global and local approaches can be based more explicitly on considerations of economic efficiency. Here it is important to note that local and global breeding methods must be held to the same standard of economic efficiency. Many who express skepticism about the cost-effectiveness of local breeding methods seem to take for granted that 'tried and true' global breeding methods are cost-effective, when the reality is that the cost-effectiveness of established breeding programs is rarely examined.

Economic efficiency considerations are important not only at the level of plant breeding programs, but also at the level of individual participants in the plant breeding process. By definition, PPB depends on participation by farmers. Proponents of PPB often seem to overlook the fact that this participation entails costs. In many cases, farmers who participate in PPB must contribute land, labor, and other inputs, and they may also be required to incur additional risk. At the very least, they must contribute time, which could have been devoted to other activities. The idea underlying PPB is that by involving farmers in the genetic improvement process, plant breeding programs will be able to produce better varieties that will be adopted more widely and generate greater benefits on aggregate. But what benefits can participating farmers expect to realize? Although it is often assumed that participating farmers will be rewarded, the benefits realized by those who participate in PPB schemes are not always obvious – and even when they are obvious, they may not be large enough to justify participation. For example, Smith et al. (2001) report that PPB programs carried out in Mexico and Honduras involving stratified mass selection without pollination control in maize required only limited time and labor commitment from farmers, but they still did not show enough progress in the long run to justify farmers' involvement. Thus, another challenge will be to determine modes of participation that ensure equitable compensation for participating farmers. For a given amount of expected benefits, there presumably exists an optimal level of participation, but we still do not understand the economics of PPB well enough to be able to say much about the costs and benefits of participation.

Institutional challenges

A third set of challenges that will have to be overcome to achieve integration of global and local approaches to plant breeding relates to institutions. The term 'institutions' is used here in a broad sense to include not only organizations, but also laws, regulations, 'rules of the game,' and standard operating procedures that govern the current international plant breeding system.

One set of institutions that will have to be modified to accommodate new types of information generated by PPB are national and international regulatory frameworks that govern the evaluation, approval, and release of new plant varieties. Most countries currently have well-defined varietal testing and release procedures in place; before a new plant variety is approved for official release, it must undergo a long and often cumbersome evaluation process (Morris, 1998; Tripp, 1997). In most countries, new plant varieties are approved for release only if it can be shown that they differ in some significant way from varieties already in the market. Evidence of significant difference generally consists of data generated through conventional varietal evaluation trials conducted under the supervision of duly certified testing authorities. Subjective performance data such as those generated through PPB are usually not recognized in varietal approval guidelines, suggesting that existing regulatory procedures will have to undergo major revisions to accommodate products of PPB programs.

Another set of institutions that will have to be overhauled to accommodate new PPB realities are the rules and procedures to assign credit for genetic improvement efforts and determine compensation. Under intellectual property rights (IPR) regimes currently prevailing in most countries, credit for breeding accrues to the breeder or breeding program that made the final selection or selections. The key criterion for claiming IPR is that the selection or selections must have created 'novelty' in the resulting cultivar, i.e., modified it in some way that makes it recognizably distinct from cultivar or cultivars from which it was derived. Usually a breeder working in a specific location performed the selection or selections that created the novel cultivar, so assignment of credit is relatively straightforward. But with PPB, the nature of the breeding process can change fundamentally, depending on the mode of participation. In cases in which farmers are asked to evaluate materials developed by breeders, one can argue that there is really little difference from the existing system. But in cases in which participating farmers not only evaluate materials but also select plants for further improvement, the line becomes blurred, and it is difficult to deny participating farmers a share of the breeding credit.

Once it is acknowledged that farmers share the credit, the issue of compensation arises. How should farmers who participate in PPB programs be compensated for their contribution? Currently in most countries, IPR systems afford little recognition to the role played by farmers in plant breeding. Recently attempts have been made to acknowledge farmers' contribution in improving cultivars commonly referred to as 'landraces' or 'farmers' traditional varieties,' but efforts to link this recognition to formal compensation generally have made little headway. Discussions often have become bogged down because of the enormous practical difficulties involved in determining what would be an equitable level of compensation and who should receive payment. While the lack of progress is perhaps understandable, at the same time, it shows the inadequacy of existing intellectual property laws and points to the enormous challenges that have to be overcome to establish revised IPR regimes capable of equitably assigning credit in the more participatory breeding system of the future.

Discussion

The recent emergence of the PPB movement represents a response to weaknesses of the traditional global approach to plant breeding. The term 'participatory plant breeding' does not refer to a single, well-defined method for plant genetic improvement; rather, the term refers to a set of breeding methods characterized by many different potential forms of interaction between farmers and breeders. What these many forms of interaction have in common is that all are designed to shift the locus of plant genetic improvement research toward the local level by directly involving the end user in the breeding process.

Depending on the circumstances, the locus of breeding activity can vary (Figure 1). Prior to the appearance of modern scientific breeding programs, all plant breeding was essentially local. Individual farmers saved seeds collected in their own fields or in their neighbors' fields for replanting the following season, and in so doing, performed the complete range of tasks associated with plant genetic improvement, including selection of source germplasm, trait improvement, cultivar development, and final evaluation of finished varieties (Model 1). Following the emergence of modern scientific breeding programs, plant breeding effectively became globalized. Under the current international plant breeding system, a small number of professional plant breeders develop MVs for distribution throughout the world, in the process assuming responsibility for all breeding tasks (Model 5). In between these two extremes lie many different possible approaches to plant breeding characterized by varying degrees of interaction between farmers and scientists at different stages of the breeding process. These range from "complete participatory breeding' (Model 2) in which farmers and scientists collaborate continuously throughout the breeding process to 'participatory varietal selection' (Model 4) in which the initial stages of the breeding process are performed exclusively by scientists and farmer participation is restricted to evaluating finished cultivars.

PPB clearly has potential to enhance traditional global approaches to plant breeding, but at this point it would be premature to say that the potential has been realized. Before the effectiveness of PPB is conclusively established, tangible evidence will be needed to demonstrate that participatory breeding methods can live up to the expectations of PPB proponents. A number of important questions still must be answered. Will varieties developed using PPB differ from those produced using conventional breeding methods? If they differ, will they be better? If they will be different and better, will the additional benefits justify the additional costs implied by PBB? How exactly will the costs and benefits of PBB be distributed? Will institutional plant breeders find it useful to adopt PBB methods? Will farmers find it worthwhile to participate in PPB schemes? Partial answers to some of these questions

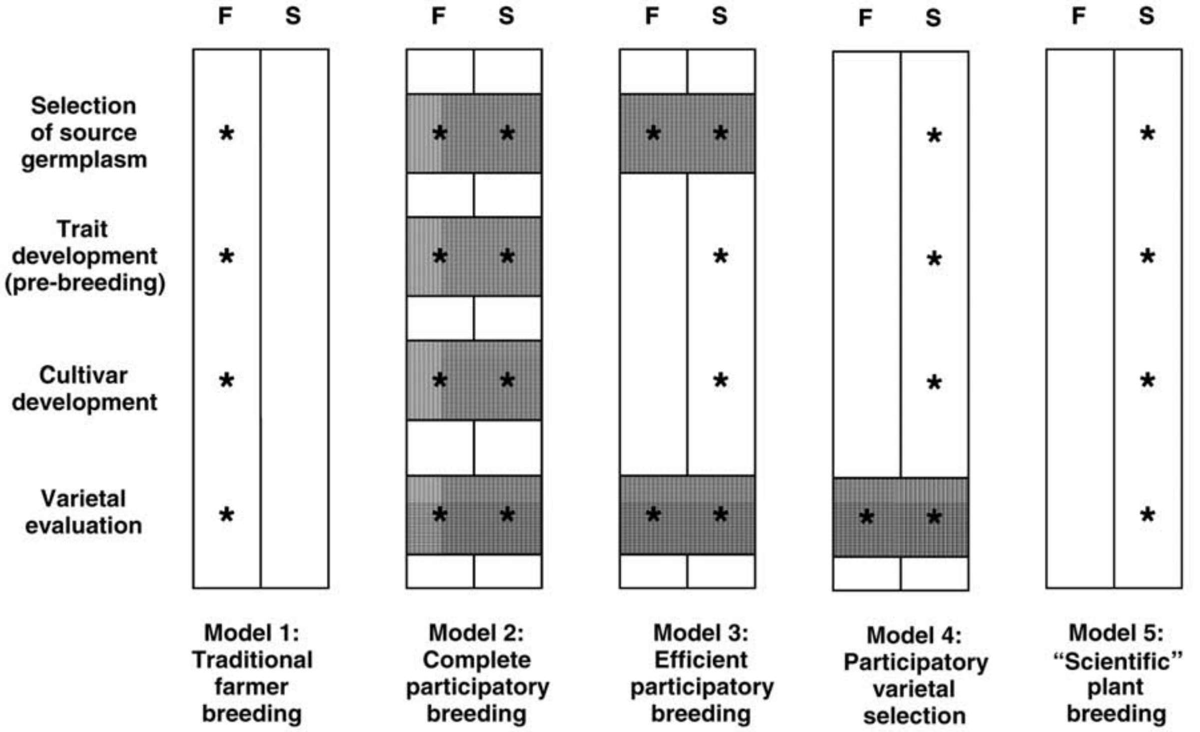

Figure 1. Integrating global and local approaches to plant breeding. Note: F = farmer; S = scientist.

are beginning to emerge, but additional research is needed to clear many remaining uncertainties. (For examples of recent work in this area, see the special issue of *Euphytica* 122 (3), 2001.)

Questions concerning the cost-effectiveness of PPB are particularly important. Even if it turns out that PPB leads to the development of varieties that are not only different from conventionally-bred varieties but also better, development of these varieties is likely to entail added costs for not only for plant breeders, but also for end users. Thus a major challenge facing managers of institutional breeding programs is to figure out ways to foster increased participation by end users, but only during those stages of the breeding process at which participation makes a difference. The term 'participatory research' has become something of a mantra in some circles, but it is important to keep in mind that more participation is not necessarily better. Participation should not be seen as an end in itself. Rather, it should be seen as a means to an end – namely, the production of varieties that are better adapted to the needs of end users.

The distinction between ends and means is important. During some stages of the breeding process, there is no reason to believe that increased participation by end users will necessarily be beneficial. For example, most trait improvement work (i.e., pre-breeding) and even many types of cultivar development work can be carried out very efficiently by station-based plant breeders using well-established scientific selection strategies and statistically valid analytical procedures. It is difficult to imagine how involving farmers in these activities will lead to improvements in breeding efficiency. As suggested by Curtois et al. (2001: 539): '*. . . we need to define the breeding operations for which participation is most necessary. Farmers' participation in goal and selection criteria settings and/or selection by farmers within well-chosen pre-released varieties may be enough to increase the rate of adoption. Then farmers' participation in the breeding process itself, which is one degree of complexity further, may not be necessary.*' On the other hand, farmers often have unique knowledge of characteristics of existing varieties, especially landraces, so it is likely to be advantageous to involve them in the selection of source germplasm to be used in a breeding program. Similarly, the acceptability of a variety may depend on characteristics that are difficult for scientists to measure and quantify, so it is likely to be advantageous to ensure that farmers participate in the evaluation of finished cultivars before they are released.

Recognizing that farmers and plant breeders have comparative advantages for different aspects of the breeding process, and taking into account cost considerations, the most efficient PPB system (Model 3) is likely to fall somewhere in between complete participatory breeding (Model 2) and participatory varietal selection (Model 4). It is important to recognize, however, that no single 'optimal' model exists, because the cost-effectiveness of end user participation will vary depending on the characteristics of the crop, the agroclimatic characteristics of the environments in which the crop is grown, the socioeconomic characteristics of those who produce and consume the crop, the institutional setting, and other factors. Trial-and-error experimentation and 'action learning' approaches often will be needed to determine what works best in a given situation. In this vein, the Participatory Research and Gender Analysis Program, a System-wide Initiative of the CGIAR, has funded a number of participatory breeding initiatives through its small-grants program in the hope of generating experience in this area (for a summary of the PPB work that has been funded through this program, see http://prgaprogram.org/publica.htm#ppb_rep).

Improved integration of global and local plant breeding methods has the potential to deliver better varieties to farmers in developing countries, especially poor households in marginal environments who grow mainly non-commercial food crops. Until now, such households have been bypassed by the international plant breeding system, leaving them vulnerable to periodic production shortfalls and chronic food insecurity. How to implement and sustain the integration of global and local breeding methods remains to be worked out, however, particularly in light of institutional asymmetries in the existing international plant breeding system. For many crops, especially food crops of limited commercial importance, global breeding presently is carried out by Future Harvest Centers. Meanwhile, local breeding is all too often left to national research organizations, many of which are poorly funded and inadequately staffed. Considerable challenges will have to be overcome to strengthen the latter without weakening the former. Global and local breeding are complementary activities, rather than substitutes, so simply reassigning resources away from the Future Harvest Centers and toward national research organizations cannot strengthen the international plant breeding system. The challenge facing the international community thus will be to strengthen local breeding programs while preserving the excellence of existing global breeding programs – especially those of the Future Harvest Centers.

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