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PARTICIPATORY PLANT BREEDING IS BETTER DESCRIBED AS HIGHLY CLIENT-ORIENTED PLANT BREEDING. I. FOUR INDICATORS OF CLIENT-ORIENTATION IN PLANT BREEDING

By J. R. WITCOMBE†, K. D. JOSHI‡, S. GYAWALI§, A. M. MUSA¶, C. JOHANSEN††, D. S. VIRK *and* B. R. STHAPIT‡‡

CAZS, University of Wales, Bangor, LL57 2UW, UK, ‡*CAZS, CIMMYT, PO Box 5186, Kathmandu, Nepal,* §*Local Initiatives for Biodiversity, Research and Development* (*LI-BIRD*), *PO Box 324, Pokhara, Nepal,* ¶*Peoples Resource-Oriented Voluntary Association* (*PROVA*), *Kazihata, Rajshahi, Bangladesh,* ††*Independent Consultant, Apartment 2B, Palmdale, Plot 6, Road 104, Gulshan-2, Dhaka 1212, Bangladesh and* ‡‡*International Plant Genetic Resources Institute* (*IPGRI-APO*), *10, Dharmashila Buddha Marg, Nadipur Patan-3, Pokhara, Nepal*

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SUMMARY

In this paper we attempt to remove the dichotomy created by distinguishing between participatory and non-participatory breeding programmes by using the degree of client orientation as the basis for an analysis. Although all breeding programmes are implicitly client-oriented, we examine how participatory approaches explicitly increase the extent of client orientation. We briefly review the history of participatory plant breeding (PPB) and analyse the participatory techniques used at different stages of the breeding programme. In common with several other authors, we find that farmer involvement in selecting in the segregating generations may not be an essential component of PPB. However, in some circumstances such collaboration is required and is the subject of a second paper in this series. The purpose of all the techniques used in PPB programmes is to better meet the needs of clients. Thus, breeding programmes can be differentiated by their extent of client-orientation removing the dichotomy involved with the term participatory. We discuss four techniques in the suite of techniques that have been employed by PPB: identifying the target market or clients; using germplasm that can best meet the needs of target clients; matching the environments of the target clients; and product testing in the target market with target clients. Most attention is paid to the last of these four that is often referred to as participatory varietal selection (PVS) and how it is done varies with circumstances. Rice varieties from a client-oriented breeding programme in Nepal were tested in mother and baby trials in Bangladesh. The rapid acceptance of these varieties by farmers illustrates the power of the participatory trials system and the success of a highly client-oriented breeding approach.

INTRODUCTION

Building bridges

When participatory techniques are appropriately employed in plant breeding they can have an impact by quickly and cost-effectively producing much-improved crop varieties. These varieties may be for resource-poor farmers in marginal environments who previously were entirely dependent on landraces (Virk *et al*., 2003; Witcombe

† Corresponding author: E-mail: j.r.witcombe@bangor.ac.uk

et al., 2003) or for farmers in more productive environments where they were dependent on very old improved varieties (Witcombe *et al.*, 2001 and paper 2 in this series). Thus, despite a general trend for the benefits of farmer participation to be lower in more productive environments (Okali *et al.*, 1994), farmer participatory techniques fit well with more productive agricultural environments where there is often a greater diversity of client needs (Witcombe, 1999).

However, the benefits of farmer participation may not be universal and we attempt here to create a balanced view of its necessity and its benefits. We do so by examining participatory plant breeding (PPB) in an analytical framework of the degree of client orientation that is increased by all of the commonly used techniques in PPB. Although good client orientation is always needed, we argue that collaboration with farmers in intensive participatory methods is not always essential to achieve it. Hence, more farmer participation is not always better from the viewpoint of increasing the efficiency of breeding programmes. However, maximizing farmer participation may be better for other outputs for which participatory research is used (Okali *et al.*, 1994), such as the development or the empowerment of individuals or communities.

From our analysis, we concur with Biggs and Gauchan (2001) that it is better not to use any qualitative label that implies a dichotomy among breeding programmes, e.g. participatory or conventional. Such a dichotomy requires a 'yes' or 'no' type of decision on defining a breeding programme. Biggs and Gauchan (2001) point out that 'A "them-and-us" mentality is being established: you can belong to one camp or the other.' Instead, we argue for building a bridge between camps by using a quantitative description of the *degree* of client orientation thereby avoiding the pitfalls of a dualistic definition. A possible argument against such a description is that all breeding programmes are highly client-oriented. Indeed, all implicitly have client orientation, but few explicitly adopt techniques to meet client needs more effectively. Our analytical framework suggests several indicators on how well client needs have been explicitly addressed.

In the context of increased research efficiency we describe the commonly used participatory techniques. One of the most important of these is the on-farm testing of varieties with farmers, so it is described in the greatest detail.

Formalizing a tradition

In many countries, resource-poor farmers in more marginal agricultural environments have not benefited from modern plant breeding. The reasons were summarized by many authors as a lack of farmer involvement and the recommended solution was the 'farmer-back-to-farmer' and 'farmer first' approach (Rhoades and Booth, 1982; Chambers and Ghildyal, 1985). However, this built on a long history of farmer participatory research. A long-established form of participatory research is for breeders to use varieties selectively adopted by farmers as parents. Biggs (1989) discusses many examples of farmer participatory research of the 1970s. More recent examples of participatory research have only formalized a long tradition (e.g., Maurya *et al*., 1988; Sperling *et al*., 1993; Joshi and Witcombe, 1996). This formalization has included the naming of concepts such as:

- participatory plant breeding (PPB) that was first used extensively in print at a conference in 1995 (IDRC, 1996) where, in a commonly used definition of Witcombe *et al*. (1996), farmers participate in making selections in the early (segregating) generations of breeding programmes, and
- participatory varietal selection (PVS) (Witcombe *et al*., 1996) where farmers test, under farmer management, an appropriate range of products (e.g., varieties and hybrids) from formal breeding programmes.

Sperling *et al*. (2001) defined breeding programmes as PPB that only use PVS and do not involve farmers in selection during the segregating generations. They also include steps, such as on-farm testing and seed supply, that are not normally considered as part of plant breeding by authors such as Schnell (1982). To include these additional activities, others have used the term participatory crop improvement (PCI) (Witcombe *et al*., 1996; Almekinders and Elings, 2001) as a broader term that encompasses greater farmer involvement in all processes of crop improvement including plant breeding, seed supply and agronomic interventions (e.g., Harris *et al*., 2001, for seed priming).

Although PVS is now widely used, programmes where farmers collaborate in the selection in the segregating generations are much rarer. Both theoretical and practical reservations are common. From many discussions with fellow plant breeders, one reason for not employing farmer participation in selection in the earlier generations is the assumption that years of training on the theory and practice of plant breeding gives an advantage to breeders over farmers in realizing genetic gains from selection. This may be because it is thought that farmers have to be capable of conducting complex selection schemes involving thousands of entries while ignoring the possibilities of adopting more appropriate, simpler methods for collaborative research. There are also concerns about the transaction costs of working with farmers, although these costs can be greatly reduced by working in collaboration with extension services and non-governmental organisations (NGOs). Some or all of these reservations may be shared by scientists who readily accept the need for the greater involvement of farmers in varietal testing. We, therefore, consider the evidence on the effectiveness of collaboration with farmers in selection in the earlier generations (Witcombe *et al*., second paper in this series). We conclude that such a collaboration can give great advantages, but only under particular circumstances, and that participation as an end in itself should be avoided.

STAGES OF BREEDING, STAGES OF PARTICIPATION

A client-oriented analytical framework

PPB is an imprecise concept and Atlin *et al*. (2001) refer to a suite of techniques some or all of which are used in breeding programmes that are diverse in scope and approach. Morris and Bellon (2004) draw a similar conclusion when they say, 'PPB refers to a set of breeding methods characterised by many different forms of interaction between farmers and breeders all designed to shift the locus to the local level by directly involving the end user in the breeding process'. We provide a theoretical framework for PPB by analysing this suite of techniques by their purpose which, we argue, is to orient programmes more closely to the needs of clients and by which stage in the breeding programme each technique is used (Table 1). Plant breeding was conveniently summarized into three main stages by Schnell (1982) of generating variability, selection, and testing of experimental varieties (usually on the research station). However, goal setting where the desired traits in a new variety are specified is an essential precursor to generating variability (Table 1). In considering crop improvement as a whole we add two additional steps: seed supply and outcome assessment, both of which can provide invaluable information for feeding back into a breeding programme. (We use the term 'outcome assessment' to avoid the assumption in the more usual 'impact assessment' that an impact exists that can be assessed). All these steps can be placed in the product innovation context of Sumberg and Reece (2004) (Table 1).

Four techniques are commonly used in PPB programmes, each relating to one of the first four stages in the breeding process (Table 1). All these techniques orient the breeding programme closer to client needs and hence their use can indicate the degree of client-orientation of any breeding programme.

Knowledge of the market is sufficient for choosing crosses (knowing what varieties farmers currently grow and what they need in new varieties) and is also sufficient for appropriate selection procedures in the segregating generations (knowing the environments in which farmers grow the varieties and knowing which traits are important). Hence, in many circumstances it is not essential to involve farmers in the breeding process. Usually only two stages greatly benefit from the active participation of farmers: at the beginning of the breeding programme (stage 1) and at the end (stage 4).

Several authors have already pointed out that involving farmers in the breeding process may not be essential. Morris and Bellon (2004) define the model of farmers only being involved in stages 1 and 4 as 'efficient participatory breeding' rather than 'complete participatory breeding'; Courtois *et al*. (2001) state that participation of farmers in the breeding process may involve a degree of unnecessary complexity, and Weltzein *et al*. (2003) draw similar conclusions for some of the case studies they reviewed. However, the collaboration of farmers in breeding in the segregating generations (collaborative breeding) is an option that has been used with success because it can be an inexpensive and simple method of matching the selection environment with the target environment. In certain circumstances, such collaboration is essential (Witcombe *et al*. Paper 2 in this series).

Defining markets and clients in this framework

The analytical framework examined how the needs of the market for seeds of the new variety can be better met by using farmer participatory techniques (Table 1). This hinges on the definition of 'market' that, even for non-profit-motivated, public-sector plant breeding, is an appropriate term. It draws parallels with the product innovation

Table 1. A deconstruction of a typical crop improvement programme§ (only the first four steps are strictly plant breeding) and the application of participatory techniques.

Product innovation stage	Stage in crop improvement programme	Purpose of farmer participation – leads to better client orientation	Farmer participatory techniques that aid research efficiency	Optional and more collaborative techniques
1. Product design	1. Goal setting (or specifications of the variety)	1. Identify the target clients needs (varietal specification)	Participatory rural appraisal – farmers and other stakeholders (e.g., consumers, purchasers) are consulted.	
2. Product development	2. Generating diversity: a. Choosing parents	2. Use germplasm that can best meet the needs of target markets/ clients.	Use knowledge of farmers' selective adoption and farmers perceptions of germplasm in PVS. Improve by incorporating the specified traits from complementary germplasm.	
	b. Making crosses			Train farmers to make crosses.
	3. Selection in segregating generations	3. Match the selection environment to those of the target market/ clients.	Match the selection environment to the farmers' fields using information primarily from crop improvement Stage 1 and Stage 4.	Farmers make selections in their fields.
3. Product testing	4. Testing varieties	4. Test products in the target market with target clients.	PVS – farmers collaborate in trials on their fields. (Simultaneous research station trials).	
4. Product marketing	5. Seed supply		Community-based seed production.	
5. Customer feedback	6. Outcome assessment		Field surveys of clients and purchasers of harvested products. Participatory appraisals.	

§Where we assume that hybridization is used rather than simple introduction or selecting from existing variation in landraces.

system in the private sector. However, the private-sector market is comprised of customers for seeds of the new varieties ('new seeds'), but in the public sector, where it may well be considered advantageous to maximize benefits rather than sales, the market can be more broadly comprised of the users of new seeds. Benefits increase when farmers obtain new seeds, outside of formal commercial or state sources, in an informal farmer-to-farmer network by gift, seed exchange or barter. Hence, public-sector breeders may regard the term 'customer' as too narrow. 'Client' conveys a broader meaning, 'user' rather than 'customer' so when participatory techniques are effectively used in crop improvement programmes they can be described as highly client-oriented (following Biggs [1989] who used the term on-farm, client-oriented research).

We have defined the market as that for new seeds not for the produce such as food grains or industrial products such as cotton. New varieties only succeed when the needs of both farmers and consumers are met, i.e., they have to possess desirable pre- and post-harvest traits. Hence, even in cash and industrial crops where the qualities required in the produce are well defined and well known, techniques that improve client orientation in pre-harvest traits are still required and Lançon *et al*. (2004) have shown their potential for breeding cotton. In food crops, the desired post-harvest traits are often not well known, particularly when the needs of local markets vary, so grain purchasers and farmers need to be consulted on the qualities that determine price.

This analytical framework avoids dualisms

Describing the degree of client orientation avoids the artificial dichotomy between participatory and conventional breeding: a highly client-oriented but so-called conventional breeding programme is no longer separated from a so-called participatory one. Other descriptions also provide more inclusiveness such as impact-oriented breeding (Sperling, personal communication), adaptive breeding or decentralized breeding. These alternative descriptions are in a hierarchy: farmer participation is an activity or a mode of working, market or client orientation the purpose of this mode of working, and impact orientation its goal. However, all still create a dichotomy between two types of programmes unless qualified by degree, for example, 'highly' or 'poorly'.

Using a more inclusive term that describes the purpose – better client-orientation – has advantages. This is illustrated by an example of a highly client-oriented breeding programme that, in the dualism between conventional and participatory breeding, has never been described as participatory. This is the improvement of the single-cross pearl millet hybrid HHB 67 in India. HHB 67 was chosen for improvement because it is popular with farmers; in 2003 it was cultivated on over half a million hectares in the state of Haryana. The reasons for its popularity (high yield combined with very early maturity) were known and there were no alternative hybrids available in this maturity class. The product design of the new variety was to retain the traits of HHB 67 considered advantageous by farmers (by producing a hybrid of very similar phenotype and maturity) whilst improving the downy mildew resistance of the hybrid and its yield under drought stress. Downy mildew resistance was chosen because all widely grown, single-cross, pearl millet hybrids in India have ultimately succumbed to downy mildew disease as pathogen virulence has evolved to overcome host plant resistance. Drought tolerance was prioritized because it is the most commonly encountered abiotic stress that causes large reductions in grain and stover yields. Hence, the location, size and nature of the market were well defined and the prioritized traits targeted at client-needs.

These breeding objectives were achieved using marker-assisted selection (MAS) in a backcross breeding programme (Hash *et al*., 2000; 2003). The new versions of the hybrid were tested against the original versions of HHB 67 for one year, in a line × tester experiment using the original and new versions of both parents of HHB 67 i.e., 843A (the seed parent) and H 77/833-2 (the pollinator). Although these trials were on research stations, five out of the six were in the target area and all had environments that matched the commonly encountered abiotic stresses in farmers' fields. The most promising versions were multiplied for immediate testing with farmers to evaluate if they were at least as good as the original HHB 67 (whilst conducting parallel on-station multi-locational trials required by the regulatory framework for crop variety release in India). This programme has used all of the techniques of an exemplary PPB programme without ever having been labelled as such.

Another example is the improvement of wheat varieties by the International Maize and Wheat Improvement Centre (CIMMYT) that are highly popular with farmers and are improved by a limited backcross breeding approach to incorporate durable disease resistance genes while improving yield and quality (Singh *et al*., 2001). As Sumberg and Reece (2004) point out, when adding a single trait to an otherwise acceptable variety the design specification is simple: all the qualities of the new variety plus the new character. Singh *et al.* (2001) added incremental gains for yield and quality to this simple specification.

Indicator 1. Orientation to markets and clients (product design)

The goals of a breeding programme can only be set efficiently by an analysis of the target market or clients. How efficiently this is done determines how well the product is specified and hence the degree of client-orientation. There is a lack of published evidence that public-sector breeding programmes pay attention to a formal analysis of markets, and public-sector breeding programmes have been unsuccessful in product innovation as farmers continue to grow landraces or obsolete cultivars at the same time that officially-released and promoted varieties lack the traits demanded by the market, e.g. early duration, high straw yield, or high grain quality. Sumberg *et al*. (2003) also argue that the public sector fails in market analysis: 'the public sector is a monopoly supplier to the market for innovations and one that struggles to relate to its client base'.

When market analyses are done by the public sector they are described in terms used by social scientists, e.g. participatory rural appraisal (PRA) (Chambers, 1997). This approximates to the market research approach of the private sector, a parallel that has been drawn by Sumberg and Reece (2004) who point out that methods initially developed by industry have been used to elicit consumer perceptions for agricultural innovations in the public sector (Adesina and Baidu-Forson, 1995; Sall *et al*., 2000). Private-sector market research uses techniques such as customer profiling and customer behaviour for assessing the market for new or existing products and involves the collection and use of data about consumers gathered from a wide variety of sources.

The PRA, when employed in PPB, focuses on the issues relating to the particular target crop. For a breeding programme, well-applied PRA techniques or customer profiling result in better client-orientation and make possible efficient goal setting (e.g. Weltzein *et al*., 1996) or product design (Sumberg and Reece, 2004). A successful PRA provides the information needed to specify the characteristics needed in a new variety:

- *The physical environment*. This defines where the crop will be grown, the agroecosystem, the common abiotic and biotic stresses and the common management practices including the typical levels of purchased inputs.
- *The existing varietal diversity*. The degree of potential fragmentation of the market into a diversity of niche-specific varieties can be understood from the diversity of varieties grown by farmers and the reasons for this diversity. It also identifies locally adapted germplasm that has the greatest potential for use in a breeding programme.
- *The size of the market*. The public sector may wish to analyse how poor are the farmers in the target market to see how efficiently public money will alleviate poverty, while the private sector will want to know how many well-off farmers there are (the customer profile) that have the capacity to purchase seed.
- *The desired traits*. It identifies the traits needed in a new variety for key traits such as duration and balance between grain and stover. Sometimes these traits may be unexpected, e.g. pericarp colour in rice (Sthapit *et al*., 1996) and easy threshability in rice (Joshi *et al*., 2002).

At the end of this process, a product specification can be made that includes all of the major adaptive, yield and quality traits needed. Hence, perhaps Sumberg and Reece (2004) are unduly pessimistic when they argue that *de facto* PPB programmes do not lead to a new product development orientation. A successful PRA (above) provides everything they argue should be included in the full design specification of a new crop variety. They also point out that while user involvement in product design and development may be valuable, it is not sufficient to guarantee a successful innovation process. For plant breeding this may also be pessimistic because the processes of new product development in plant breeding are well understood. As Sumberg *et al.* (2003) state, 'the need is . . . to increase the raw material that farmers can incorporate into their ongoing experimental activities' and this is exactly what is achieved when new products are tested in PVS trials.

The PRA techniques or surveys of Stage 1 can be replaced by feedback from other stages of crop improvement that involve farmer participation. For example, by implementing Stage 4 directly, when farmers test novel varieties on their own fields, a great deal of information is obtained such as the benefits or disbenefits of the traits of the new varieties. In the process of PVS, information is obtained on the biotic and abiotic stresses most commonly encountered in the target area, and on the currently adopted varieties and their important traits. However, without some prior knowledge of the target area, starting with Stage 4 involves the risk of wasting resources and losing credibility with farmers by testing highly unsuitable varieties. Valuable feedback can also be obtained from farmers selecting in the segregating generations (Joshi *et al*., 2002), from seed multiplication and supply and from outcome assessment.

It is of significance that some public-sector breeding programmes have excellent client-orientation because farmer groups fund them. These are clearly better-off, well-organized farmers that have generated financial surpluses they can invest. There are examples from Mexico and Australia. In Mexico, Patronato is a group of farmers from the Sonora region who voluntarily contribute to a fund from which they commission research; they also fund activities through a levy on seed sales. In Australia, the Grains Research and Development Corporation collect a voluntary levy from growers (with more than 99 % compliance) that is used to commission research. The federal government matches the levy dollar for dollar and farmers participate in the management of the corporation and the selection of research projects. In both cases, the farmers drive the research agenda by only funding what they collectively agree is relevant.

Indicator 2. Orienting germplasm to the target market

The understanding of which varieties are popular with farmers facilitates the targeting of the breeding programme for greater impact. This gives a breeding strategy of using, as one parent of a cross, a locally adapted variety that, preferably, is also adopted on a wide scale. Witcombe and Virk (2001) observe that if this strategy is used, many fewer crosses are made than is common in many breeding programmes They describe this as a few-cross strategy in which the parents are carefully chosen. The few crosses are 'smart crosses' or 'clever crosses'. The use of a clever cross strategy is now a proven concept with very successful examples such as the breeding of new maize varieties in India and Nepal (Witcombe *et al*., 2003; Virk *et al*., 2005), and rice varieties in India and Nepal (Gyawali *et al*., 2002; Virk *et al*., 2003). In wheat, the client-oriented approach, of improving popular varieties by limited backcross breeding, uses a few clever crosses (Singh *et al*., 2001). In annual crops, the strategy of using few crosses may be a novel one, but breeders of tree crops and large animals have always worked within the limitation of only being able to make a few crosses or improve single populations without any evidence that the genetic gain per generation has been lower.

The use of locally adapted germplasm and a knowledge of client needs are illustrated by the case of rice breeding in the mid-hills of Nepal. The breeding goal (product design) was to incorporate the good eating quality and yield potential of the most popular variety in the mid-hills, Khumal-4 (derived from a cross between a local landrace Pokhereli Masino and IR28) into the locally popular landrace Mansara (Sthapit *et al*., 2001; 2002). Mansara was chosen as a parent for its excellent local adaptation to 'poor' rice fields where no other rice varieties perform well. Resource-poor households grew this landrace despite its poor taste, low yield and poor market value (Rana, 2004). The products of this cross have been evaluated by farmers who like them for the improved combination of adaptation and quality. Another example, from rice in the low altitude regions of Nepal, is the cross between Kalinga III/Radha 32 that has produced variety Judi 582 (see the section on mother and baby trials below). In participatory trials, Radha 32 proved to be very high yielding and spread remarkably rapidly from farmer to farmer (Witcombe *et al.*, 2001). However, this rapid spread ceased when farmers realized that it has very poor grain quality (we now always test quality with farmers before we enter material in participatory trials). Radha 32 was crossed with Kalinga III that was known to have highly acceptable grain quality, earliness and adaptation to the target population of environments.

Duvick (2002) argues that the most important contribution of farmers is one that breeders may not realize or acknowledge. He states that breeders have a very strong tendency to choose the most popular varieties (or their parent lines in the case of hybrids) as parents of new breeding populations on the reasonable assumption that they must have a favourable selection of genes for good performance by farmers' standards. Thus, as farmers selectively popularize varieties, they also prescribe the genotypes used in the next cycle of breeding and, in a sense, control the direction of professional plant breeding. We would add that the more rigorously a breeder applies farmer adoption (= local adaptation) as a criterion for choosing parents, the closer the alignment to client needs and the greater the chance of success of the cross.

In international breeding programmes, germplasm can be oriented to the target countries by making a different set of crosses for each target country. For example, the barley breeding programme at the International Center for Agricultural Research in Dry Areas (ICARDA) uses crosses of in-country landraces to target individual countries in North Africa (Ceccarelli *et al.*, 1994). The International Maize and Wheat Improvement Center (CIMMYT) have adopted similar approaches. Early generation material is delivered to the target region, for example Kazakhstan, where they are selected under local conditions. In Kazakhstan, traditional CIMMYT germplasm was unadapted to the drought stress, susceptible to leaf rust and had poor market quality. Kazakhstan germplasm was crossed to CIMMYT lines and, after selection for photoperiod response using lights to extend day length, non semi-dwarf height, rust resistance and grain quality, the resultant F_3 and F_4 bulks are sent to the region for selection for agronomic adaptation. Selection both among and within crosses takes place in northern Kazakhstan (Trethowan, 2003). The products of this decentralized breeding approach are now significantly higher yielding than local germplasm in variety trials.

Indicator 3. Orienting the selection environments to the target market

A criticism of public sector-breeding programmes targeted at less favourable agricultural environments has been the unrealistically favourable selection environments (SE) under which selection is undertaken (Ceccarelli *et al.*, 1996;

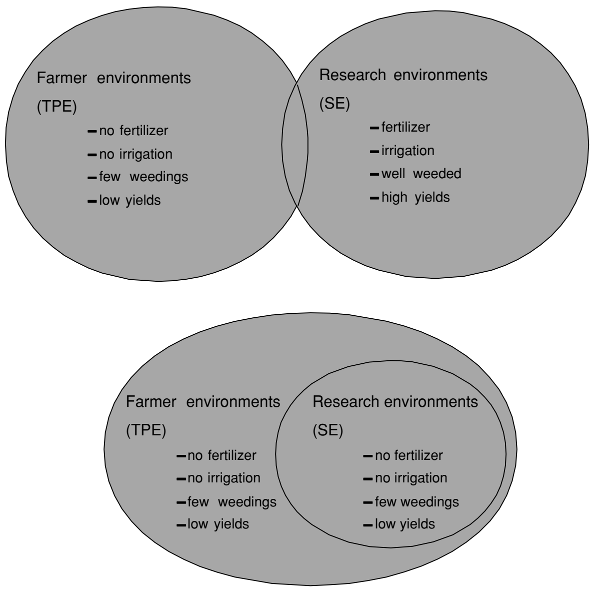

Figure 1. An idealized diagram of the gap between the selection environments and the farmers' environments (top) and the elimination of this gap (bottom). Modified from M. Bänziger (personal communication).

Witcombe *et al.*, 1996; Packwood *et al.*, 1998; Almekinders and Elings, 2001; Virk *et al.*, 2003). Research station trials usually employ the 'package of practice' approach designed to give a well-managed crop with a high yield. However, farmers in marginal areas invariably apply lower inputs to match better their limited capacity to procure resources, to reduce risks, and to maximize the long-term benefit cost ratios by avoiding or reducing negative returns from purchased inputs in drought years. Hence, if the SE is to match the true target population of environments (TPE) (Fischer *et al.*, 2003) then the SE must not be optimal but encounter similar stresses to the TPE, such as low fertility and limited water.

M. Bänziger (personal communication) has shown a typical mismatch between the SE and the TPE by using a simplified graphic (Figure 1) where only the poorer research station environments overlap with the farmers' fields. A better match can be achieved by modifying the management of the research station environment to those of farmers' fields. This can involve deliberately creating managed stress environments (low fertility, drought) to breed for tolerance to stresses encountered in farmers' fields (Bänziger and Cooper, 2001). By testing material in both managed stress environments and more favourable environments, varieties can be bred that tolerate common stresses but that can also respond to more favourable environments (Bänziger and Cooper, 2001; R.M. Trethowan, personal communication). A further advantage is that the stresses can be carefully controlled so that the heritability of the trait that is selected is increased and genetic gains enhanced.

Alternatively the SE and the TPE can be matched by carrying out selection in farmers' fields by breeders, or farmers, or both (see paper 2 in this series). If the selection is unreplicated then a representative (typical) farmer needs to be chosen with a typical field. In PVS, this is less important as there is a high replication that allows a good sampling of the TPE.

In more favourable agricultural environments, the risk of a significant mismatch between the SE and the TPE is lower – both scientists and farmers manage the crop well with applied, purchased inputs. Nonetheless, there are possible pitfalls. A mismatch still occurs when higher levels of purchased inputs are applied on the research station because the true economic cost or risks to farmers of applying them have not been fully considered. A mismatch can also be caused by disparities in cropping systems. Researchers may employ more fallow or green manuring, because it is the recommended rotation, even when farmers rarely adopt it.

Matching environments can easily be extended from the management (levels of fertilizer, irrigation, weeding) to the physical location of the breeding programme. Highly client-oriented programmes do not select for wide adaptation in a research station geographically remote from the target population of environments. They are decentralized so that the decentralized SE matches the TPE from the viewpoint of geography and climate. For productive environments the theory of target mega-environments is sound and the practice effective (e.g., Rajaram *et al.*, 1995). They allow, for example, selection in Mexico in wheat by the International Maize and Wheat Improvement Center (CIMMYT) to produce worthwhile genetic advances in south Asia, and selection in the Philippines in rice by the International Rice Research Institute (IRRI) to produce similarly useful genetic advances for south and east Asia. However, the complex set of stresses typical of more marginal environments is more difficult to represent in a SE geographically located outside of the TPE. The similarity between the SE and the TPE may be the most important reason why our breeding programmes for rainfed rice in Nepal and India have been successful quickly. Varieties from these programmes are beginning to replace varieties that are decades old, are giving considerable benefits to farmers while increasing genetic diversity as the number of varieties grown by farmers increases.

Indicator 4. Orienting varietal testing towards farmers in the target market

In the conventional approach, the testing of products (Stage 4 of Table 1) remains largely the domain of breeders and scientists who test varieties in, replicated trials managed and designed by researchers. Since these are usually on research stations, we refer to them as on-station trials. After on-station testing only, the best-performing varieties are tested with farmers. This is the traditional, linear or pipeline model of research and extension rather than a more participatory, parallel system (Sulaiman and Hall, 2002). As described below, in the participatory approach, on-farm testing becomes an integral part of varietal testing in PVS so extension specialists collaborate with researchers thereby breaking the artificial barriers between these disciplines.

On-farm trials differ in their degree of farmer participation. All public-sector breeding programmes eventually test their products with farmers but, as Witcombe *et al*. (1996)

pointed out, the stage and degree of participation of farmers can differ widely. For a programme to be highly oriented towards the market, farmers need to test a wide diversity of varieties that have been pre-selected to match farmers' criteria. The objective is to establish which variety is best among a varied choice, not an attempt to confirm that one or two varieties pre-selected by breeders from research station trials are acceptable to farmers when grown under the recommended 'package of practices' for the agronomic management of the crop. The latter approach is a transfer of technology model, not a client-oriented one. Most traditional methods of on-farm testing do not qualify as participatory or client-oriented (Table 2) and renaming these traditional methods as participatory devalues the term and removes clarity. Testing with farmers a small choice of recommended, released varieties selected on the basis of yield in research station trials is an inadequate client input. Perhaps surprisingly, the degree of client-orientation of the approach is determined as much by the methods used to choose the genetic material tested as by the methods used to conduct the trials (Table 2).

How are the participatory mother and baby trials carried out?. PVS is now widely used and accepted. For example, Atlin (2003) states that all breeding programmes should include participatory on-farm trials. Weltzien *et al*. (2003) report that most cases of PPB they reviewed were only employing PVS. However, there are many ways of carrying out highly participatory trials. Private-sector breeders use strip trials in which each entry occupies a single strip of land across the farmer's field. The public sector employs some form of a mother and baby trials system (Snapp, 1999). However, they may not have always been referred to in that way: for example, the trials system used by Joshi and Witcombe (1996) consisted entirely of baby trials and it was called farmer-managed participatory research (FAMPAR).

The designs vary greatly. For example:

- CIMMYT and its national programme partners in maize trials in southern Africa use a 3-replication mother trial (12 entries) repeated twice by having two management regimes (Bänziger and Cooper, 2001). The baby trials have four entries in an incomplete-block lattice design and the entries in the mother and baby trials are entered in the same year.
- The West Africa Rice Development Association and its national programme partners in rice trials in western Africa use a single replicate mother trial of about 60 entries (Gridley *et al*., 2002). Sometimes this is repeated twice by having two management regimes: high input and farmer's management (Monty Jones, personal communication). The baby trials in the following year have entries according to the number selected from the mother trial. This can vary from one to as many as seven or eight.
- Trials by the CAZS and its NGO and government organisation collaborators in Asia use a single-replicate mother trial grown under a single management regime (the farmer's own) and baby trials where usually each farmer grows only one test entry alongside his or her local control (Witcombe, 2002). Genotypes may be entered

Table 2. Some examples of public-sector, on-farm varietal testing and a consideration of how participatory (client-oriented) they are.

Methods in increasing order of farmer participation	Typical management	Genetic material	Evaluation includes	Does it involve farmers?	Is it participatory/ client-oriented?
1. Researcher-managed and -evaluated on-station trials	Package of practices	Advanced material	Yield data	No	No/ transfer of technology.
2. Researcher-managed and -evaluated on-farm trials	Package of practices	Few pre-released varieties at final stage of testing	Yield data	Yes	No/ transfer of technology.
3. On-farm (front-line) 'demonstrations'	Package of practices	Few released varieties recommended for the area	Yield data	Yes	No/ transfer of technology.
4. Farmer-managed trials	Farmer management	Few released varieties recommended for area	Yield data and farmers' perceptions	Yes	Only partly/ varieties are transfer of technology.
5. Farmer-managed trials	Farmer management	Choice of varieties (mainly non-released, also released non-recommended, and released recommended)	Yield data (optional) and farmers' perceptions (essential)	Yes	Yes/ both choice of varieties and evaluation of varieties are participatory.

simultaneously in the mother and baby trials or are entered in baby trials after a year of testing in mother trials; this depends on seed availability and the resources available for baby trials.

Which of the above designs for mother trials are most efficient?. There is no 'correct' version. The design varies with researchers' and farmers' capacities, with logistics, and with the type of genetic material available. For example, in southern Africa the great distances between villages and farmers make it sensible for researchers and farmers to collaborate in trials with replicated designs. In Asia, more densely populated villages allow more trials to be managed and this makes a simple, single-replicate design efficient. The decision is based on the most cost-effective way of increasing replicates: either more farmers or more replicates with each farmer. For example, Dofing and Francis (1990) working on sorghum in the United States recommended that one replicate trial should be used at as many locations as can be afforded, as long as the cost of an additional location relative to the cost of an additional replication is not excessive. The methodology presented by them allows the researcher to determine the efficiency of one-replicate testing for a programme while varying location and replication costs. Johnson *et al*. (1992) looked at the trade-off between replications within a site and additional locations with fewer replications. They examined the situation from the viewpoint of grain sorghum yield trials in West Africa and looked at the type of errors involved in trials:

- Type I – the risk of declaring one entry better than another when there is really no difference;
- Type II – the risk of declaring two entries to be the same when they are really different; and
- Type III – the risk of declaring an entry inferior when it is really superior.

They found that controlling type I error required many less locations than controlling type II and III errors. If a type III error was to be controlled then the large number of locations required became impracticable. For the error structures pertaining to their study, they found that three-replicate tests could be replaced by 42 to 65 % additional single-replicate locations, and this allowed, with the same precision, a tripling in the number of cultivars that could be tested, or the same number of varieties can be tested more accurately with many fewer resources. They concluded that 'single replicate testing requires only rudimentary statistical skills, complements extension activities, and is a viable alternative for rapid, reliable identification of superior cultivars in food production environments where both reliability and speed are critical'. Bhatt *et al*. (1984) examined the correlation between randomly selected single replicates at each site with the overall entry means using all of the replicate data. The correlations so obtained varied from + 0.88 to + 0.98 with a mean over the 16 data sets examined of + 0.94. They concluded that 'un-replicated multi-site tests offer breeders an effective and efficient means of identifying high yielding genotypes, particularly early in the breeding programme when seed supplies are limited'.

Informal designs. The simplest design for a baby trial, originally called informal research and development (IRD) by Lumle Agricultural Research Centre, Nepal (Joshi and Sthapit, 1990) is where small packets of seed are informally distributed to many farmers. This is also called extensive PVS (Gridley *et al.*, 2002). We found that IRD gave the same results as more elaborate baby or mother trials and costs much less (Joshi and Witcombe, 2002). We have also found that simple surveys of farmers that have grown a variety for more than one season are just as informative as baby trials and require even fewer resources.

Testing products with farmers can be the most significant change. Testing varieties with farmers is probably the most important single change in the suite of interventions called PPB provided the information is used to feedback into the breeding programme. If there is a participatory testing system on a range of variable cultivars (Table 2), there is much feedback from farmers to scientists about the market/client requirements. In short, it identifies the target set of traits (TST) by testing varieties in the target population of environments (TPE).

Indeed PVS contributes five main improvements over more conventional varietal testing:

1. In many breeding programmes fewer resources are allocated to testing lines in the most advanced stages of testing (Witcombe *et al.*, 1998). PVS activities redress this balance by allocating more resources to these important lines.
2. It allows farmers to evaluate varieties for all traits and to make trade-offs between traits, e.g. grain yield against stover yield, maturity, and grain quality.
3. It tests varieties under realistic management (it brings the varietal testing into the TPE).
4. It tests varieties across more of the physical niches in which the crop is grown because the trials are replicated across more locations.
5. It tests varieties across social niches where food preferences might vary.
6. It promotes adoption.

The first five of these can be achieved by substantial changes in research station varietal testing systems in conjunction with laboratory-based tests for food quality. However, it is almost certainly cheaper to use a mother and baby trial system and on-station testing does nothing to help the promotion of varieties.

An example of the results of mother and baby trials. For mother trials, we give the example of the testing of four rice varieties in Bangladesh produced by highly client-oriented breeding in Nepal. The mother trials were conducted in three locations in the main (transplanted *aman*) season of 2003 under farmer management and rainfed conditions. The varieties from Nepal yielded as much or more than the highest-yielding control varieties (Table 3) and the best performing variety outyielded the best control by 48 %. Judi 567 gave the highest grain yield and was the most preferred variety across all the environments (Table 4). Barkhe 2001, in spite of its moderate yield potential, consistently ranked as the second-most preferred variety because of its very good grain

Table 3. Mean grain and straw yield, maturity and farmers' preferences for rice varieties across three districts of the High Barind Tract of Bangladesh, 2003. Three sites in Rajshahi, three in Nawabganj, and two in Naogaon.

Variety	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Maturity (days)	Mean preference rank†
Barkhe 2001‡	2.7	4.0	116	2.0
Judi 565‡	2.5	3.6	99	4.2
Judi 566‡	2.7	3.6	100	3.4
Judi 567‡	3.4	4.6	102	1.0
Swarna§	2.4	3.9	128	4.7
BRRI dhan 32§	2.0	3.7	116	6.2
BRRI dhan 39§	2.5	4.1	116	5.4
s.e.d.	0.32	0.31	1.9	0.44

†Preference rank where a variety ranked 1 is the most preferred.
‡Variety bred by highly client-oriented breeding in Nepal.
§Adopted and control varieties.

Table 4. Farmers' preferences for rice varieties in three districts of the High Barind Tract of Bangladesh, 2003.

	Preference order (mean preference rank) †		
Variety	Rajshahi ($n = 24$, site = 3)	Naogaon ($n = 12$, site = 2)	Nawabganj ($n = 26$, site = 3)
Barkhe 2001‡	2 (1.7)	2 (2.0)	2 (2.3)
Judi 565‡	3 (3.3)	5 (5.0)	5 (4.3)
Judi 566‡	4 (3.7)	3 (3.0)	4 (3.7)
Judi 567‡	1 (1.0)	1 (1.0)	1 (1.0)
Swarna§	5 (5.3)	6 (5.5)	3 (3.3)
BRRI dhan 32§	6 (5.7)	7 (6.5)	7 (6.3)
BRRI dhan 39§	7 (6.7)	4 (4.0)	6 (5.7)
s.e.d.	(0.47)	(0.67)	(0.94)

†Preference rank where a variety ranked 1 is the most preferred, and n is the number of farmers evaluating the trial.
‡Variety bred by highly client-oriented breeding in Nepal.
§Adopted and check varieties.

quality, as even in a rainfed area where rice yields are unstable, farmers gave a high priority to grain quality.

There was a significant interaction between varieties and locations for the preference ranking. An inspection of the preference ranks in three locations shows that most of the variation in ranking between sites is for the lower ranked entries. The consistency of preference for the two most preferred entries is remarkable (Table 4).

Baby trials are highly informative in providing information on the strengths and weaknesses of varieties. For example, we consider the performance of rice variety Judi 582 that was bred in Nepal using client-oriented methods from the cross Radha 32 Kalinga III/IR64. In baby trials across three districts of High Barind Tract of Bangladesh in the main (transplanted *aman*) season of 2003 it was compared over recommended or adopted varieties: Swarna, BRRI dhan 32, or BRRI dhan 39. For all traits Judi 582 was clearly preferred (Table 5). Its early maturity, nearly four weeks earlier than Swarna the most adopted variety in the area, was greatly liked. Early-maturing varieties can escape terminal drought under the entirely rainfed conditions of the Barind and they allow the timely sowing of a subsequent crop such as chickpea.

Table 5. Farmers' perceptions of Judi 582 relative to check varieties in the High Barind Tract of Bangladesh, 2003.

Trait	Judi 582 preferred	Both the same	Alternative preferred†	$\chi^2(1 d.f.)$ corrected	Probability
Yield	10	2	1	2.8	*n.s.*
Maturity	13	0	0	11.1	<0.01
Grain quality	11	2	0	4.9	<0.05
Market price	10	3	0	2.8	*n.s.*
Growing next season	12	0	1	7.7	<0.01

†Either Swarna or BRRI dhan 32 or BRRI dhan 39.

The farmers' strong preference for Judi 582 was confirmed by their intention to grow it again in the next season (Table 5).

These examples illustrate not only the power of the mother and baby trials system to give highly informative results. They also illustrate the success of highly client oriented breeding. That rice varieties bred in Nepal perform well in Bangladesh is not unexpected. The latitude is identical and both the SE in Nepal and the TPE in Bangladesh are rainfed and in both farmers use moderate levels of purchased inputs.

CONCLUSIONS

The adoption of what has been called participatory plant breeding has not been as high as would appear warranted from its success. We believe that part of this failure to adopt these techniques has been a lack of clarity in the diffuse concept of PPB and a rejection of the concept of collaboration by farmers in selecting in the segregating generations that, in fact, is only an optional component of PPB. The terminology of PPB has created an artificial dichotomy between those in the 'participatory' camp and those in the 'conventional' camp.

The need to build bridges between the two camps is not just an academic matter. In marginal environments throughout the developing world in Asia, Africa and Latin America farmers are growing landraces, obsolete varieties and non-recommended varieties in contrast to more favourable environments where modern varieties are more common. Increased client-orientation in plant breeding has produced new varieties that perform extremely well in marginal agricultural environments such as the rainfed uplands and lowlands. Plant breeders of any camp can use the techniques described here. They can do so to differing extents, depending on resources and circumstances, but all result in increases in client orientation and lead to crucial gains in plant breeding efficiency.

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