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RESEARCH PAPER

Participatory maize improvement for enhancing yield and production

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Abstract: Most of the data on different types of farmer participation in selection of better plant ideotypes suggest that there is little to lose and much to gain by involving farmers, and more generally the users, in the process of plant breeding. Decentralized-participatory plant breeding should not be seen as "an alternative" type of plant breeding, but rather as an approach to specifically address situations such as marginal environments, or where there is a variety of different requirements (quality, crop duration, management, etc.). In the past, researchers have relied heavily on the extension department of the Ministry of Agriculture to transfer technologies to the farmers. Without intensive interaction with farmers in the development of maize varieties, there is a possibility of ignoring certain characteristics that would be of importance to farmers in their decision making process of whether to adopt a variety or not. In the very poor, rain-fed rice-growing areas of South Asia that the green revolution passed by, participatory plant breeding is now paying off with strong early adoption of farmer selected varieties that provide 40% higher yields in farmers' fields. The approach needs to be more widely tested in the heterogeneous rain-fed environments of Africa, where involving farmers, especially women farmers, in selecting varieties has shown early successes for beans, maize and rice. The cost effectiveness of the approach for wider use also needs to be evaluated.

Keywords: Farmers field · Maize · Participatory breeding · Varieties

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Introduction

Participatory plant breeding (PPB) is the process by which farmers are routinely involved in a plant breeding programme with opportunities to make right decisions throughout. It involves scientists, farmers, and others, such as consumers, extensionists, vendors, industry, and rural cooperatives in plant breeding research. The primary aim of this activity is to enable tribal and farm families to initiate PPB along with scientists. In the recent years there has been an increasing interest towards participatory research in general, and towards participatory plant breeding in particular. It is termed "participatory" because many actors, and especially the users, can have a research role in all major stages of the breeding and selection process. PPB is an extension of Participatory Varietal Selection (PVS).

Participatory breeding will help to convert on-farm conservation to on-farm management of agro-biodiversity. Such participatory breeding work will be linked to training in seed technology, including aspects of post-harvest technology. The project, initiated in June 1998, took into account the tribal and farm family status and environment and chose the crops for PPB in three target sites: Jeypore Tract of Orissa (rice), Wayanad district of Kerala (medicinal rice, pepper) and Kolli Hills of Tamil Nadu (minor millets). PPB provides benefits to a specific user and builds farmer skill to enhance farmer selection and seed production efforts. Participatory Crop Improvement (PCI) involves farmers in different stages of selection and evaluation of future varieties, and proposes several levels of involving farmers in decision making (Sperling *et al.*, 2001). In PPB, farmers are actively involved in the breeding process, from setting goals to selecting variable, early-generation material. In PVS, farmers are given a wide range of new cultivars to test for themselves in their own fields. In our PPB programmes we have exploited the results of PVS by using identified cultivars as parents of crosses.

Need of participatory plant breeding (PPB)

1) To build a better linkage between users' demand and breeders' offer (spontaneous in private breeding)
2) To help the farmers to get a better output from poorly controlled cropping environments (thanks to more diverse and locally adapted genetic material)
3) To facilitate knowledge and know-how sharing between users and scientists
4) To contribute to *in situ* managing the genetic resources valuable for the local communities

It is based on the principle of sufficient knowledge of farmers' specific production needs and of the advantages and disadvantages of the local varieties they use. When farmers are involved from the first segregating generation (F_2 or F_3) and when selection is to be carried out in their own fields, PPB should necessarily be conducted with relatively few plants. That is, the number of either crosses or plants from the F_2 generation should be smaller than that used in a conventional programme on an experiment station. Considering this limitation, some authors consider that PPB should involve a strategy that makes only a few crosses, rigorously selects parental varieties and uses a large number of plants from the F_2 generation (Witcombe and Virk, 2001). Another PPB strategy comprises population improvement methods associated with recurrent selection, using a narrow genetic base and well-selected specific germplasm. It can be applied to autogamous crops when several traits are being selected and the proportion of desired recombination is expected to increase, thus limiting the risks of a strategy of few crosses (Witcombe and Virk, 2001). Progress from plant breeding has been slow in some marginal environments. Conventional or formal plant breeding (FPB) programs conducted by international agricultural research centers or national programs in developing countries have been criticized for ignoring indigenous germplasm, failing to breed for conditions facing poor farmers, and emphasizing selection for broad versus local adaptation.

A suite of techniques, referred to as participatory plant breeding (PPB) and including farmer-participatory or farmer-led selection, on-farm evaluation, and use of local landraces, has been advocated in response to this critique. PPB programs are diverse in scope and approach, but often rely heavily on farmer visual evaluation or phenotypic mass selection to select for simply-inherited traits, with limited replicated yield testing in multiple-environment trials (MET), one of the main tools of Conventional Plant Breeding. Prediction equations derived from selection theory can be used to examine the conditions under which idealized versions of CPB and PPB may be expected to achieve genetic progress for traits such as yield. The effectiveness of any selection environment is determined by both the genetic correlation between genotype performance in it and the target environment (r_G) and the heritability of genotypic differences in the selection environment (H_s). The r_G is a measure of the accuracy with which performance of genotypes in the selection environment predict performance in the target environment; H_s is a measure of precision with which performance differences among genotypes can be measured in the selection environment. In this paper we use this framework to compare FPB and PPB with respect to these determinants of selection response. Particular areas examined include: (i) selection for broad and specific adaptation; (ii) on-station versus on-farm selection; and (iii) selection under high-yield versus low-yield conditions.

In general, PPB systems attempt to maximize gains through the use of on-farm evaluation and the skills of farmer-selectors to maximize r_G. FPB exploits METs to maximize Hs. PPB is most likely to develop cultivars that out-perform the products of FPB when it is applied in low-yield cropping systems, because it is in such situations that r_G between high-yield breeding nurseries and low-yield target environments is likely to be low or negative. To make continued gains, and to compete with internationally-supported CPB programs, PPB systems will need to counter the obscuring effects of uncontrollable within-field, site-to-site, and year-to-year heterogeneity. Simple and robust designs for on-farm METs are needed for this purpose.

Modern plant breeding stands among the greatest scientific and human success stories of all time. Yet the fruits of major advances in agricultural science, such as those from the Green Revolution, have by passed hundreds of millions of farmers in developing countries, most of whom operate small farms under unstable and difficult growing conditions. The adoption of new plant varieties by this group has been abysmally low. For years, this gap has haunted scientists, development workers, governments, donors, and all others with a stake in agricultural progress and the fight against poverty. But, beginning in the 1980's, it also stimulated the creation of a novel and promising set of research methods collectively known as participatory plant breeding (PPB).

Goal of PPB

Over the last decade, PPB has been applied as a crop improvement strategy primarily in non-commercial crops and in very unpredictable, stressed production environments. A range of other goals have also been defined within PPB programs i.e., enhancing biodiversity and germplasm conservation; developing adapted germplasm for especially disadvantaged user groups (example: women, poor farmers); making breeding programs more cost efficient, particularly through decentralization of programs which target more niches. As partners usually have to accept trade-offs in reaching certain goals, it is important at the very beginning of a PPB collaboration for those concerned scientists, farmers, development /NGO personnel- to discuss explicitly primary and secondary goals, and the minimal agreed-upon outcomes for which collaborators are aiming.

Key assumptions for PPB

1) Farmers are interested in participating in plant breeding
2) Farmers and scientists can successfully collaborate
3) It will not fail because:
a) The parents of crosses include locally adapted material;
b) Selection is in the local environment; and
c) Varieties are selected by farmers for the traits farmers consider important.

Types of PPB

PPB can be consultative and collaborative. The approach used will depend on the crop and the availability of resources.

Consultative

Farmers are consulted at every stage - for example, in setting the breeding objectives, choosing the appropriate parent, and by making joint selections with breeders from material grown by breeders. Hence, until there is a finished product from the breeding programme for farmers to test in PVS trials, farmers are not involved in growing material in their fields.

Collaborative

Farmers grow the variable PPB material in their own fields and select the best plants from it. Scientists can then obtain seed from farmers to test their selections in research station and participatory trials.

Steps for participatory plant breeding

1) Set the breeding objectives: a) Crop-focused PRAs, b) Analyze results of participatory varietal selection.
2) Identify the parent material: a) From local landraces, b) From varieties tested by PVS, c) From high-yielding varieties with complementary characteristics.
3) Decide on the model (consultative/collaborative): a) On the basis of available resources, b) On the basis of the crop (collaborative participation is simpler in an inbreeding crop).
4) Enter the best participatory plant breeding lines in PVS trials and facilitate their entry in normal on-station trials.
5) Prepare release proposal, if success is achieved

Possible Outcomes/Benefits of PPB

1) Production gains: yield increases; increases in stability of yield; faster uptake; wider diffusion; and higher market value of products.
2) Biodiversity enhancement: communities have wider access to germplasm; wider access to related knowledge; and increased inter- and intra-varietal diversity.
3) Cost-efficiencies and effectiveness: fewer researches dead-end; more opportunities for cost-sharing in research; and less expensive means of diffusing varieties.
4) Effective meeting of user needs: higher degree of farmer satisfaction; broader range of users reached,

including marginal farmers; and promotion of group learning through farm walks.

Advantages of participatory over conventional breeding methods

1) At least one parent in any cross is well adapted to the local environment.
2) Genotype × environment interactions is used positively because breeding is done in the target environment.
3) The impact of genotype × year interaction is probably reduced because local parental materials have adapted to local year-to-year variations.
4) Only a few crosses are made, so large F_2 and F_3 populations can be grown to increase the likelihood of selecting desirable segregants.

Effects of PPB on adoption

Although PPB and PVS programs are relatively recent, there are already some examples of impact. For examples there are cases where varieties preferred by farmers were identified in environments where no improved varieties have ever been available to farmers, such as the rice variety combining the frost tolerance of a landrace with the higher yield of a modern variety which has been adopted in the mountains of Nepal. A bean variety combining disease resistance with a desirable coat color has been adopted in northeastern Brazil before the variety could be formally recommended. Other examples are provided by rainfed rice varieties in India, potatoes in Ecuador, maize in Ethiopia, and, surprisingly, irrigated wheat and rice in Gujarat, in India, demonstrating that even in the areas where formal plant breeding has been particularly successful, farmer participation can identify desirable varieties at an earlier stage than in conventional breeding. One of the best examples of fast adoption through farmers' participation in variety testing (PVS), is the spreading of the rice variety Kalinga III in India. Seed of this variety, which has neither been recommended nor released, was initially made available to farmers in three villages in Rajasthan in 1993 through a farmer-managed participatory research trial. By 1997 in one of the villages 65 per cent of the area was planted with Kalinga III, while the lowest adoption was about 20 per cent of the area. The variety also spread to other villages with very high rates of spread, and with the number of villages growing Kalinga III increased by a factor of 2.3 to 7.0.

1. Participatory research (PR) increases the benefits and is more effective at reaching women and the poor.
2. PR improves research efficiency. One of the efficiency gains from including participatory approaches in plant breeding is based on the extent to which breeding priorities or research practices are reoriented in ways that save time and/or money. Here too it is useful to first look at expert opinion from the PRGA survey: 82 per cent of the respondents concluded that PR led to the formation of feedback links and 54 per cent considered that this led to changes in priorities. Another 75 per cent considered that PR led to a change in breeding methods.
3. PR accelerates adoption. The incorporation of participatory approaches consistently enables breeding programs to "break through" adoption bottlenecks caused by low levels of acceptability of new varieties to poor farmers.
4. PR changes cost structures of breeding. One of the main concerns of conventional breeding programs about the inclusion of participatory approaches into their portfolio of breeding methodologies is that PR looks very time intensive and therefore costly. Many aspects of PPB seem likely to increase costs: on farm testing begins earlier, more seed is needed of experimental varieties, the trials are dispersed outside the experiment stations, different kinds of personnel may be needed to interact effectively with farmers.

Participatory plant breeding in maize

A case study in Gujrat describes how plant breeders and farmers worked together to produce improved varieties of maize for the low-resource farmers of the Panchmahals district of Gujarat, India. Initially, farmers tested a range of maize varieties in a participatory varietal selection (PVS) programme. However, none of these proved to be very popular with farmers, although farmers who had more fertile fields adopted the variety Shweta from Uttar Pradesh. Hence, in 1994, a participatory plant breeding (PPB) programme was begun to generate new, more appropriate varieties. Yellow- and white-endospermic maize varieties were crossed that had been either adopted to some extent following PVS or had attributes, such as very early maturity, that farmers had said were desirable. In subsequent generations, the population was improved by mass selection for traits identified by farmers. In some generations, farmers did this in populations which were grown by breeders on land rented from a farmer. Soil fertility management was lower than that normally used on the research-station. The breeding programme produced several varieties that have performed well in research-station and on-farm trials. One of them, GDRM-187, has been officially released as GM-6 for cultivation in hill areas of Gujarat state, India. It yielded 18 per cent more than the local control in research-station trials, while being seven days earlier to silk. In farmers' fields, where average yields were lower, the yield advantage was 28 per cent and farmers perceived GDRM 187 to have better grain quality than local landraces. PPB produced a variety that was earlier to mature than any of those produced by conventional maize breeding, and took fewer years to do so. A case in point was the maize breeding program at Pantnagar, one of the leading agricultural universities in India. On-farm research was a prime component of that program, and a routine was developed to enhance the odds that information generated in the on-farm stage would be utilized in decision-making on breeding priorities (Agarwal, 1979; Biggs, 1983).

In China, a project team has been established in which local farmers cooperate with the Centre for Chinese Agricultural Policy, which is part of the Chinese Academy of Sciences, and the Guangxi Maize Research Institute. The multidisciplinary research team carries out trials in six villages and on-station using both PPB and PVS experiments. The trials allow for comparison in terms of locality, approach, objectives and the types of varieties tested. Varieties include landraces, open-pollinated varieties, so-called waxy maize varieties and varieties introduced by CIMMYT. Some of the CIMMYT varieties have been locally improved through crossings and selections. Agronomic traits, yields, taste and palatability of these improved varieties are satisfactory. They are showing better adaptation to the local environments. Varietal diversity is increasing. The project team supports farmers' groups by bringing them into contact with formal system actors through training, network building and raising awareness about markets. Since the early 1990s, scientists in CAZS-NR (Centre for Arid Zone Studies) at the University of Wales, Bangor, in the United Kingdom have worked in participatory variety selection and participatory plant breeding. For PPB, they have focused on cereals, mostly rice and maize, in marginal regions of South Asia, mainly India, Nepal, and, most recently, Bangladesh.

A major PPB project is being carried out in Guangxi province in south-west China and follows up on an impact study carried out from 1994 to1998 by the International Maize and Wheat Improvement Centre (CIMMYT) to assess the impact of CIMMYT's maize germplasm on poor farmers in south-west China (Yiching Song, 1998). One of the key findings of the impact study was that the systematic separation between the formal and the farmers' seeds system resulted in inadequate variety development, poor adoption of formally bred modern varieties, an increasingly narrow genetic base for breeding and a decrease in genetic biodiversity in farmers' fields.

Participatory plant breeding programme (Kharif 2018)

A client oriented comprehensive initiative was undertaken to address location-specific issues pertaining to maize cultivation in various maize growing pockets of intermediate altitude zones of valley since 2015. In this regard 22 trials were constituted comprising of advanced pipeline genotypes of maize (Table 1).

The validation trials were laid in 14 villages across various districts of the valley and one set of trial each type was also laid out at the station for metric trait estimation and validity of findings. The basic aim of the trials was to access the performance of cultivars in actual farm conditions and to accumulate feedback from the farming masses so that a redefined and comprehensive strategy can be devised for the betterment of crop productivity on long term basis.

The information generated from the trials was collected in the form of questionnaire pertaining to diverse facets of maize and rajmash cultivation, utilization and farming pattern of the individual farmers. The cumulative average results of the trials are appended based on individual experience of the farmers. Further the farmer's preference ranking of most promising genotypes (cumulative average) is also appended in the document (Table 2-5).

Table 1. Description of the trials

S.No.	Crop	Trial Type	Entries involved	Checks	Locations
1	Maize	Baby trial	H 17, KDM 72, KDM 322 and KDM 111	SMC 4, Local Check	13
2	Maize	Mother trial	SKUA-MH-46, SKUA-MH-47, SKUA-MH-49, SKUA-MH-50	Local Check	9

Table 2. Kernel profiling of the test entries

Entry	Test weight (g)	Specific gravity	Protein (%)	Tryptophan in protein (%)
KDM 322	253.7	1.15	7.59	0.35
KDM 72	250.0	1.16	7.97	0.42
H 17	399.0	1.17	12.95	0.52
KDM 111	289.2	–	–	–
SMC-4	356.0	1.19	5.91	0.65

Table 3. Average coordinated performance of test entries

Test Entry	Trial	Year	Average yield (kg/ha)
KDM 322	103	2010	5503
KDM 72	103	2012	7199
H 17	103	2008	5402

Future prospects of PPB

1) PPB should take a broader approach to solve the critical problems arising out of modern agriculture such as economic viability of crop production, food and nutritional insecurity, degradation of land, destruction of biodiversity and unsustainable agricultural practices.
2) PPB should recognize and value the knowledge and important role of women in conservation of biodiversity and agriculture and should address gender imbalances in participation, decision-making and benefit sharing.
3) PPB should be based on principles that emphasis deposition of problems to be addressed, symmetrical relationships among partners and constant evaluation and monitoring of the success of participatory improvement programmes.

Table 4. Average performance of test entries in station trials (*Kharif* 2013)

Entry name	Days to 50% pollen shed	Days to 50% silking	Days to 75% dry husk	Plant height (cm)	Ear height (cm)	Shelling (%)	Grain yield (t/ha)
KDM 72	77	80	139	215	115	79	6.087
KDM 322	75	78	138	190	85	78	6.321
KDM 111	80	83	142	165	75	79	5.834
H 17	77	80	141	195	75	81	6.917
SMC 4	78	82	138	185	85	80	5.526
SKUA-MH-46	77	80	137	200	100	78	7.259
SKUA-MH-47	76	79	137	195	85	78	7.424
SKUA-MH-49	84	87	145	190	85	79	5.908
SKUA-MH-50	78	81	139	185	80	78	7.039

Table 5. Farmer's preference ranking for different traits and future intensions with respect to best possible test entries involved in the PPB trials over all locations (117 farmers) during *Kharif* 2013

Entry	Maturity Fitness	Productivity performance	Crop feel	Will grow again	Taste	Realized farm yield
KDM 72	4	5	5	Yes	4	49.71
KDM 322	5	4	3	Yes	3	51.23
KDM 111	4	3	3	Yes	2	42.73
H 17	5	5	5	Yes	2	57.71
SMC 4	4	3	3	–	3	41.31
SKUA-MH-46	4	5	4	Yes	4	59.19
SKUA-MH-47	3	4	4	Yes	3	56.47
SKUA-MH-49	1	2	3	No	2	35.13
SKUA-MH-50	2	4	4	Yes	2	55.78

Rating Scale: 5= Excellent, 4= Good, 3= Average, 2= at par with local check, 1= below local check

4) PPB should be into account farmer's gendered priorities and practices, and strive for social and gender equity in conservation.
5) Participatory breeding need to be cost-effective, work on downstream technology and breed site-specific varieties capable of sustaining production.
6) Farmers' gendered ITK and wisdom need to be recognized rewarded and incorporated in participatory initiatives.
7) Scientific analysis of PPB data should be a course of strength for farmers for making optimal decisions.
8) PPB options should not deal only with improving yield of farmers' varieties, but also provide a strategic frame for saving grains and seeds and gainful marketing, as provided in the protection of plant varieties and farmers' Right Act, 2001. Government should make it a policy to procure farmers' landraces at a remunerative price and distribute them through the Public Distribution System (PDS).
9) Participatory research has been shown to be efficient and accelerate adoption of acceptable varieties.
10) Novel genetic combinations incorporating drought and salinity resistance need to be properly programmed into participatory breeding taking care to assign proper weight age to phenotypic expression.
11) Indigenous varieties like Indian rice with special traits like *Njavara, Kalajeera* and *Kalanamak* should have their place in participatory improvement. It is essential to characterize them for bimolecular that are relevant to the medicinal properties.

Conclusion

Most of the data on different types of farmer participation in selection of most suitable plant ideotype suggest that there is little to lose and much to gain by involving farmers, and more generally the users, in the process of plant breeding. Decentralized-participatory plant breeding should not be seen as "an alternative" type of plant breeding somewhat opposed to the formal plant breeding, but rather as an approach to specifically address situations such as marginal environments where GE interactions are repeatable and large, precluding the adaptation of one or few varieties, or where there is a variety of different requirements (quality, crop duration, management, etc.). One specific advantage of decentralized participatory plant breeding is to rapidly adapt the crops to a changing agronomic management. Eventually, PPB could be the only possible type of breeding for crops grown in remote regions, for crops which required a high level of diversity within the same farm, or for those crops locally important but globally considered as minor crops and therefore neglected by formal breeding. In the past, researchers have relied heavily on the extension department of the Ministry of Agriculture to transfer technologies to the farmers. Without intensive interaction with farmers in the development of maize varieties, there is a possibility of ignoring certain characteristics that would be of importance to farmers in their decision making process of whether to adopt a variety or not. In the very poor, rain-fed rice-growing areas of South Asia that the Green Revolution passed by, participatory plant breeding is now paying off with strong early adoption of farmer selected varieties that provide 40% higher yields in farmers' fields. The approach needs to be more widely tested in the heterogeneous rain-fed environments of Africa, where involving farmers, especially women farmers, in selecting varieties has shown early successes for beans, maize and rice. The cost effectiveness of the approach for wider use also needs to be evaluated.

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