Shortened title: ***Farmer participatory crop improvement. III.***

FARMER PARTICIPATORY CROP IMPROVEMENT. III: PARTICIPATORY PLANT BREEDING, A CASE STUDY FOR RICE IN NEPAL

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SUMMARY

A Participatory Plant Breeding (PPB) programme was conducted for high altitude areas of Nepal to examine the potential of PPB for utilising farmers knowledge to breed acceptable varieties with minimum use of resources. Farmer participation began at the F_5 stage and progress was followed over two seasons in two villages. Farmers proved to be willing participants and made selections in the segregating material, often with great success. Large differences between the F_5 bulks were found and the most popular were adopted at a high rate. The most preferred material, Machhapuchhre-3, has performed well in the formal trials system, and much better than the products from conventional centralised breeding. The PPB programme increased biodiversity in the two participant villages.

INTRODUCTION

In Nepal, as in many developing countries, rice must pass through a highly centralised process of varietal testing, release and certification, and typically this procedure takes many years. For example, 13 to 15 years are required for new cultivars in the National Rice Research Programme (NRRP) to reach farmers' fields (Sthapit, 1995).

Less than two varieties are released each year for farmers situated in a wide range of Nepalese rice ecosystems, and only 41 varieties have been released since 1966 (Sthapit, 1995). However, extreme agro-ecological diversity and ethnic-specific preferences of farmers demand the release of many location- and purpose-specific varieties. The limited varietal options available to the farmers lead to poor adoption levels. For example, only 10 to 11% of farming households were growing improved rice cultivars in a survey of more than 1688 households in 11 districts of Eastern and Western Nepal (LARC, 1995; Chemjong *et al.,* 1995).

Rice improvement programmes have been even less successful for the high altitude areas (>1000 m) of Nepal where cold injury is common, partly because of the allocation of limited research resources by national and international programmes and partly due to a failure to use well-adapted material as parents. Most entries in cold-tolerant nurseries from the International Rice Research Institute (IRRI) failed to produce grain when grown in Nepal at Lumle (1450 m) and

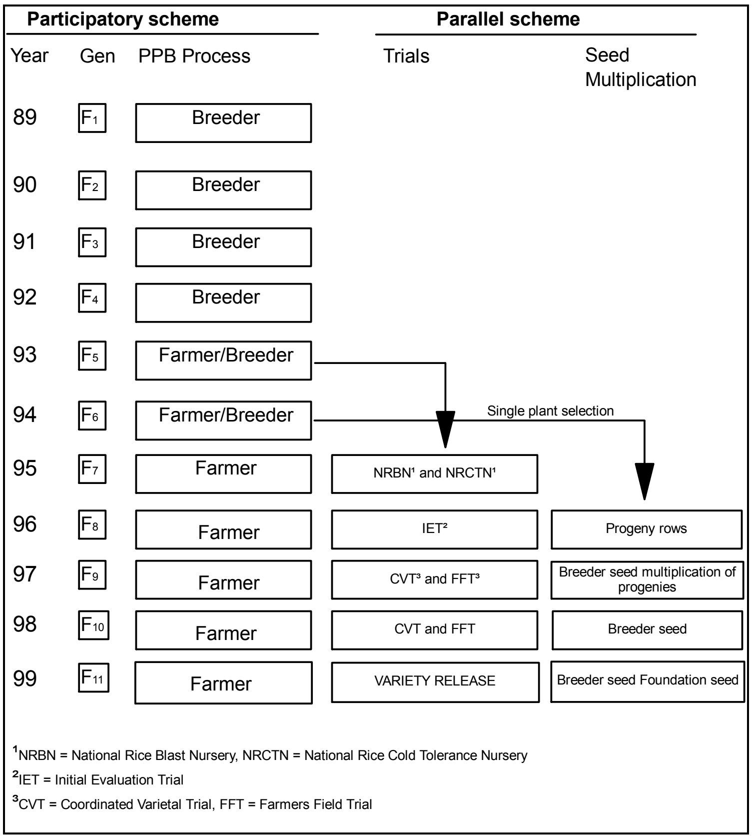
Chhomrong (2000 m) (Sthapit, 1992). Nepal has many genetically diverse, cold-tolerant rice landraces but little use has been made of them in the national breeding programmes.

Maurya *et al.* (1988), Galt (1989), Sperling *et al.* (1993), Sthapit *et al.* (1994), Joshi *et al.* (1995) and Witcombe *et al*. (1996) considered alternative approaches to address the problems of the limited varietal choice available to farmers. Traditionally, the development of rice varieties has been the task of breeders, and farmers are merely the recipients of finished products. The objective of the programme was to involve farmers at a much earlier stage to produce more efficiently farmer-acceptable cultivars. PPB was employed for high-altitude rice breeding using crosses involving locally-adapted parental material. It was intended that PPB would minimise resource use, produce farmer-acceptable cultivars, and increase the genetic diversity of rice in the participating villages.

MATERIALS AND METHODS

Overall breeding scheme. The PPB programme involved farmers selecting from F_5 bulks onwards (Fig. 1). To satisfy formal release requirements a "parallel" breeder-led scheme was followed (Witcombe *et al.,* 1996) in which the best material was entered into the formal trials system and purified by progeny row selection for certified seed production (Fig. 1).

Figure 1 Participatory plant breeding using a parallel breeding scheme for the formal release system



Identification of sites. Cold air and water at Chhomrong (2000 m) caused a high level of spikelet sterility. There was also a naturally high disease pressure for bacterial Sheath Brown Rot (ShBR) disease caused by *Pseudomonas fuscovagainae* (Sthapit *et al*., 1995) and blast caused by *Pyricularia oryzae* (Sthapit, 1995). Environmentally-induced spikelet sterility was lower at Ghandruk (2000 m) and disease pressure was less. Favourable socio-economic conditions also existed. Rapport had been established between scientists and farmers over many years of research by LARC in these villages. It was known from participatory rural appraisals that farmers wished to improve the milled grain colour and the quality of their local rice. Hence, the goal of the programme was to develop a rice variety with white grain, a trait highly preferred by the local community, and 'white grain' was used as a catch phrase to draw the farmers' interest.

Identification of segregating materials. Several diverse crosses were used (Table 1), and most involved the rice cultivar Chhomrong Dhan (Ch. Dhan), a pure line selection by Lumle Agricultural research centre (LARC) from a cold-tolerant landrace with resistance to ShBR. It was released in 1991 for the high-hill areas of Nepal and is the only released cultivar that is well adapted to altitudes above 1500 m. About 25 years ago this landrace was introduced from an unknown location in India by a farmer into Ghandruk and Chhomrong villages where rice had not been grown previously. Six lines, from two crosses, were selected by breeders from the F_4 nursery in 1992 and four, from three crosses, in 1993. Until the F_4, these lines were selected by breeders for cold tolerance and ShBR resistance by the pedigree-bulk method of selection. F_5 bulk seed was harvested from each F_4 row and given a local name to aid identification by farmers. In 1993 and 1994, previously- identified farmers were given 20-25g of seed of the F_5 bulks (Table 2).

Table 1. The parentage of the three crosses from which the F_5 bulks were derived

Genotype	Sub-species	Origin	Source	Important traits
Fuji-102	*Japonica*	Japan	IRCTN[1]	Cold tolerant, dwarf, white grain and good quality; Not released in Nepal
Chhomrong Dhan (Ch. Dhan)	*Japonica*	Nepal	Local selection	Multiple resistance to cold, ShBR and Blast diseases, medium plant height, red grain; released in Nepal
K-332	?	India	IRCTN	Cold tolerant, released in Kashmir, blast resistant
NR-10157-2B-2	*Indica*	Nepal	Breeding line	Early, cold tolerant, fine quality, not released in Nepal but sister line adopted by farmers
Stejaree-45	*Japonica*	Russia	IRCTN	Cold tolerant, coarse grain

[1] IRCTN = International Rice Cold Tolerance Nursery (IRRI).

Identification of expert farmers. Expert farmers from Chhomrong and Ghandruk villages, with knowledge and skill in rice farming, and willingness to participate in this study, were identified by the local community with the help of researchers. In October 1992, the programme objectives were discussed with about 20 rice growers, including the previously-identified expert farmers in each village. The role of the participating farmers and the level of their knowledge on selection and inheritance of traits was also discussed. Initially, six farmers from Chhomrong, and four from Ghandruk were involved in the programme (Table 2). In 1994, as more seed became available, more farmers and more F_5 bulks were included in Ghandruk and Chhomrong, and the villages of Lumle and Sabet were also added to the programme (Table 2).

Both males and females from the same household were included in the study to take account of gender-specific knowledge and perceptions. Women were always included in the post-harvest evaluations, whereas men were more involved in the evaluation of pre-harvest and yield traits.

Management of the trials. The farmers were asked to grow and manage the bulks according to their normal practices, except that the test entries had to be maintained separately in the field and store. Farmers assessed and selected according to their own criteria, and the methods they used were monitored and recorded by field staff. In each year, seeding for nurseries and transplanting of all the test varieties and the local (Ch. Dhan) were done within a week. At each plot sign-boards were erected to display the name of the variety and the farmer so that the attention non-participating farmers was drawn.

Training in plant selection. Farmers were informed that the offspring from two contrasting parent plants would vary (segregate) for traits. They were told that selection within variable traits should be done for two to three years in the F_5 bulk seed that they had been given, until the trait no longer varied. They were also told that some traits, such as grain colour, were “strongly” inherited and therefore good targets for selection. This training on simple principals of genetics and heritability was given to complement indigenous knowledge. Farmers were asked to return, after each harvest, half of the selected seed to LARC for on-station testing. The retained seed was used by the farmers in any way they chose.

Table 2. Farmers and genetic materials in the participatory breeding programme, 1993 and 1994

		Name of the participating household member			
Parentage	Vernacular name of F_5 bulk	Chhomrong	Year[1]	Ghandruk and Lumle	Year[1]
Fuji 102 x CD	Machhapuchhre-1 (M-1)	R.B. Gurung	1993	M.K. Gurung	1993
Fuji 102 x Ch. Dhan	Machhapuchhre-2 (M-2)	K.B. Gurung	1993, 1994	J.B. Gurung	1993, 1994
Fuji 102 x Ch. Dhan	Machhapuchhre-3 (M-3)	J.B. Gurung	1993, 1994	R.B. Gurung	1993, 1994
Fuji 102 x Ch. Dhan	Machhapuchhre-4 (M-4)	C.B. Gurung	1993, 1994	P.B. Gurung	1993, 1994
Fuji 102 x Ch. Dhan	Machhapuchhre-5 (M-5)	R.K. Gurung	1993	K.M. Gurung	1993
K332 x NR10157-2B-2	Himchuli-1 (H-1)	M.B. Gurung	1993	B.B. Paudel[2]	1993
K332 x NR10157-2B-2	Himchuli-2 (H-2)	H.B. Gurung	1994	D.J. Devkota[2]	1994
Stejaree 45 x Ch. Dhan	Nilgiri-1 (N-1)	C.B. Gurung	1994	J.N. Devkota[2]	1994
Fuji 102 x Ch. Dhan	Machhapuchhre-6 (M-6)	J.B. Gurung	1994	-	
Fuji 102 x Ch. Dhan	Machhapuchhre-7 (M-7)	I.B. Gurung	1994	-	

[1] Year of first participation.
[2] At Lumle.

Farmers' preference ranking. In 1993, farmers' plots were visited in each village by the group of participant farmers and the breeders in ‘farm walks’, but no preference ranking was done. In 1994 and 1995, the on-farm and experimental plots at Chhomrong and Ghandruk villages were jointly monitored by participating and non-participating farmers, breeders, a socio-economist and affiliated researchers. At the outset, a breeder explained the purpose of the farm walk, and everyone visited all of the test plots in each village.

In 1994, after the farm walk, farmers were individually asked to rank varieties from 1 (for excellent) to 7 (for worst). Farmers, with the help of researchers, listed positive and negative characteristics of each variety using an open format questionnaire. The extent of agreement among farmers, and between male and female farmers, based upon preference ranking, was assessed by Kendall's W (Siegel, 1956), a measure of the concordance among multiple judges. Rank correlation was also used to measure agreement between two groups of multiple judges, breeders and farmers, using Spearman's coefficient of rank correlation (Steel and Torrie, 1960).

On-farm yield measurement. In 1994, the crops of all participant farmers were sampled by cutting a 1 m² plot. After threshing, grain yield was measured and adjusted to 12% moisture content. Plant height and fresh straw yield at harvest were also recorded.

On-station yield trials. Machhapuchhre-3 (M-3), selected by R.B. Gurung from Ghandruk-6, was the most liked F_5 bulk in the 1993 farm walks even though no formal preference ranking had been made. In 1994, it was entered in the first stage of national varietal testing, the National Rice Cold Tolerance Nursery (NRCTN). This nursery was grown at Chhomrong, Shera (1250 m), and Kavre Agricultural Farm (1700 m) during the rainy season of 1994. Trials were designed in a randomised complete block design with two replicates at Shera and Chhomrong. At Kavre the trial had only a single replicate.

The trials were researcher-managed with standard recommended agronomic practices. The seedlings were transplanted from nursery beds in mid-July 1994 into fields applied with 60-30-20 kg NPK ha^{-1}. Plot size varied from 1.2 to 4 m². Data on agronomic traits and disease incidence related to cold tolerance were measured. Analyses of variance were used in the replicated trials to evaluate the significance of differences between the varieties.

Post-harvest evaluations by women farmers. Post-harvest evaluation was done three months after the harvest. In the 1994 season, this study was carried out with only those varieties that farmers intended to grow again in the next season. The questionnaire used in the evaluation was designed after discussions with women farmers. Farmers consumed the rice after milling and cooking using local methods. Seven household questionnaires on post-harvest evaluation were completed.

Monitoring of varietal spread. Varietal spread was monitored with all participant farmers in 1993, 1994 and 1995. The reasons for the adoption or rejection of varieties were also recorded.

RESULTS

Farmers' selection of trial sites and performance of the F_5 bulks. Most of the farmers conducted their trial in medium fertility conditions, at altitudes from 1400 m to 2000 m. Four examples illustrate how farmers often carried out risk-aversion strategies. H.B.Gurung of Lumle, transplanted Himchuli-2 in a small area where water was at its coldest on first entering from the stream, and where, as a result, severe spikelet sterility had always been present in his local rice. D.Devkota of Lumle evaluated Himchuli-2 (H-2) under highly fertile conditions that caused the best local varieties to be partially sterile. H-2 yielded well, and a greater area was planted in the next year. The most extremely risk-averse strategy was adopted by J.N.Devkota of Lumle who transplanted Nilgiri-1 into a plot where he had never seen a rice plant produce a single grain. The plot had an inlet of cold water from a mountain stream which carried animal manure with it. Cold water in the presence of high fertility induces high spikelet sterility (Sthapit, 1992). The variety yielded 3.3 t ha^{-1} and the farmer was excited by this unexpected result. He said he would grow N-1 in better land in larger areas, but later changed his mind because of poor post-harvest traits. R.B.Gurung of Ghandruk first tried M-3 in the worst parts of his land in a corner of a high terrace that received little sunlight and cold irrigation water. He selected the best plants from this area, and the land he devoted to the variety expanded from 6 to 1250 m² within two years.

Farmers' perceptions of the F_5 bulks. In 1993, most of the entries included in the participatory programme were cold tolerant. However, the performance of Himchuli-1 was not very satisfactory due to high panicle sterility. Among the Machhapuchhre (M) lines, farmers dropped M-1 after the first year because it was very dwarf and was more sterile than Ch. Dhan, and M-5 because of its low yield. Although the performance of M-2 was average, farmers decided to evaluate it again in the next season. M-3 and M-4 appeared promising and farmers retained seed of them for a further season of testing.

In Chhomrong, in October 1994, 14 farmers from 10 farming households took part in the farm walk. The comparative performance of the three retained varieties from 1993, and the four additional varieties given in 1994 (Table 2) was judged by preference ranking. The overall rank of M-3 was the highest followed by M-2 and M-4. Himchuli-2 was ranked lowest (Table 3) because the panicles were small and had poor seed set.

Table 3. Comparison by preference ranking of rice lines when near to maturity under farmer-managed conditions, Chhomrong, 1994

	Preference ranking				
Variety	Mean male[1] farmers (n=9)	Mean female[1] farmers (n=5)	All farmers[2] (n=14)	Breeders[2] (n=2)	Overall (n=16)
Machhapuchhre-2	2	2	2	2	2
Machhapuchhre-3	1	1	1	1	1
Machhapuchhre-4	3	3	3	3	3
Machhapuchhre-6	4	6	4	3	4
Machhapuchhre-7	6	4	5	4	5
Himchuli-2	7	7	7	5	7
Nilgiri-1	5	5	6	4	6
Kendall's 'W'[3]	0.81	0.83	0.67	0.96	0.77

[1] Rank correlation (ρ) between male and female farmers, ρ = 0.82.
[2] Rank correlation (ρ) between breeders and farmers, ρ = 0.82.
[3] Kendall's 'W' is measured on the scale 0 (no agreement) to 1 (perfect agreement).

There was significant agreement between the evaluation scores of men and women farmers in Chhomrong village (Table 3). Agreement between the two breeders was higher than amongst the 14 farmers. However, the higher consistency amongst the breeders judgments is almost certainly because it is easier for two people to have common views than fourteen. Agreement between breeders and farmers was high (0.82). This is not unexpected because the farmers were carefully chosen for their skills, and the breeders had been exposed to farmers' preferences.

Out of the 14 participating farmers, two at Ghandruk and three at Chhomrong, retained seeds for further testing and evaluation (Table 2).

Yield from farmer-managed plots. Grain yields and other agronomic traits were measured from a 1 m^2 sample of the on-farm plots used for the preference ranking (Table 4). Although single crop cut data cannot be statistically analysed, there was good agreement between farmers' perceptions of the variety and crop cut results. The most-preferred variety, M-3, produced a higher or equal yield to Ch. Dhan while the other test varieties yielded less than Ch. Dhan (Table 4). The plant height and straw yield of M-3 was also superior to Ch. Dhan.

Table 4. Grain yield and other agronomic traits measured from a 1 m² crop cut from farmers' fields at Chhomrong and Ghandruk (1700-2000 m), 1994

Variety	Grain yield (t ha^{-1})		Plant height (cm)		Straw yield (t ha^{-1}) at harvest		Tillers plant^{-1}	
	Chhomrong	Ghandruk	Chhomrong	Ghandru k	Chhomrong	Ghandruk	Chhomrong	Ghandruk
Machhapuchhre-2	5.22	-	1.16 (1.18)	-	20.0 (18)	-	8.0 (5)	-
Machhapuchhre-3	(6.35)[1]	6.50 (6.50)	1.23 (1.10)	1.30	24.0 (17)	29.0 (24.0)	6.7 (4)	7.0 (2.5)
Machhapuchhre-4	6.32 (5.06)	3.35 (3.03)	1.14 (1.16)	(1.19)	11.2 (25)	9.2 (10.0)	5.6 (5)	6.2 (3.0)
Machhapuchhre-6	3.55 (5.06)	-	1.00 (1.16)	1.18	5.0 (5)	-	5.2 (6)	-
Machhapuchhre-7	3.14 (4.09)	-	1.11 (1.20)	(1.20)	16.0 (11)	-	6.0 (4)	-
Himchuli-2	3.23 (4.72)	-	1.17 (1.25)	-	20.0(26)	-	4.0 (5)	-
Nilgiri-1	1.43 (5.06)	-	1.10 (1.06)	-	18.0 (18)	-	5.6 (5)	-
	3.52 (5.06)			-				
				-				
Mean	3.77 (5.05)		1.13 (1.16)		16.3 (17)		5.8 (5)	

1. Figures in parenthesis represent grain yield data of Chhomrong local grown adjacent to a test variety, n=1.

Farmers' methods of plant selection. Farmers used various criteria to select the best plants. At maturity some farmers selected for grain colour without considering plant height or how early the plants matured. This resulted in an unimpressive segregating crop in the next year. Others bulked seeds only from plants of similar plant height, maturity time and grain colour. Apart from grain colour, farmers' criteria for selecting plants were that they should have long, compact and drooping panicles, good grain setting, and freedom from ShBR disease.

For example, M.B.Gurung selected plants of M-3 with intermediate height, compact panicles and filled grains, and selected plants where the flag leaves remained green after maturity, as he thought the straw quality of such plants would be better. He also considered the maturity of the test plants in comparison to those of the local that were grown alongside. P.B.Gurung, a retired livestock field officer of LARC, who had some knowledge of selection and heritability, firstly removed undesirable plants i.e., those that were dwarf, too tall, or diseased. He then selected panicles from white-grained plants with high grain set and long panicles. Another farmer, R.B Gurung, who tested M-3 in the worst plots of his land, harvested the best tall plants. He examined the grain colour of each selected plant and bulked the seed from those plants with white-grained panicles. He planted this seed in 1994 in his best field.

The major selection criteria were grain colour, yield, plant height, and maturity relative to the local variety. Besides grain yield, farmers considered how densely grain has set in the panicle, panicle length and tillering ability. Single-plant selection was usually only done in the best plots, because if the overall appearance of an entry was poor then farmers rarely bothered to select the few best plants from it. Farmers showed willingness to spare time and care in selection, though the degree of care and time increased in the third year of participation after they had appreciated the potential value of the exercise in the first two years.

The end results of selection on the same material varied. Farmers from similar ethnic groups and farming backgrounds selected in Chhomrong and Ghandruk from the same F_5 bulk seed. The resultant bulks, M-3C from Chhomrong and M-3G from Ghandruk, were very different when grown alongside each other at Lumle.

Post-harvest assessment by women farmers. Women farmers said they would like to decide on the best varieties after post-harvest evaluation. They used several qualitative criteria to assess the quality of rice (Table 5). Varieties M-6 and M-7 scored poorly for several traits, while M-2, M-3 and M-4 were liked for most traits and farmers chose to expand the area under them. White-grained rice is preferred over red-pericarped rice as it saves women time in milling (Table 6, comment 2). The post-harvest evaluation was the ultimate criterion upon which farmers either rejected or adopted the varieties. For example, J.N. Devkota was very impressed with the performance of Nilgiri-1 but decided not to grow it outside his problem plots because of its poor taste, and M-6, which performed reasonably in the field, was rejected because of the peculiar smell of the cooked rice.

Table 5. Post-harvest assessment† of various rice varieties relative to the local check (Chhomrong Dhan), Chhomrong, 1994

Traits‡	M-2	M-3	M-4	M-6	M-7
Milling %	50.0	45.0	56.0	45.0	40.0
Broken rice %	1.9	5.0	1.3	5.0	5.0
Water-absorbance capacity	+	+	+	-	+
Elongation capacity	+	=	+	-	+
Aroma	+	-	-	-*	-
Dryness	+	+	+	-	+
Stickness	+	+	+	-	+
Taste	+	+	+	+	+
Appetite delay	+	+	+	-	+

† Better than local check, = equivalent to local check; - Inferior to local check
‡ Assessment was done by farmers after cooking in their own way and relative to check variety Ch. Dhan.
*The rice had a peculiar aroma that was disliked by farmers.

The milling percentage of all the rice varieties was generally poor (40 to 56% by volume with 1.3 to 5% broken rice), but farmers considered 50% milling recovery acceptable. M-4 had the highest milling recovery (56%) with the lowest percentage of broken rice and was easier and quicker to mill by *Dhiki* (the local implement for dehusking which is usually operated by two women) as it has very thin husk. P.B.Gurung was so impressed with this that he planted all the seed of M-4 he had, both selected and unselected. Farmers were reluctant to continue with M-7 as its milling recovery was quite poor (40%). Milling recovery of the other cultivars did not differ significantly from the local variety.

Table 6. Farmers' perceptions of the participatory breeding programme in Chhomrong and Ghandruk, 1994

Location	Date	Gender	Size of group	Comments
Chhomrong	7 Oct 94	Male	9	*"Any rice variety that grows at this altitude is good. We need a variety which yields more and gives more straw. If variety has white grain colour it is a bonus. We will further select the plants to grow in larger plots next year."*
Chhomrong	7 Oct 94	Female	5	*"If we can change our local rice into white grain rice it will save a lot of our (womens') time. We spend one to two hours extra time to dehusk rice until we get white grain."*
				"Machhapuchhre-3 has both more grain and more straw. It has long panicles and grains are plenty. It matures at the same time as the localvariety and the plant are taller. If it tastes good we would like to continue with this variety."
Ghandruk	9 Oct 94	Male	1	*"In the beginning I was not interested to involve myself but when LARC scientists told me that it has white grain then I became curious. I first tried it in the worst parts of my land. I saw tall plants producing really good panicle. I selected all of the best plants with white grain and maturity similar to our local variety. This year it looks really good and better than last year. Now I am happy to grow in all my plots. I have no plan to share the seeds until I fulfill my requirement."*

The best panicles selected by farmers were kept for seed whereas the grains from the late tillers and small panicles were used for the post-harvest evaluation. This resulted in a relatively lower milling percentage and a high proportion of broken rice. Farmers, therefore, considered that if a variety had a similar milling percentage to the check variety it would have a better milling recovery if the best panicles were evaluated.

Monitoring of spread. The preferred varieties had spread substantially within two years of their introduction (Figure 2). M.B.Gurung of Chhomrong, who got half of the seed from his friend J.B.Gurung, successfully selected from M-3 (his selection is identified as M-3C) and increased the area under it from 3 m^2 to 150 m^2 within a year. Similarly, R.B.Gurung of Ghandruk also selected M-3 (identified as M-3G) and increased the area from his 6 m^2 plot to 50 m^2 in 1994, and sowed sufficient for a cropped area of about 1250 m^2 in 1995 (Fig. 2). This variety occupied 3% of his rice fields after the first year of selection and over 60% after the second. The most-preferred bulks spread at a logarithmic rate, whilst other bulks are abandoned after one or two years (Fig. 2). Whether the bulks are grown again, or not, is also location dependent.

Farmers' perception of the programme. At the beginning of the programme, farmers were not very enthusiastic. They were accustomed to conventional, labour-intensive, researcher-managed on-farm trials. However, farmers' participation increased as the programme began to produce encouraging results. Comments made during field visits reflect the satisfaction of the participating farmers (Table 6). P. Shrestha, a LARC staff member reported: "In the beginning it was difficult to find a farmer willing to participate but now the whole community is willing to offer their help."

On-station yield trial. The performance of farmers' selected varieties were compared in on-station yield trials to varieties bred through centralised breeding programmes. Results from these trials can be used to satisfy the variety release regulations by validating participatory on-farm data with on-station data. At Chhomrong, M-3 performed as well as the check variety Ch. Dhan ($P \leq 0.05$) (Table 7). Both varieties showed superior resistance to ShBR disease (Table 7) and cold at anthesis. At Kavre, the farmer-selected M-3 out-yielded the check Ch. Dhan (5.4 t/ha). It also out-yielded other superior local varieties known for their high cold tolerance in Nepal (Table 7). M-3 also showed a comparable incidence of ShBR and neck blast under natural inoculum pressure as compared to most breeder-selected varieties. One of the farmer-selected rice varieties M-3G, (Machhapuchhre-3 Ghandruk) was multiplied and included in the national varietal testing system of the NARC (1994), and promoted to the Initial Evaluation Trial as a promising entry.

Figure 2 the area of adoption of new rice bulks in Chhomrong and Ghandruk villages, 1993-95

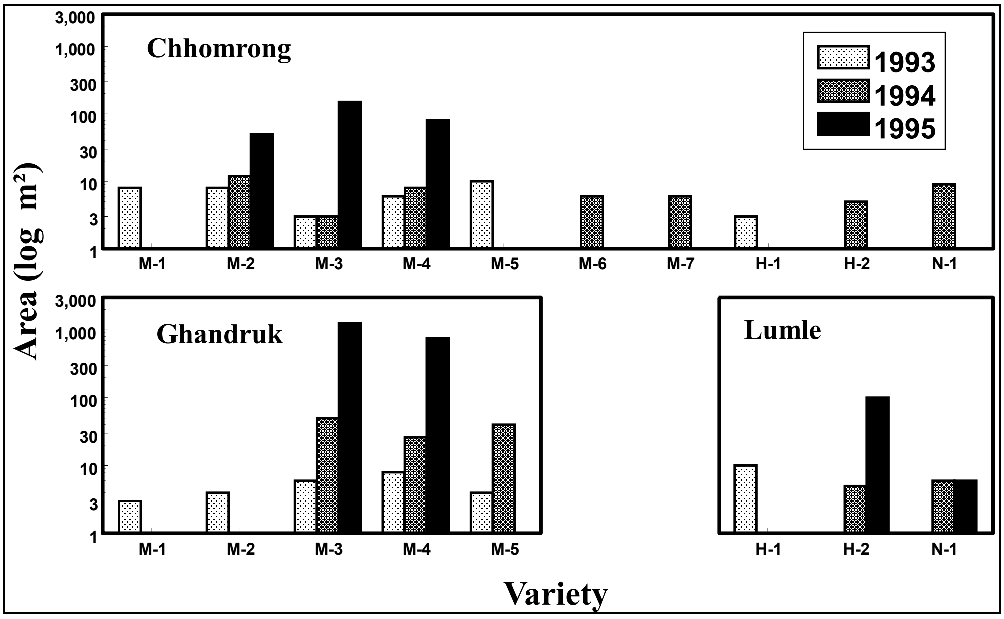


Table 7. Performance of Machhapuchhre-3 in comparison to the mean yield of best yielding entries from conventional breeding and local controls in the National Rice Cold Tolerance Nursery (NRCTN), 1994 summer at Shera (1250 m), Kavre (1700 m) and Chhomrong (2000 m) under researcher-managed conditions

	Grain yield (t ha^{-1})			Days to 50% heading			Plant height (cm)			ShBR† (%)		
Variety	1250m	1700m	2000m	1250m	1700m	2000m	1250m	1700m	2000m	1250m	1700m	2000m
M-3 (W)*	5.2	6.7	4.3	96	118	156	120	136	119	11	10	2
Ch. Dhan (R)*	6.1	5.4	4.9	91	105	147	130	116	127	4	12	5
Darmali (W)*	1.9	5.0	0	111	123	180	137	116	129	5	4	2
J. Marshi (W)*	1.6	6.0	2.7	90	145	131	119	109	141	13	36	12
Best (n=5)‡	5.8±0.38	5.4±1.1	2.4±0.5	99.0±2.1	117.0±4.8	151.0±5.7	133.0±4.0	100.0±3.3	124.0±5. 9	5.8±2.2	15.2±3.6	8.5±2.5
Overall (n=10)‡	4.7±0.4	3.9±0.8	0.5±0.3	94±2.2	115±2.0	154±3.5	127±4.0	101±2.9	105±4.9	5.7±1.2	17.1±2.9	19.4±8.0
Mean	4.1±0.21	-	2.2±0.30	134±0.6	-	186±1.2	129±1.5	-	121±2.4	7.0±0.7	-	11.9±2.2
SE for variety	1.03	-	0.87	1.94	-	1.88	7.87	-	7.8	4.38	-	14.4

† Bacterial Sheath Brown Rot disease in incidence (%) at maturity
*R = Red grain and W = White grain Ch. Dhan, Darmali, and Jumli Marshi (J. Marshi) are standard local check varieties.
‡ Products from conventional breeding method i.e., Nepal Agricultural resaech Council (NARC) selection from IRRI nurseries and NARC breeding materials (mean of best five and all 10 entries).

DISCUSSION

Many workers have advocated decentralisation of research for plant breeding (Maurya *et al*., 1988; Farrington and Martin, 1988; Galt, 1989; Joshi and Sthapit, 1990; Sperling *et al*., 1993; Sthapit *et al*., 1994; Joshi and Witcombe, 1996; Witcombe *et al*., 1996). Formal research systems in developing countries are highly centralised and do not target the problems of resource-poor farmers, as evidenced by the poor adoption of officially released rice varieties in India (Maurya *et al*., 1988; Joshi and Witcombe, 1996) and Nepal (LARC, 1995, Chemjong *et al*., 1995).

We believe that this is the first well-described example of participatory plant breeding (PPB) in which farmers have selected within segregating lines. It has successfully produced cultivars which are performing well in the conventional trials system and which are spreading in farmers' fields. In a conventional breeding system, material such as M-3G and M-3C would have still been in very preliminary stage of varietal screening in very small plots and still at least 7 years away from being given to farmers for them to grow in minikit tests. A release proposal can be submitted three years earlier than in the conventional system, even if time is allowed to select for greater uniformity within a farmers' cultivar to satisfy seed certification requirements.

The area under the cultivation of the preferred cultivars increased at a high rate in the first three years of the PPB programme. In the conventional system there is a long period, typically 5-6 years, after release before appreciable adoption occurs (Morris *et al*., 1992). Some farmers have already started distributing seed of the preferred varieties to other farmers. We anticipate that M-3G will be widely cultivated in domains similar to Ghandrak and Chhomrong by the time the variety is released through the formal system.

A large number of exotic, cold-tolerant rice varieties have been supplied from IRRI through the International Rice Cold Tolerance Nursery (IRCTN) and many have been included in the National Rice Cold Tolerance Nursery (NRCTN). These nurseries were evaluated at Chhomrong and the majority of the entries failed to set grain in high altitude villages (Sthapit, 1992). In comparison, the varieties developed jointly with farmers were far superior to the best entries from the conventional system (Table 7). The advantage of using locally adapted parents and selection in the target environment can be seen over the introduction of international nurseries. A farmer-selected variety can not only be farmer acceptable but also yield well in the formal varietal testing system. The ability of M-3 to perform well in both systems is, in part, because the trial locations are appropriately situated to represent farmers' non-problem fields and because trial management does not differ too radically from that of the farmers, and because M-3 is adapted to both stressed and non-stressed environments.

There were significant differences among farmers' and researchers' strategies for selection of testing sites. It is a common practice in formal research systems to use good, uniform land for trials. In contrast, farmers avoid risk by first testing new materials on their worst land where severe abiotic stresses occur and then growing them on better fields if they have performed well. This strategy shows how difficult it is to represent the heterogeneous environments of farmers' fields in uniform on-station conditions. Any cultivar from the centralised system will first have to pass the test of being grown in the poorest fields, a factor which is only fully taken into account in PPB. The farmers' risk aversion strategy also shows that they are not exposed to unjustifiable risk, which is a common criticism levelled at participatory approaches.

Careful choice of farmers is important for the success of PPB. Farmer methods of plant selection varied with the farmers' knowledge and circumstances. Machhapuchhre-3 was given to three farmers but only two of them succeeded in selecting superior types from it. The farmer who failed to identify superior types had only mass selected for grain colour. Women farmers were particularly skilful in assessing post-harvest traits such as milling recovery, cooking and eating quality. Men farmers showed more skill in the assessment of standing crops for yield potential, and management requirements.

Farmers evaluate new varieties at all stages of crop growth and the range of traits they consider is far more than breeders can evaluate in trials. Farmers paid particular attention to the crop near to maturity and also at threshing, milling and consumption. Although, farmers involvement in formal variety testing in Nepal is limited to preference ranking at maturity, most of farmers made the final decision of retaining or rejecting the variety at the post-harvest stage. For example, the area under M-4 expanded because farmers liked its good milling recovery whereas M-2 was rejected due to its peculiar smell when cooked. M-3 was preferred at all stages because of its yield potential and straw height and good post-harvest traits. Nilgiri-1 was first selected by a farmer in Lumle village, who later abandoned his plan to expand the variety in the remaining good fields, because of high shattering and poor taste. Himchuli-2 was rejected by farmers at Chhomrong, Ghandruk and Lumle where rainfall is very high at the time of maturity and causes pre-germination before harvest. In contrast, Himchuli-2 was liked by farmers of Patlekhet village (1500-1700 m), where rainfall and humidity at maturity is less. In Lumle, the mother of D. Devkota selected non-sprouted panicles and planted the seed from them in a 100 m^2 area to see whether the problem of sprouting would continue. Such examples strongly support the decentralisation of selection.

The study also found that farmers have particular preferences for the eating and cooking quality of rice. Rice with soft white grain, with ability to expand after cooking was preferred. Whether these criteria can be related to standard grain quality testing procedures needs to be investigated. The present varietal testing systems have no mechanisms to consider farmer-relevant traits such as post-harvest varietal qualities. Laboratory measurement of such grain quality traits are important, but grain quality is often not assessed in the formal varietal testing system of Nepal until it reaches the final stage of release (Sthapit, 1995).

As anticipated, PPB increased biodiversity in the participating villages (Witcombe *et al*., 1996). Varietal diversification has been repeatedly achieved and a dynamic form of genetic diversity will persist as farmers select plants for specific niches. An example is the retention of the otherwise unacceptable Nilgiri-1 by one farmer for the one small plot where an inlet of cold stream-water causes high sterility. Cultivars derived from the same F_5 bulks looked different, and, even when similar, they may contain significantly different latent genetic variation within the population (Berg *et al*., 1991). PPB has resulted in a dynamic form of *in situ* genetic conservation by farmer participation in the selection of materials generated from landrace x exotic crosses (Witcombe *et al*., 1996).

The decentralised selection of segregating material from a few carefully chosen crosses drawing on the active participation of expert farmers, presents an attractive prospect for fostering a more sustainable and productive agriculture for diverse risk-prone environments. The prerequisites of the method are that objectives are clearly identified, local material is involved in the crosses, farmers are willing participants, and breeders are flexible enough to learn from and work with farmers.

The institutionalisation of decentralised technology is a most challenging issue (Ashby and Sperling, 1994) . However, PPB has already been institutionalised within LARC on the basis of the work reported in this paper. If the success of these efforts is to be sustained, incentives are required for field staff to work in difficult areas. PPB can deliver the wide range of rice varieties needed for the diverse socio-economic circumstances of farmers. Conventional approaches which concentrate on grain yield and wide adaptability are not always feasible in developing countries where research resources and trained manpower are limited.

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