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HOW CAN PARTICIPATORY BREEDING CONTRIBUTE TO THE MAINTENANCE OF BIODIVERSITY ? EXPERIENCES FROM RAJASTHAN, INDIA

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Abstract

Participatory plant breeding (PPB) has a considerable potential to maintain local biodiversity. With PPB, breeders and farmers share their knowledge and skills in order to develop varieties or breeding strategies together. Diagnostic methods used in PPB help to create a more effective dialogue between researchers and farmers. This enables scientists to better understand the local farming conditions, the farmers' traditional diversity management as well as their specific needs and preferences. Therefore, participatory breeding programs work with a wider range of diverse breeding materials. Furthermore, participatory plant breeding implies decentralised selection, i.e. farmers grow crops in their own fields and make local selection decisions themselves. In Rajasthan, India, a project was initiated by the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) and the University of Hohenheim, to form the basis for a breeding program that would involve farmers as research partners. The approach was based on: the understanding of farmers' concept of a variety, the analysis of farmers' management of pearl millet seed, and the utilisation of farmer-generated populations to develop locally acceptable and improved pearl millet germplasm. Farmers' seed management strategies and variety concepts were analysed using social science methods. The effects of farmers' seed management practices (introgression of modern varieties and selection) on the genetic structure of pearl millet populations were analysed by quantitative genetic methods. For this purpose samples of 33 farmers' seed stocks were collected in western Rajasthan and evaluated in field trials together with control cultivars. Results showed that farmers' variety concept is effective and farmers' seed management practices affects diversity, adaptation and productivity of pearl millet populations. A participatory plant breeding program in Rajasthan would thus allow making use of farmers' breeding interventions and farmers' knowledge to achieve together breeding aims and to safeguard the local pearl millet diversity.

Key words

Genetic diversity, pearl millet, participatory plant breeding, seed management, landraces, adaptation

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Introduction

Biodiversity can be evaluated at different levels: at regional level, within a village on a farm, or on a field. Witcombe and Joshi (1996) have pointed out the difficulties in defining biodiversity in crops. It can be defined in a variety of ways: by the number of cultivars, by their genetic relatedness or by the proportion of area these cultivars occupy. It can also be defined at the DNA level, by measuring the similarity/dissimilarity between molecular marker.

The loss of biodiversity and specifically the erosion of landrace diversity is commonly attributed to a range of factors :

- The release and adoption by farmers of modern varieties (MVs) .
- Changes in the production systems, e.g., the introduction of new crops, and production techniques, that render traditional varieties unadapted, or less preferred
- Changes in market demand for quality, uniformity and timing of availability

In this paper we are mainly interested in factors relating to the activities of formally led farmer participatory plant breeding programs and their impacts on the diversity of the crop under investigation.

How can participatory breeding (PPB) support the preservation of existing genetic diversity and the maintenance of evolutionary processes that form diversity, and simultaneously improve cultivar performance? In recent years, participatory approaches have contributed significantly to the understanding of evolutionary processes (biological and social) that form, and affect, diversity in agricultural systems. By studying and understanding the local farming and seed management system PPB strategies can be developed that respect farmers' diversity needs and that fit into the local farming systems and that help to overcome the limitation of the local seed system.

In the following, some arguments are listed of how PPB strategies can contribute more effectively to the maintenance and development of biodiversity:

- By supporting and understanding traditional diversity management in the farming systems, e.g. using the traditional seed system for the propagation and the dissemination of seed, which can be more effective than the formal system (Almekinders *et al*. 1994)
- By making available a wide range of genetic material to the farmers. PPB offers a greater choice of material than conventional breeding programs. In order to ascertain farmers' preferences and needs breeders must work with released cultivars, landraces of different origin and experimental varieties. Exposing farmers to a great choice of plant material cultivar replacement rates can be substantially increased, especially in the case when biodiversity in farmers' fields is low (Witcombe and Joshi 1996).
- By utilising as many locally adapted landraces in crossing programs as possible.
- By evaluating materials in a large decentralised set of experimental fields in order to address different environmental conditions and also to address the needs and preferences of a range of user groups and their production objectives. In PPB, the farmers grow crops in their field and make local selection decisions themselves. Specific adaptive traits, therefore receive adequate weights as selection criteria.
- **By allowing natural selection to act against poorly adapted genotypes.**
- **Samples of locally-selected populations could be collected by breeders for use in gene pool management and to improve traits requiring laboratory or controlled-**

environment techniques, which are necessary to make local material more productive and competitive.

In 1997 a project was initiated by the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) and the University of Hohenheim for Rajasthan, India, to form the basis for a breeding program that would develop locally acceptable and improved germplasm, and that would involve farmers as research partners. The project with the title "Enhancing the productivity, diversity and quality of farmers' pearl millet genetic resources in Rajasthan" was funded by the Ministry for Economic Co-operation and Development (BMZ) through the German Society for Technical Co-operation (GTZ). The present study reports some of the results of the project.

The objectives were:

1. To evaluate farmers' concept of a variety and farmers' seed management strategies to understand regional diversity and to investigate the relevance of farmers' selection criteria
2. To analyse the effects of farmers' seed management in regard to MVs adaptation, productivity and diversity
3. To evaluate the usefulness of farmer-generated populations for breeding purposes.

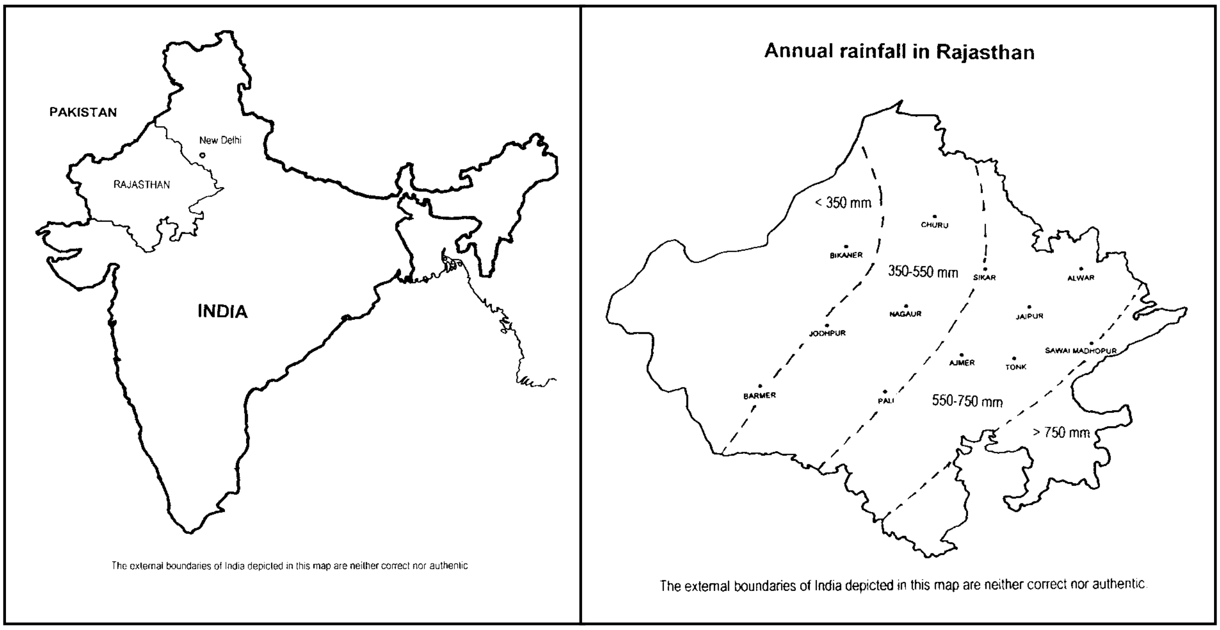

Figure 1: The state of Rajasthan in the north-west of India, district capitals and zones of mean annual rainfall in the study area.

Pearl millet (*Pennisetum glaucum* [L.] R.Br.) is a drought-tolerant cereal crop well adapted to the semi-arid tropics. In north-west India, particularly in the state of Rajasthan (Figure 1), it is the staple food and fodder crop. Western Rajasthan pearl millet landraces are extremely tolerant to stress conditions. In the dry, western parts of Rajasthan, which border on the Thar Desert, farmers prefer to grow adapted, traditional landraces of pearl millet. Modern pearl millet varieties have a low adoption by farmers in this region, mainly because of the MV's poor grain and fodder yield under severe drought stress. Nontheless, some farmers do mix small quantities of MV seed into their landrace seed grain, as farmers are attracted by the possibilities of higher yield potential under more favourable climatic conditions. They mix in only small quantities of MVs in order to safeguard themselves against crop failure in the event of drought (Dhamotharan *et al*., 1997; Weltzien *et al*., 1998).

Methods and materials

These objectives were approached by close collaboration between an agricultural social scientist (A. Christinck) and a population geneticist (K.vom Brocke). Methods include interviews, participatory rural approval (PRA), observation, in addition to action research for the part of the social scientist and field and laboratory trials as well as molecular marker studies in the part of the population genetic part.

For **the purpose of the first two aforementioned objectives, two experiments were** conducted in five environments (site/season combinations) between 1997-1999 in western Rajasthan: the Central Arid Zone Institute (CAZRI) research station at Jodhpur (JOD97, 98), the Rajasthan Agriculture University (RAU) research station at Mandor (MAN97, 98), and the CAZRI station at Pali (PAL97). The first experiment comprised 48 pearl millet grain stocks from farmers and 33 MVs. The farmer grain stocks had evolved through different seed management practices i.e. various levels of MV introgression and different seed selection methods. Three of these farmer grain stocks were chosen as base populations for the second experiment (third objective). One population represents a typical landrace (Population RR), and the two other populations comprise grain stocks that had been modified through introgression of MVs (population DR and SB). The experiment was conducted in the form of progeny trials comprising 100 full-sib families of each population.

Results and discussion

Evaluating farmers' concept of a variety

Farmer' seed management cannot be evaluated if one does not fully understand the farmers' concept of a "variety". In order to learn how farmers perceive "varieties", informal interviews as well as classification and ranking exercises were carried out during workshops with Rajasthan farmers (Christinck *et al*. 2000). The results demonstrate that environmental adaptation was the main criteria for farmers' classification of pearl millet plants in western Rajasthan. Potential uses and quality aspects were also important in the farmers' grouping different plant types. In western Rajasthan, farmers distinguish between two plant types: the traditional adapted landrace, called "desi" pearl millet and the modern, introduced varieties, called "sankar" pearl millet. Traditional landraces that have adapted to the environment display a high basal and nodal tillering ability, indicating low requirements to soil fertility as well as tolerance to drought. If these characteristics are combined with thin stems, narrow leaves and thin compact panicles with small grains, farmers will conclude that such a plant will grow under low-input conditions (i.e. in their fields) and produce grain and straw of high nutritional quality. In contrast, characteristics of modern varieties are low basal and nodal tillering ability, thick stems with broad leaves, and large panicles with relatively large grains that are mostly round in shape. From farmers' experience, this plant type is not tolerant to drought stress, requires higher soil fertility and has inferior food and fodder qualities. Farmers however, are aware that pearl millet plants showing such characteristics can produce higher yields under more favourable conditions. Farmers are therefore concerned with the composition of their seed stocks, i.e. which plant types and thus which properties are present. Farmers expect plant types to change over time in reaction to environmental conditions such as soil quality and rainfall. Thus, the seed stock generated in one year cannot be exactly reproduced the next season. Farmers have a strong concept of continuous interaction between plant type and environment as evidenced by their belief, or experience, that any pearl millet cultivar, including modern varieties, that is grown in their field for some years, will eventually become like their local cultivars.

The adaptive role of the described traits agreed with the phenotypic relationship between grain yield and plant characteristics show in Table 1. Under drought stress, nodal tillering, number of productive tillers as well as diversity of plant types showed a positive phenotypic relationship with grain yield (r=0.3-0.9), whereas stem diameter, leave width, panicle girth, and grain weight had negative correlation coefficients (r=0.2-0.7) with grain yield. The relationships were reverse under favourable conditions. Farmers' concept of plant-type classification is thus indeed effective.

Table 1: Coefficients of phenotypic correlations of grain yield to yield traits and plant-type characteristics in favourable and low-rainfall environments

	ENVIRONMENT†				
	Favourable			Low rainfall	
Trait	***MAN97***	***JOD97***	***PAL97***	***MAN98***	***JOD98***
Grain weight	0.69**	0.75**	0.42**	0.08	-0.25*
Stem diameter	0.62**	0.69**	0.41**	-0.65**	-0.14
Panicle girth	0.70**	0.83**	0.42**	-0.60**	-0.24*
Leaf width	0.38**	-‡	0.33**	-0.62**	-0.24*
Nodal tillering	-0.65**	-‡	-0.41**	0.56**	0.27*
Diversity	-0.57**	-‡	-0.36**	0.32**	0.11
Productive tillers	-0.54**	-0.46**	-0.41**	0.90**	0.48**

*, ** Significant at P=0.05 and P=0.01, respectively.
‡ Trait not observed.

Analysing the effects of farmers' seed management

Various strategies of how farmers improve and maintain their pearl millet cultivars were identified for Rajasthan. These strategies not only differ according to agro-climatic factors, but they also differ according to socio-economic factors or individual preferences. Three main management strategies were identified for the village of Aagolai in western Rajasthan (vom Brocke *et al*. 2001a):

(1) Farmers who grow and maintain pure landraces only, and who prefer a winnowing method for separating seed and food grain;

(2) Farmers who occasionally introgress modern varieties and also follow the winnowing method when selecting;

(3) Farmers who frequently introgress MVs into their own seed stock, and who mostly practise panicle selection in separating seed from food grain.

A principal component analysis based on the performance of 12 plant characters (Figure 2) and a genotype×environment (GE) analysis based on grain yield data (Figure 3) was carried out in order to gain an overall view of the effects of these strategies on plant-type diversity and adaptation of farmers' seed stocks. The pattern analysis classifies environments and assesses the relationship between entries and environments.

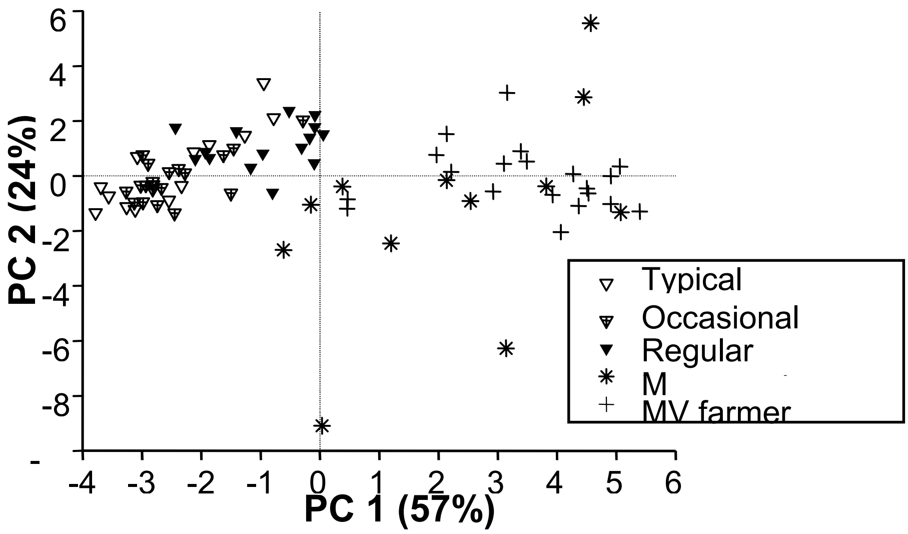

Figure 2 : Scores of 80 pearl millet entries for principal components PC1 and PC2 calculated from the correlation matrix of entry means for five yield traits (excluding grain yield) and nine plant-type characteristics.

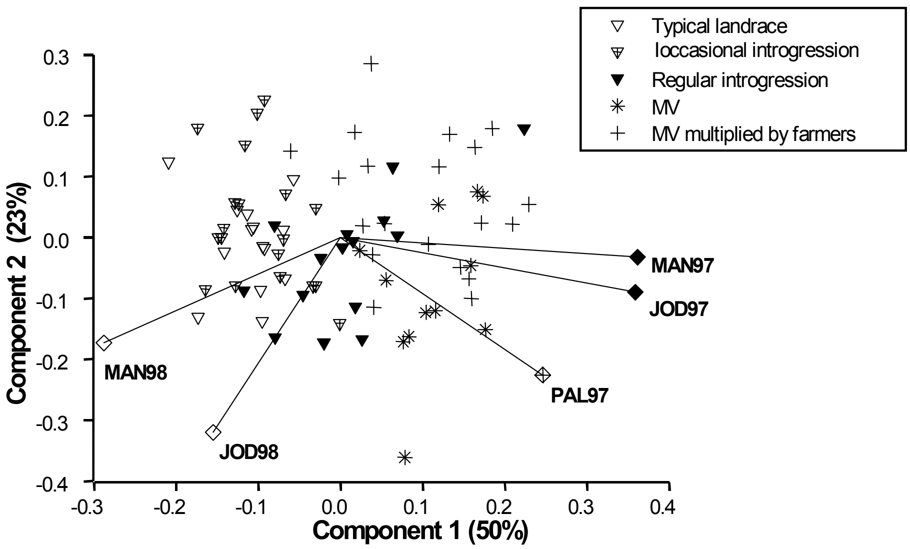

Figure 3 : Biplot displaying principal components 1 and 2 obtained by ordination techniques from environmental standardised grain yields of 80 pearl millet entries. (MAN=Mandor, JOD=Jodhpur, PAL=Pali).

The characterisation of entries by principal component and pattern analysis demonstrates that farmers in western Rajasthan produced grain stocks that are specifically adapted to drought conditions. Strong entry×environment interactions confirmed farmers' perception that modern varieties are not adapted to the stress conditions of western Rajasthan. Occasional introgression of modern varieties does not offer significant advance in regard to adaptation and productivity. Regular introgression, on the other hand, resulted in seed stocks resembling improved populations or top-cross hybrids based on western Rajasthan landrace material. Further, the behaviour of entries as visualised in the biplot (Figure 3) indicates that regular introgression resulted in more stable yield under stress conditions and a higher yield potential under favourable conditions compared to the other entries. However, it should not to be overlooked that the introduction of modern varieties into the farming system leads to a loss of typical landrace plant characteristics, as it can be concluded from Figure 2.

Evaluating the usefulness of farmer-generated populations for breeding purposes

The quantification of the most common seed management strategies of western Rajasthan provided evidence that farmers generate variability by introgressing modern varieties into their landrace seed stocks (Table 2) (vom Brocke *et al*. 2001b).

Table 2 : Estimates of the genetic variance between full-sib progenies ($\square^2_g$) and their approximate standard errors, estimates of heritability (h^2) for yield, developmental and morphological traits of 100 full-sib progenies of three farmer population, one typical landrace (RR) and two modified landraces (DR, SB), combined across four environments.

	$\square^2_g$						h^2		
Trait	**RR**		**DR**		**SB**		RR	**DR**	**SB**
Grain yield	20.54**	±6.5	60.16**	±15.2	55.70**	±15.2	0.53	0.65	0.62
Productive tillers	37.59**	±7.6	45.26**	±10.1	63.41**	±12.9	0.77	0.71	0.78
Stover yield	9.27**	±2.7	14.27**	±4.1	30.60**	±6.9	0.54	0.60	0.74
Grain weight	3.14**	±1.0	5.25**	±1.4	4.79**	±1.2	0.52	0.61	0.67
Flowering	2.09**	±0.4	4.66**	±0.7	5.56**	±0.8	0.93	0.93	0.94
Plant height	21.34**	±24.9	60.83**	±12.9	87.08**	±17.0	0.79	0.75	0.81
Panicle length	2.18**	±0.4	1.70**	±0.3	3.40**	±0.6	0.87	0:83	0.91
Panicle girth	0.15**	±0.0	0.40**	±0.1	0.34**	±0.1	0.92	0.91	0.92
Stem diameter	0.28**	±0.1	0.37**	±0.1	0.71**	±0.1	0.87	0.85	0.91
Nodal tillering ‡	69.70**	±16.9	132.26**	±29.7	67.07**	±28.4	0.76	0.79	0.53

*, ** F-test of respective mean squares significant at the 0.05 and 0.01 levels, respectively.
‡ Only three locations included in the analysis.

A population generated by farmers would express farmers' preferred traits, maintain local genetic resources, offer a buffer against heterogeneous conditions on account of the inherent genetic diversity, and safeguard against the processes of evolution. Breeders could benefit from the potential recombination in farmer-generated populations obtained under farmer-field conditions, that have high population size i.e. high selection intensity.

Conclusions

The analysis of farmers' seed management methods led to the identification of factors affecting diversity, i.e. introgression of modern varieties, maintenance of typical landrace properties, selection methods and criteria. Participatory breeding would allow making use of farmers' breeding interventions to achieve together breeding aims.

In the case of Rajasthan, farmers are interested in a range of plant types and are keenly experimenting and introgressing modern genetic material. The present study has shown that farmer' management strategies increase genetic and plant-type diversity within and between populations. The diversification by regular introgression of MVs and farmer-selection leads to an increase in productivity by maintaining yield stability. Breeders could benefit from potential recombination in populations obtained under farmer-field conditions that have high population size. Therefore, farmers' seed management should be considered a valuable pre-breeding activity that can produce ideal starting material for improving grain and forage yields in semi-arid India. Farmer participation in the selection process would ensure that farmer preferences and adaptation to their specific environmental conditions is properly addressed. A further role of breeders could be to provide suitable genetic material that has the ability to combine with local landraces, and that has the potential to achieve genetic gains in farmers' preferred traits.

Considering that the introgression of MVs also leads to erosion of local landraces and decreased expression of adaptive traits, linking variety development programs with *in situ* conservation programs should also be taken into consideration.

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