and is normally a difficult combination to achieve in any maize-breeding program. GDRM 187 also had other advantages, including improved grain quality, that should increase its speed of adoption and its adoption ceiling. All this was achieved with modest resources, since only a single composite was created and only a few varieties were derived from it.

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Towards a Practical Participatory Plant-Breeding Strategy in Predominantly Self-Pollinated Crops

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Abstract

There is a limit to the capacity of any breeding program, and the more crosses that are made, the smaller the size of each cross. The theory of the optimum number of crosses in inbreeding crops is briefly reviewed. The theory is unsatisfactory in determining the optimum number of crosses, but models that take linkage into account show that very large populations are needed to recover specified genotypes. Hence, one possible strategy is to select a small number of crosses that are considered favorable and produce large populations from them. This strategy is ideally suited to the particular constraints and advantages of participatory plant breeding (PPB). When a breeding program is based on few crosses, the choice of parents is crucial and farmer participatory methods are highly effective in narrowing the choice. Modified bulk-population breeding methods are desirable strategies in the participatory plant breeding of self-pollinating crops when combined with a low-cross-number approach, and a participatory breeding program for rice in Nepal is described.

Introduction

In most, perhaps all, conventional breeding programs for inbred crops on research stations, breeders deal with many crosses each season. Even with fairly limited resources many hundreds, or even thousands, of F_4 or F_5 lines can be tested. Unless there is considerable researcher input into the layout of trials in farmers' fields, participatory plant breeding (PPB) has to employ many fewer crosses and entries than conventional or classical breeding. In farmer-designed, farmer- managed trials, each farmer usually grows only one entry (e.g., Joshi and Witcombe 1996) and the number of participating farmers thus limits the number of entries. However, a very large population of any entry can be grown, with little or no cost, or even with a benefit. In PPB, a farmer replaces his or her cultivar with a population for PPB on land that would normally have been devoted to the crop. The cost of this replacement is any decrease in value of the harvest caused by the replacement and the benefit is any increase in harvest value. In contrast, in classical breeding all the costs of any increase in the area of the cultivated crop are borne by the breeding program. We briefly review the theoretical evidence on the number of crosses that are required in a breeding program. We describe a rice breeding program in Nepal that is using a low-cross-number, high-population-size strategy.

Theory on the number of crosses in a breeding program

The optimum number of crosses required in an inbreeding crop was reviewed by Witcombe and Virk (forthcoming) and only a summary is presented here. To calculate the optimum number of crosses, crucial assumptions are required on the rate of the inevitable decline in the potential value of each cross as more and more crosses are made. If the decline is very significant (e.g., a few

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crosses can be identified as having a higher probability of giving desirable segregants than others), then only a few crosses are needed. If the decline cannot be predicted, then many are required. The lack of quantitative data to support assumptions on the rate of decline limits the role of theory in deciding the optimum number of crosses. However, to recover specified genotypes, large population sizes are needed that, given a limit to the overall size of any breeding program, will limit the number of crosses. Whether a high-cross-number or a low-cross-number approach should be used depends greatly on the judgment of the researcher as to whether the value of crosses can be predicted with any certainty. In a decentralized breeding program, the target environment and the required traits in a finished variety are known, and the knowledge of existing adapted germplasm is considerable. This allows such predictions to be made, so a low-cross-number strategy appears sensible. Many fewer crosses than are common in most breeding programs will be used, and for all of them there will be logical reasons as to why the cross should have a high probability of producing favorable segregants. There will be many fewer crosses than commonly suggested from theoretical calculations that invariably assume there is no prior information on the value of any cross, i.e., that all crosses are considered to have an equal chance of success (Yonezawa and Yamagata 1978; Wricke and Weber 1986; Huehn 1996).

In a large-cross-number strategy, population sizes are likely to be limited to a few hundred rather than several thousand. In a low-cross-number strategy, population sizes can be larger and increase the probability that desirable segregants that are an improvement over the best parent are recovered. All that is needed is that the two parents differ significantly for an important trait (a practical certainty) at some point in the genome. A segregant that has a genome substitution from the other parent at this point will be superior, providing the sum of the rest of the genome is equal to the best parent. The existence of a cross that cannot give rise to superior segregants is theoretically impossible, although the population size required to recover desirable segregants may be impracticably large. However, choosing complementary parents increases the likelihood that there will be a sufficiently high frequency of desirable segregants for them to be selected.

Towards a practical participatory breeding strategy

PPB is ideally suited to the strategy of rigorously selecting parents, using a small number of crosses and employing large populations. Participatory varietal selection (PVS) is the first step in selecting desirable parents. It allows local and introduced germplasm to be evaluated using participatory approaches; it identifies candidate varieties having suitable traits and determines their acceptability to farmers.

A PPB program in an inbreeding crop can start on the basis of one cross or very few crosses. Even with a low-cross-number strategy, the number of crosses covered will gradually increase over time if one, or a few, new crosses are made each year. This will help to maintain the farmers' interests by a supply of novel germplasm and allows a continuing incorporation of new genetic material from more centralized breeding programs.

Pedigree breeding generates a large number of lines (the selection units) that can only be accommodated with difficulty in a PPB program. The most effective methods keep the number of selection units to a minimum, thus allowing one, or an acceptably low number, of selection units per farmer. However, large population sizes can be used because the marginal costs to the program of increasing population size are very low (figure 1). Hence, bulk-population breeding is ideal for PPB, in either its pure form or modified by dividing the population into sub-populations according to

Figure 1. A very large population grown by a farmer, Chitwan, October 1998. The only possible cost to the farmer is that there might be a reduction in the yield of the F_4 bulk of Kalinga III x IR64 (right) compared to Masuli (left).

farmer-important traits. Bulk-population approaches have been used with success in classical breeding, e.g., Carver and Bruns (1993) report that 30% of wheat releases from a breeding program resulted from bulk population breeding that took less than 8% of the resources.

We are conducting a PPB program in rice, targeted at a range of environments in Nepal. These vary from the *Terai* (alluvial, low-altitude, flat land in the southern part of Nepal at about 150 m altitude) in both the main season (sown in June) and the *chaite* season (sown in February). The breeding program is also targeting a range of irrigated environments up to 1500 m altitude. Only a few crosses have been made during the course of this breeding program, which commenced in 1996 with two crosses made by the International Rice Research Institute (IRRI) at the request of the project and one cross made at the Center for Arid Zone Studies (CAZS), Bangor, by Dr. D.S. Virk.

All three crosses involved the upland rice variety Kalinga III as one of the parents. Kalinga III was identified in western India in a PVS program (Joshi and Witcombe, 1996). Farmers like it for its very short duration and, an unusual trait for an upland rice variety, its slender grains. Although it is an upland rice variety adapted to marginal conditions, it is widely adapted even though it was rejected from All-India Co-ordinated Crop Improvement Program multilocational trials. It was released for rainfed, drought-prone, cold-susceptible environments only in Orissa, on the basis of trials in that state, but is now widely grown in Bihar, West Bengal, Madhya Pradesh, Rajasthan, and Gujarat. In PVS trials, it performs extremely well as a *chaite* rice in the Nepal *Terai* under partially irrigated conditions and can be grown as a main-season rice in the low hills of Nepal up to 1000 m under rainfed conditions.