be second or higher cycle inbreds, otherwise not. The development of second and higher cycle inbreds is considered later in Section 21.7. In U.S.A., single crosses are the most commonly used as source population for this purpose. The *production of first cycle inbreds* is briefly outlined here.

### 22.4.1. Isolation of Inbreds through Inbreeding

Inbreds are usually developed through a suitable system of close inbreeding. But self-pollination is desirable, wherever possible, as it leads to homozygosity very rapidly: one generation of selfing leads to the same level of inbreeding as is achieved by three generations of full-sib or six generations of half-sib mating. In geneal, 5-6 generations of selfing are required to produce nearly homogeneous inbred lines. It has been suggested that less intense forms of inbreeding should provide greater opportunities for selection, but inbreds developed through half-sib mating were not superior to those produced through selfing. The procedure for the isolation of inbreds through self-pollination is described below; generally, the pedigree method is used for this purpose.

*1. First Year.* A number of plants with desirable phenotypes are selected from a source population and are self-pollinated. The selected plants should be vigorous and free from diseases. They may be selected on the basis of their GCA estimates obtained by testing the performance of their testcross progeny (the tester should have a wide genetic base). Experimental evidence clearly reveals that open-pollinated ($S_0$) plants differ in their GCA and that GCA can be successfully selected for. In addition, intensive visual selection is carried out during $S_1$ to $S_4$ generations; as a result, only ~8% of the $S_1$ progenies reach $S_4$. The selection is effective in improving vigour, maturity, ear and kernel traits and disease and insect pest resistance. However, its effectiveness in improving grain yield of hybrids produced from the inbreds is doubtful.

*2. Second Year.* About 30-40 plants are space-planted from the selfed seed from each of the selected plants. Best plants are selected from the best progeny rows and are self-pollinated.

*3. Third to Sixth Years.* The process of the second year is repeated. But as the number of generations of self-pollination increases, individual plant progenies would become more and more homogeneous. Consequently, in the later phases of inbreeding, selection is primarily among the progenies rather than within the progenies. Most of the material would be discarded due to deficiencies and weaknesses, but a few outstanding lines would remain. These lines would be the inbreds that might be useful in a hybrid programme.

*4. Seventh Year.* At this stage, individual plant progenies would be almost homogeneous as they would be expected to be nearly homozygous. Selfing may be discontinued and the inbreds may be maintained by sib-pollination. But in the long run, inbreds do become variable, some being more prone to variation than others. Therefore, *inbred lines are generally maintained by a system of self-pollination combined with the growing of ear-to-row progenies.* This enables the elimination of progenies showing variation.

developed, *e.g.*, in forage crops and clonal crops. Most breeders use early testing, but a majority of them delay it to $S_2$ to $S_4$, $S_3$ being the most common generation. Use of early testing enables breeders to discard lines showing poor testcross performance at an early stage of the inbred development process, and helps in a better sampling of the source population.

## 22.5. EVALUATION OF INBREDS

*If all the inbreds developed from an open-pollinated variety (without any selection before, during and after the inbreeding process) were mated at random, the average yield of all the single crosses would be the same as that of the open-pollinated variety.* This is because it amounts to random mating after several generations of self-pollination in a Mendelian population. We have already seen that selection for GCA is effective in the $S_0$, $S_1$ and $S_2$ generations. But visual selection during the isolation of inbreds is not likely to affect, to any appreciable extent, the performance of hybrids derived from them although it is highly effective in the elimination of weak, inferior and defective lines, and in keeping the number of inbred lines within manageable limits (Table 22.3). This is self-evident from the fact that of the more than 100,000 inbreds tested till 1950 in U.S.A., only 60 were fit for commercial exploitation. Thus *the most important operation in a hybrid programme is the identification of inbreds that would produce an outstanding hybrid suitable for commercial use* (Table 22.3). And undoubtedly it is the most expensive operation in the development of hybrid varieties.

If $n$ inbreds are to be tested in all possible single cross combinations, there would be $n(n-1)/2$ single crosses that must be evaluated in replicated yield trials. With $n = 20$, the

**TABLE 22.3**

**Role of selection in the development of hybrid varieties**

| *Stage of hybrid programme* | *Objective of selection* | *Remarks* |
|---|---|---|
| Initial stages of inbreeding process *i.e.*, $S_0$, $S_1$ or $S_2$ plants | Identification of plants that will yield outstanding inbreds, both in terms of phenotype and combining ability | Selection is successful; early-testing was devised for this purpose; *selects for superior $S_0$, etc. plants* |
| During the inbreeding process | Elimination of weak and defective lines | Successfully removes weak and defective lines |
| Evaluation of inbreds | Identification of inbreds that produce outstanding hybrids | ***The most critical step of hybrid development programme*** |
| 1. Phenotypic evaluation | Elimination of weak and inferior inbreds | Inbred yield shows a small (0.2) but positive correlation with hybrid yield |
| 2. Topcross test | Selection of inbreds showing high GCA | About 50% of inferior inbreds eliminated; reduces the number of inbreds for the next step |
| 3. Single cross evaluation | Identification of the outstanding single or double cross | The final step; outstanding hybrid released as a commercial variety |

number of single crosses would be 190. But the number of double crosses from $n$ inbreds in prohibitively large, that is, $3 \times n\ !\ /[(4!)(n-4)\ !]$, which for 20 inbreds would be 14,535. Therefore, double cross combinations of inbreds are not evaluated, except for release as a variety. The modern practice of inbred evaluation may be divided into the following four steps: (1) phenotypic evaluation, (2) topcross test for GCA, (3) single cross test for SCA, and (4) prediction of the double cross performance from data on the performance of single crosses. *These steps, briefly outlined below, are followed in the given order.*

### 22.5.1. Phenotypic Evaluation

It is based on the phenotypic performance of the inbreds themselves. It is highly effective for characters with high heritability, *i.e.*, high GCA. To some extent, it is effective in improving the yielding ability of hybrids as the yield of inbreds shows a small (usually 0.2) but positive correlation with the performance of their hybrids. Thus inbreds with very poor performance can be safely rejected. The performance of inbreds is tested in a replicated yield trial, and the inbreds showing poor performance are discarded.

### 22.5.2. Topcross Test

It is generally accepted that the performance of topcross progeny of an inbred is a reliable measure of the average performance of all the single crosses involving that inbred, and that topcross performance provides a reliable estimate of GCA. The inbreds remaining after the phenotypic evaluation are crossed to a tester with a wide genetic base, *e.g.*, an open-pollinated variety, a synthetic, or a double cross. A simple way of producing topcross seed in maize is to plant alternate rows of the tester and the inbreds to be tested. The inbreds are detasselled, and the seed from the inbreds is harvested; this seed represents the topcross seed. The performance of topcross progeny is evaluated in replicated yield trials, preferably over locations and years. *Based on the topcross test, about 50 per cent of the inbreds are eliminated.* This reduces the number of inbreds to a manageable size for the next step.

There is considerable controversy regarding the use of a broad or narrow base tester, and that of a low or high performance tester. Although theoretically desirable, *a low performance tester is of little use in a variety development programme*. In the initial stages of a programme, topcross test is used for preliminary evaluation. But in advanced programmes, a synthetic constituted from inbred lines or a doubel cross of the four most commonly used inbred lines may be used as a tester. In case the breeder wishes to identify good combiners for an inbred line or a single cross, the inbred line or the single cross itself should be used as tester. Suggestions have been made for the use of narrow base testers as well. In any case, *a tester should be simple to use, should correctly classify the merit of inbred lines and discriminate among them, and should maximise the genetic gain.*

### 22.5.3. Single Cross Evaluation

It is believed that an important part of heterosis is due to SCA. Hence the outstanding single cross combinations can be identified only by testing the performance of single crosses. The final evaluation of the inbreds, therefore, consists of the evaluation of single crosses produced from them. The inbreds remaining after the topcross test are generally crossed in a