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A Proposed Procedure for Rapid Development of Inbred Lines for the Production of Hybrid Maize in Nigeria.

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Abstract

A procedure is described for the rapid development of inbred lines to be used as parents of high-yielding hybrid cultivars of maize (*Zea mays* L.). This procedure involves the production of S_1 lines from three unrelated populations A, B, C whose F_1 hybrids are known *a priori* to demonstrate significant yield heterosis. The S_1 lines are evaluated *per se* and S_2 lines obtained from the best performing 5 or more S_1 lines from a population are intercrossed with those from the other populations to give 75 or more $S_2 \times S_2$ crosses. The $S_2 \times S_2$ crosses are evaluated with check cultivars (e.g. cultivar hybrids, the best widely grown cultivars and single-cross hybrids, if available) and the top 5 are selected for the National Zonal Maize Yield Trials (NZMYT) coordinated by the National Cereals Research Institute (NCRI), Ibadan. $S_4 \times S_4$ hybrids of these top 5 selections are evaluated in the NZMYT as well as several other locations available to the researcher and inbred lines of the best 1 or 2 hybrids are released as parent materials.

The advantages of this procedure include (i) simultaneous inbreeding and evaluation trials, (ii) flexibility for concurrent population improvement and extraction of inbredlines, and (iii) with two rainfed cropping seasons and an off-season with irrigation facilities, near-homozygous inbred lines (F 0.99) can be obtained within 3 calendar years.

Introduction

Maize (*Zea mays* L) is one of the major cultivated cereals in Nigeria, some others being rice (*Oryza sativa* L) and Sorghum (*Sorghum bicolor* L. (Moench)). Maize is used as human food, livestock feed and a host of industrial uses such as the manufacture of vegetable oil, commercial starch and pulp for rough paper. The supply, however falls far short of the demand for several reasons, the most important being the type of cultivar grown by farmers. Although research in maize has been conducted in Nigeria for more than 50 years (Oblilana and Fajemisin, 1977), only improved open pollinated varieties, composites and synthetics are grown by farmers. Reports from countries such as U.S.A., Britain, and Kenya have shown however that hybrid varieties are higher yielding than these types. Thus, efforts need to intensified on the development of inbred lines and production of hybrids for Nigerian farmers.

The value of an inbred line ultimately lies in its ability to produce high yield in combination with other inbreds. The progeny of the cross between two inbred lines must show considerable amount of heterosis to make it valuable economically. Unfortunately, the development of inbred lines is not nearly as difficult as evaluating them for combining ability; i.e., productivity in crosses. The direct method of crossing individual inbreds with as many other inbreds as possible is quite effective if the number of lines to be crossed is not large, perhaps less than 20. Because ½n(n - 1) such crosses can be made from n inbreds, the number of hybrids to be evaluated soon becomes too large to handle as a increases. For example, if n = 25, one would evaluate 300 hybrids, but if n = 40, the number of hybrids to be evaluated escalates to 780.

Two procedures have been adopted by maize breeders to reduce the number of hybrids to be evaluated without reducing the number of inbred lines. First is the topcross test in which the inbred lines are crossed to a variety to determine their general combining ability. On the basis of this test, few elite lines are selected for single-cross tests. The second procedure, proposed by Jenkins (1935), involves test-crosses of S_0 or S_1 plants and evaluation of the resulting progenies for yield. Lines with poor combining ability are eliminated and efforts are concentrated only on the promising lines. Both of these methods are efficient but they require a long period of time for the development of near-homozygous elite lines.

In this paper, a procedure is described for the rapid development and evaluation of inbred lines for use in hybrid production. The procedure is particularly suitable to tropical rainforest locations where two natural rainy seasons and an irrigation season can be utilized. In such locations, single-cross hybrids are obtainable in approximately 3 calendar years. An evaluation of the effectiveness of the procedure is already in progress at the University of Ife.

Proposed Methodology

Three unrelated populations A, B, and C, whose F_1 hybrids are known *a priori* to demonstrate significant yield heterosis, are used in the programme. The probability of identifying high-yielding lines increases if each population demonstrates yield heterosis in combination with the others. Inbred lines developed by this model will be for the production of hybrids to be used in the early season only. The procedure, as outlined below, utilizes hypothetical years to allow for clarity.

Season 1 (Irrigation, 1981)	Seeds of each population are grown in separate blocks (isolation not necessary) and 100 or more plants are self-pollinated to obtain S_1 seeds. Some visual selection against undesirable traits like lodging, susceptibility to insects and diseases, etc. can be done before pollination and at harvest.
Season 2 (Early Season, 1982) (E.S.)	The S_1 lines from each population are evaluated in field trials to determine their yield potential. The source populations *per se* and their crosses are included as standard checks. Also, S_1 seeds are planted in the breeding nursery for the production of S_2 seeds. Remnant seeds from each S_1 line is kept in cold storage.
Season 3 (Late Season, 1982) (L.S.)	On the basis of the yield trials conducted in season 2, the top 5-10 lines are selected and S2 x S_2 crosses are made; i.e. A lines x B lines, A lines x C lines and B lines x C lines. If the top 5 lines are used, a total of 75 S_2 x S_2 crosses will be made. During this season also, remnant S_2 seeds of the selected lines are advanced to S_3.
Season 4 (Irrigation, 1982)	— —
Season 5 (E.S. 1983)	Field evaluation of S_2 x S_2 crosses and advancement of S_3 lines to S_4. Remnant seeds of S_3 are grown *per se* to evaluate them for yield and agronomic traits.
Season 6 (L.S. 1983)	On basis of the yield trials in season 5, the top 5 S_2 x S_2 hybrids are selected and S_4 x S_4 crosses of their parents are made. Remnant S_4 seeds are advanced to S_5.

Season 7
(Irrigation, 1983)

Season 8 (E.S. 1984) — Evaluation of S4 x S_4 hybrids in the National Zonal Maize Yield Trials (NZMYT) and other available locations. S_5 lines are advanced to S_6. Remnant seeds of S_5 lines are further evaluated for yield and agronomic traits, especially vigour, silking and pollen production.

Season 9 (L.S. 1984) — The top 1 or 2 hybrids from the evaluation trials in season 8 are selected and S_6 seeds of their parents are increased for release to the National Seed Service or commercial seed companies.

This procedure is essentially the same when developing lines for the late season. The difference is that S_1 lines are produced in E.S. 1982 and evaluated in L.S. 1982, thereby shifting all other operations to a season later than described above. An irrigation season may not be needed when breeding lines for adaptation to the late season.

If lines more homozygous than S_6 are needed, they still can be obtained within the period outlined above. The following modifications, however, would be necessary: S_3 lines obtained in season 3 would be advanced to S_4 in season 4 (Irrigation, 1982). Evaluation of S_2 x S_2 crosses (or. S_3 x S_3 crosses if they can be produced in season 4) and advancement of S_4 lines to S_5 would then take place in season 5 (E.S. 1983). In season 6 (L.S. 1983) S_5 x S_5 (rather than S_4 x S_4) crosses are made and S_5 lines are advanced to S_6. In season 7 (Irrigation 1983), S_6 lines are advanced to S_7 and in season 8 (E.S. 1984), S_5 x S_5 crosses are evaluated while S_7 lines are advanced to S_8 However, if S_6 x S_6 crosses can be made in this season, then S_5 x S_5 crosses made in season 6 may not be necessary. In season 9, seeds of S_8 lines are increased for release.

Obviously, this second alternative will require more work than the first, but it has the advantage that further inbreeding may result in the removal of some undesirable gene blocks in the lines. Therefore, where funding, facilities and highly cooperative well trained personnel are adequate, the second alternative is worthwhile

Discussion

Using a, b and c to represent the number of lines from source populations A, B, and C respectively, and r the number of replications, while e = the number of environments for evaluation, the analysis of variance (AOV) for the $S_2 \times S_2$ crosses is shown in Table 1 for the A x B set. Only one set is shown because AOV for the other sets will be similar if a = b = c and the same r and e are used in all trials.

MS_a, MS_b and MS_{ab} (or MS_a, MS_c and MS_{ac} etc. for other sets) are of particular interest to the breeder. MS_a and MS_b measure the variations in line performance averaged over all crosses in a set. This is, therefore, a measure of the general combining ability (gca) of the lines (Russell and Eberhart, 1975). Whenever the lines, in specific hybrid combination with other lines, perform better or worse than their average performance, MS_{ab} will be significant. This is a measure of specific combining ability (sca). Therefore, the gca values of each line and the sca effects of each cross can be calculated (Griffing, 1956) to identify best combiners.

If MS_a and (or) MS_b are significant but MS_{ab} is not, it would indicate the gca is more important than sca in the A x B set of crosses. In this case, one would accept the hypothesis that perfromance of a single-cross progeny can be predicted on the basis of gca alone. This is highly desirable because the best performing hybrid can then be obtained simply by crossing the parents having the highest gca effects. If, on the other hand, MS_{ab} is significant, it suggests that sca is important in determining performance of the hybrids. The extent of this interaction can be evaluated in several ways. First, the relative sizes of MS_a and MS_b to MS_{ab} can be determined. This procedure may be misleading and should therefore be interpreted cautiously. Second, the relationship $2\sigma^2_{gca}/(2\sigma^2_{gca}+\sigma^2_{sca})$ can be used (Baker, 1978) where σ^2_{gca} and σ^2_{sca} are the expectations of mean squares for gca (MS_a or MS_b) and sca (MS_{ab}), respectively. The closer this ratio is to unity, the greater the predictability of hybrid performance based on gca alone. In a strict sense, this method is more valid for completely inbred lines with random effects. When the analysis is based on a model with fixed effects, one would use equivalent components of mean squares. Third, mid-parent and/or high-parent heterosis can be used to test whether these values give better prediction of progeny performance than do estimates of gca. This method, however, is not as precise as estimating gca. A statistical method that takes cognisance of this inherent weakenss has been proposed by Gilbert (1958).

TABLE 1 – FORM OF THE ANALYSIS OF VARIANCE FOR YIELD OF $S_2 \times S_2$ CROSSES BETWEEN SOURCE POPULATIONS A AND B.

Source of Variation	*DF*		*Mean Squares*
Environment (Env.)	e - 1		
Reps within Env.	e(r - 1)		
Crosses of A lines with B lines	ab - 1		
Lines from A		a - 1	MS_a
Lines from B		b - 1	MS_b
A x B interaction		(a - 1) (b - 1)	MS_{ab}
Env. x crosses of A with B	(e - 1) (ab - 1)		
Env. x A lines		(e - 1) (a - 1)	MS_{ae}
Env. x B lines		(e - 1) (b - 1)	MS_{be}
Env. x A x B interaction		(e - 1)(a - 1)(b - 1)	MS_{abe}
Pooled error	e(r - 1) (ab - 1)		

The three interaction mean squares MS_{ae} MS_{be} and MS_{abe} (Table 1) indicate the consistency of performance of the lines and their crosses. Significant MS_{ae} and MS_{be} would indicate that gca of the lines is not consistent under varying environmental conditions. Similarly, significant MS_{abe} suggests differential environmental effects on sca. Experience has shown that genotype x environment (g x e) interactions are usually significant in yield trials such as the ones suggested herein. Among the several methods used to reduce the biases resulting from g x e interactions are (i) stratification of environments and evaluation of test genotypes within regions of similar ecological conditions (Sprague and Eberhart, 1977), (ii) using the means of all genotype at a location as an environmental index to give a general measure of stress factors affecting yield (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Fakorede and Mock, 1978) and (iii) developing indices to characterise the environment; e.g., altitude index (Eberhart et al., 1973), moisture stress or drought stress index (Corsi and Shaw, 1971; Sopher et al., 1973) and growing-degree units or heat units (Gilmore and Rogers, 1958; Cross and Zuber, 1972).

When indices to characterise the enviroment are not available, the $S_2 \times S_2$ hybrids should be evaluated in a sufficiently large number of environments to obtain the average response of each cross and reduce the biases from g x e interactions. The elite genotypes can then be expected to give superior performance. Because research funds have become limiting more than ever before, one could solicit the assistance of breeders (cooperators) in other stations and/or use microenvironments created by varying planting dates (Fakorede, 1980; Fakorede *et. al.*, 1981), plant density, and fertilizer rates (Fakorede and Mock, 1978; Balko and Russell, 1980). If, on the other hand, indices that characterise the key factors causing g x e interactions are available, response of the genotypes to such indices can be determined. Eberhart et. al., (1973) showed that this type of evaluation is of greater value than a large series of trials in environments that have not been indexed.

Review of a large number of studies (Sprague and Eberhart, 1977) and the data of Fakorede and Mock (1978) showed that recurrent selection to upgrade breeding populations would be a means of developing stable hybrids. The procedure proposed herein is flexible enough to allow both recurrent selection and extraction of inbred lines to proceed concurrently. While the inbreeding programme is in progress, a selection intensity of 10% can be applied to the 100 or more S_1 lines evaluated from each source population so that the top 10 lines can be recombined to form another population (C_1) from which 100 S_1 lines will again be obtained for evaluation. The process can be repeated several times and performance of the resulting populations at the end of each cycle (C_1, C_2, ... Cn) are compared with the orignal population (C_0). If progress has been made in the recurrent scheme, the C_n will outyield the C_0. Therefore, inbred lines that are likely to produce high-yielding hybrids can be extracted from the C_n. Such hybrids would then replace those that were developed from the C_0 populations which would have been released during the process of recurrent selection.

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