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TWENTY-FIVE YEARS OF HYBRID MAIZE RESEARCH IN NIGERIA: CONTRIBUTIONS FROM OBAFEMI AWOLOWO UNIVERSITY

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Abstract

Sustained maize (Zea mays L) improvement activities started in earnest at the University of Ife (now Obafemi Awolowo University) Ile-Ife in 1977. Ile-Ife (7° 28' N, 4° 33' E, altitude 244 m asl) is located in the marginal areas of the rainforest of the southwest of Nigeria. From the inception of the Program, emphasis was on inbred-line development and production of hybrid varieties. The Ife Maize Improvement Program conducted basic research on heterosis in Nigeria maize populations, inbreeding and inbred-line development, combining ability of inbred lines, population parameters and recurrent selection, and genotype x environment interaction. We worked in collaboration with national and international scientists, the Nationally Coordinated Maize Research Program (NCMRP), the National Seed Service (NSS), the Maize Association of Nigeria and the commercial seed companies, particularly Premier Seeds Limited and UAC Seeds. Improved research methodologies were developed in the Program and several maize varieties and hybrids from the Program were submitted into the Nationally Coordinated Maize Variety Trials over the years. Similarly, the Program provided research support for the thesis projects of many undergraduate and graduate students who are now occupying positions of responsibility in national and international organizations. The current emphasis of the Program is on breeding for tolerance of abiotic stresses, drought and low nitrogen in particular. This is being done in collaboration with the International Institute of Tropical Agriculture (IITA), Ibadan and the West and Central Africa Maize Research Network (WECAMAN) with the coordinating office in Côte d'Ivoire.

INTRODUCTION

Groundwork for hybrid maize (*Zea mays* L) started right from the beginning of maize improvement activities in Nigeria nearly 50 years ago; that is, about 1956(van Eijnatten, 1965). However, because seed companies that would produce hybrid seed in commercial quantities were not in place at that time, open-pollinated varieties (OPVs); specifically, composites and synthetics, were developed and released to the farmers (van Eijnatten, 1965).

Research into the use of hybrids was finally actualized in the 1970s at the National Cereals Research Institute, Ibadan (now at Badeggi) and University of Ife [now Obafemi Awolowo University (OAU), Ile-Ife] (Fajemisin, 1978; Fakorede *et al*l., 1978; Fakorede *et al*.., 1993). In 1979, IITA also initiated hybrid development as part of its Maize Improvement Program (Kim, 1997). In 1982, the Federal Government of Nigeria provided a special hybrid maize research grant to IITA to develop within three years, hybrid maize varieties for Nigeria (Kim *et al*.., 1985). Thus, development of hybrid maize in Nigeria resulted from a collaborative effort of scientists from several institutions, which together constitute the national research and extension system (NARES) of the country.

Progress towards the development of hybrids was rapid and in 1984, experimental hybrids were tested in a total of about 150 ha of farmers' fields located all over the country. On the average, hybrids were 25 and 43% higher yielding than the best OPVs in the forest and savanna zones, respectively. The best farmers recorded hybrid yields of 9.4 and 11.8 t/ha in the forest and savanna ecology, respectively. In 1985, Nigeria farmers planted about 6,000 ha of hybrid maize (Kim *et al*.., 1985; 1988). Thus started a new era, the era of hybrid maize, in Nigerian agriculture. The history of hybrid maize in Nigeria has been presented in greater details in earlier reports (Fakorede *et al*.., 1993; Kim *et al*.., 1993; Kim, 1997).

Application of science for the improvement of life has profited immensely from successive increases in basic knowledge and the utilization of improved technology required for advancement. Advances in the productivity potential of maize in countries such as the USA have almost always been based on increases in the understanding of the underlying principles of genetics, biology and agronomy of the crop plant, statistics, and refinements in field-plot techniques needed for detection of differences among genotypes. With this in mind, Obafemi Awolowo University has made major contributions to hybrid maize development in Nigeria by conducting basic research into several aspects of hybrid maize production, including, among others:

heterosis in Nigeria maize populations;
inbreeding and inbred-line development;
combining ability of inbred lines;

These aspects, along with the performance of hybrids in farmers' fields and the impact of hybrids on Nigerian agriculture, are highlighted and discussed briefly in the rest of this paper. In-depth presentation and cussion of the different aspects may be ound in the published papers cited in the text.

HETEROSIS IN NIGERIA MAIZE POPULATIONS

One important principle of hybrid maize research is that the highest-yielding hybrid combinations adapted to the tropical environments are produced from crosses of lines developed from different races of maize (Wellhausen, 1977). Wellhausen had identified four outstanding racial complexes for the improvement of maize production in the tropics; namely, Tuxpeño, a purely dent type that originated from the Gulf of Mexico, and its related Caribbean and USA dents; Cuban flints; Coastal Tropical Flints; and ETO. The latter three races are all flint and are more closely related to one another than to Tuxpeño. Although crosses involving pairs of the three races exhibit considerable heterosis, crosses involving Tuxpeño and the three flints are more strikingly vigorous, higher yielding and exhibit exceptionally strong heterosis.

At the initiation of the breeding program at Ife, very few of the available maize germ plasm had distinct racial background. One such population was TZPB (named FARZ 27 in the national system), a derivative of Planta Baja of the Tuxpeño race from Mexico, developed at IITA. We crossed this population, which has white grain color, to several other white-grain populations to study heterosis. Crosses involving yellow-grain populations were made also and all of the population hybrids were evaluated in 15-20 field trials to determine the pattern and magnitude of heterosis in the available germ plasm. Average mid- and high-parent heterosis was 35 and 19%, respectively. Heterotic effects for grain yield among some of the popularly grown populations are summarized in Table 1.

Table 1. Percent mid-parent (MP) and high-parent (HP) heterosis for grain yield of four white maize populations evaluated in 15-20 environments in Nigeria, 1981-84.

		FARZ 34	TZSR-W	TZSR-W-1
FARZ 27	MP	21.7	15.1	17.9
	HP	18.2	12.9	13.7
FARZ 34	MP		32.7	23.6
	HP		30.1	21.4

One objective of studying heterosis is to identify useful source populations for inbred-line extraction and base populations for recurrent selection, particularly reciprocal recurrent selection. According to the theory of quantitative genetics, greater success should be expected when inbred lines developed from populations whose crosses show substantial heterosis are used in the production of hybrids (Robinson *et al.*., 1956). Results of our studies clearly showed that heterosis was sufficiently large to warrant production of hybrid varieties for maximum exploitation of the Nigerian maize germ plasm potential.

INBREEDING AND INBRED-LINE DEVELOPMENT: Inbreeding is a means of obtaining homozygous lines in maize and is usually accompanied by deleterious effects. It is important in an applied maize breeding program to know (i) how much inbreeding is necessary to fix phenotypic traits; (ii) whether lines attain individuality early in the process of inbreeding; and (iii) at what generation inbred lines can be evaluated for combining ability.

We conducted several studies to obtain answers to these and other questions. Reviewed in this section are the results of studies on:

response of Nigeria maize germ plasm to inbreeding;
sources of inbred lines;
methodology of inbred-line development;
evaluation of inbred lines per se.

RESPONSE OF NIGERIA MAIZE GERMPLASM TO INBREEDING: Five generations of inbreeding in TZSR-W were compared with the non-inbred population for yield and agronomic traits. Inbreeding increased the number of days from planting to flowering (delayed maturity) but decreased the expression of all other traits (Table 2). For example, at complete inbreeding (F=1), grain yield of this population would be reduced to about 1.35 t/ha, a reduction of about 80% relative to the non-inbred population. Coefficients from the regression of mean values of the traits on the coefficient of inbreeding (F) were essentially linear for grain yield, ear number, ear length and kernel moisture at harvest (Table 2). Contrarily, quadratic models made large contribution to the total variance of flowering traits (tasseling, anthesis, silking) and, to a lesser extent, plant and ear heights (Table 2). Grain yield and yield components were the most sensitive to inbreeding. On the other hand, several traits had little or no inbreeding depression even after five generations of inbreeding. For example, at F=1 plant and ear heights were only about 17 and 22% lower than the original population.

Table 2. Parameters from the regression of mean values of grain yield and agronomic traits at different generations of inbreeding on the coefficient of inbreeding in the TZSR-W maize population.

Trait	Model type	μ	β_l	β_q	R^2	ΔR^2
Days to tasseling	Linear	53.98	3.92	—	0.34	
	Quadratic	55.26	-10.23	14.54	0.65	0.31
Days to anthesis	Linear	57.46	3.06	—	0.30	
	Quadratic	58.36	-6.86	10.19	0.53	0.23
Days to silking	Linear	59.16	4.97	—	0.50	
	Quadratic	60.14	-5.87	11.14	0.67	0.17
Plant height, cm	Linear	212.14	-35.08	—	0.85	
	Quadratic	207.76	13.35	-49.76	0.97	0.12
Ear height, cm	Linear	108.18	-24.70	—	0.65	
	Quadratic	105.91	0.45	-25.84	0.69	0.04
Grain yield, t/ha	Linear	5.06	-3.71	—	0.98	
	Quadratic	5.17	-4.94	1.27	0.99	0.01
Ear number/plot	Linear	20.08	-10.36	—	0.97	
	Quadratic	19.91	-8.58	-1.83	0.98	0.01
Ear length, cm	Linear	17.02	-6.03	—	0.96	
	Quadratic	17.11	-7.08	1.12	0.97	0.01
Grain moisture. %	Linear	22.34	-4.46	—	0.92	
	Quadratic	22.39	-6.44	2.19	0.93	0.01

Hallauer and Sears (1973) conducted one of the most extensive studies on changes associated with inbreeding in maize. In their study, linear model accounted for more than 92% of the variation in grain yield, plant height and ear height whereas quadratic model was significant for some other traits, including kernel-row number, ear diameter and kernel depth. To a large extent, the results from our studies corroborate those obtained by Hallauer and Sears (1973) on US Corn Belt maize germ plasm.

Results from our studies also showed that response to inbreeding differs among lines and populations. Inbreeding depression associated with the S_0 to S_5 generations of individual lines developed from TZSR-W was evaluated in field trials conducted at Ile-Ife. Rate of attainment of homozygosity for grain yield varied considerably among the lines (Table 3). The coefficient of linear regression, $\hat{a}_l$, varied from -5.10 t/ha for Line 11 to -2.74 t/ha for line 41.

For quantitatively inherited traits in a population at linkage equilibrium, theoretical expectation after one generation of inbreeding by self-pollination (S_1) is a 50% reduction in the performance relative to the non-inbred population (S_0). Data summarized in Table 4 showed that on the average, inbreeding depression for grain-yield at the S_1 generation of three maize populations was 41% and about 76% at the S_4 generation. All other traits had smaller inbreeding depressions. In this study also, the performance of several traits changed very little with inbreeding; for example, silking date. The three populations differed substantially in their response to inbreeding (Table 4). TZSR-W-1 appeared to be the most sensitive to inbreeding.

Results of our inbreeding studies have several practical implications for maize breeding programs. First, inbred lines extracted from the populations are not likely to be homozygous at most loci until many generations of inbreeding have been completed. Second, because inbreeding depression associated with plant and ear heights is small, hybrids produced from the inbred lines emanating from these populations are likely to have undesirable heights. Third, inbreeding has little effect on flowering, an indication that the maturity classes of the lines are likely to remain more or less the same as that of the source populations. Fourth, undesirable linkage blocks are likely to remain unbroken in the many inbred lines thus making such lines inherently low yielding in hybrid combinations. In other words, it will take quite a bit of effort to isolate outstanding inbred lines from these populations.

Table 3. Parameters from the regression of mean values of grain yield at different generations of inbreeding on the coefficient of inbreeding for five lines derived from TZSR-W maize population.

Line	Model type	μ	β_l	β_q	R^2	ΔR^2
11	Linear	4.94	-5.10	—	0.94	
	Quadratic	5.11	-12.21	7.82	1.00	0.06
13	Linear	5.02	-2.89	—	0.81	
	Quadratic	5.12	-6.88	4.40	0.86	0.05
21	Linear	5.13	-4.09	—	0.99	
	Quadratic	5.11	-3.34	-0.83	1.00	0.01
36	Linear	5.05	-3.77	—	0.96	
	Quadratic	5.12	-6.32	2.81	0.98	0.02
41	Linear	5.06	-2.74	—	0.64	
	Quadratic	5.13	-5.70	3.26	0.67	0.03

Table 4. Inbreeding depression (%) at the S_1 and S_4 generations of lines derived from TZSR-W-1, FARZ 27 and FARZ 34 maize populations.

	TZSR-W-1		FARZ 27		FARZ 34		Across popl.	
Trait	S_1	S_4	S_1	S_4	S_1	S_4	S_1	S_4
Grain yield, t/ha	-42.3	-82.1	-35.0	-70.6	-45.3	-74.1	-40.9	-75.6
Ear number	-9.9	-45.8	-2.8	-30.4	-24.9	-35.9	-12.5	-37.4
Ear length, cm	-12.9	-29.4	-11.2	-27.0	-6.9	-16.8	-10.3	-24.4
Ear diam, cm	-11.6	-19.8	-2.2	-20.4	-4.9	-20.8	-5.9	-20.3
Stand count	-7.2	-34.5	-4.6	-11.2	-7.1	-42.7	-6.3	-29.5
Plant ht, cm	-14.6	-28.1	-8.3	-12.4	-1.7	-7.8	-8.2	-16.1
Silking date	+2.5	+3.4	+2.8	+7.9	+4.6	+7.0	+3.3	+6.1

On the basis of our results, we established the following principles for inbred-line development in Nigeria:

i. large number of plants (close to 1000) should be sampled from the source population for self pollination;
ii. breeding methodology that includes intense selection during the inbreeding process would produced better inbred lines;
iii. there should be deliberate selection against plant and or ear heights during inbreeding;
iv. although hybrid performance of inbred lines may be evaluated in the relatively early stages of inbreeding, uniform, high-yielding inbred lines would be obtained only after several generations of inbreeding, perhaps S_6 or later.

These principles have been applied in the Maize Program at OAU-Ife.

Sources of inbred lines. At the initial stage of the hybrid program at OAU-Ife, inbred lines were extracted from improved, popularly grown OPVs such as TZSR-W, TZSR-W-1, TZPB (FARZ 27), TZB (FARZ 34), Western Yellow (FARZ 7), 096EP6 (FARZ 23), and TZSR-Y-1 (Fakorede *et al.*., 1993). We also developed lines from some local varieties, the improved cycles of modified ear-to-row selection in FARZ 7 and early maturing populations such as TZE4 and TZESR-W. Our strategy was to develop inbred lines from as many source populations as possible to ensure genetic variability that would forestall genetic vulnerability and maximize heterosis. Since we worked collaboratively with IITA and NCRI, we were careful not to duplicate source populations for inbred-line extraction. For example, IITA identified outstanding inbred lines from Tuxpeño dent, Carribean flint, material from other parts of the tropics and sub-tropics, especially through CIMMYT in Mexico, temperate material from the US Corn Belt, lowland germ plasm, mid-altitude germ plasm, and a host of other sources (Kim, 1997). Although the three institutions did not use the same germ plasm for inbred-line extraction, we had inter-institutional collaboration in testing the combining ability and hybrid performance of the inbred lines, as recommended by Fakorede *et al.*. (1978).

METHODOLOGY OF INBRED-LINE DEVELOPMENT. Maize is normally cross-pollinated; therefore, inbreeding is possible only by artificial pollination. Artificial pollination is effected as follows. Before incipient silk extrusion, the developing ear shoot is covered with a small glassine or parchment bag called "shoot bag." The silks emerge inside the bag and cannot be pollinated by pollen grains, which are now freely blown around in the atmosphere within and above the crop canopy. After the emergence of the silks, the tassel of the plant to be self-pollinated, which would normally be shedding pollen at this stage, is covered overnight with a specially designed parchment bag called "tassel bag." The next day, the pollen within the tassel bag is used to pollinate the silks of the plant and the tassel bag is used to cover the pollinated ear and firmly attached to the stalk of the plant till harvest.

Different methods have been reported in the literature for inbred-line development but only two have been used extensively in our breeding program: that is, the standard method and the single-seed descent method (also referred to as the single-hill method by Sprague and Eberhart, 1977). A third method proposed by Fakorede (1982) was also used.

Standard method. Individual plants from the source population are self-pollinated and the selfed seeds from each plant are harvested and bagged separately as an S_1 family. In the next season, seeds from each S_1 family are planted into single-row plots (ear-to-row) and selected plants within each family are self-pollinated and harvested as S_2 families. The procedure is repeated for each generation thereafter until the desired level of inbreeding is attained.

Selection is normally done during inbreeding. In the early generations of inbreeding, selection among families is emphasized and the emphasis is on selection within families in the later generations. Selection is done in two stages within each generation of inbreeding. First, selection is done about the time of flowering. Selection at this stage is based on visual rating of plant and ear heights, vigor, uniformity, freedom from diseases and pests, synchronization of flowering and other desirable traits. Second, because many desirable attributes are not apparent at the time of pollination (husk cover and lodging, for example), the formerly selected plants are re-selected at harvest. At this time, the ears are also selected. Seeds from only the plants surviving this second selection are advanced to the next generation.

Single-seed descent method. A modification of the standard method is to advance to the next generation only one seed from the ear resulting from each selected self-pollinated plant. Originally, Jones and Singleton (1934) suggested using a 3-plant hill instead of progeny rows in each generation of inbreeding. In practice, we save all the seed from each selected ear in a labeled seed envelope and plant only one for advancement to the next generation. Remnant seed of each family is kept in cold storage and, in case the planted seed does not survive, another seed is picked from the remnant seed to replant the family. In some other cases, we planted 3-4 seed from each family into a hill and thinned the resulting plants to only one per hill after the plants have been well established in the field. This latter approach is easier, more convenient and less prone to errors.

As noted by Sprague and Eberhart (1977), the single-seed descent method permits the handling of larger number of lines and, therefore, a potentially larger zygotic sample. The disadvantage of the method, however, is that selection during the inbreeding process is minimized.

Newly proposed method. Although the two methods described above for inbred-line development are quite effective, they require a long period of time before elite lines can be isolated. Therefore, Fakorede (1982) proposed a procedure for the rapid production and evaluation of inbred lines for use in hybrids. This procedure involves the *per se* evaluation of S_1 lines developed from three unrelated populations A, B, C whose F_1 hybrids are known *a priori* to demonstrate significant yield heterosis. Selected lines from one population are advanced in the inbreeding process while simultaneously testing them in hybrid combinations with selected lines from the other two populations. The procedure is repeated until the desired level of inbreeding is attained and the best few hybrids are released. The advantages of this procedure include (i) simultaneous inbreeding and evaluation trials, (ii) flexibility for concurrent population improvement and inbred-line extraction, and (iii) where two natural seasons and an off-season irrigation facilities are available, near-homozygous inbred lines can be obtained within three calendar years.

Evaluation of inbred lines *per se*. Although the ultimate goal of developing inbred lines is to identify those that produce high grain yield in hybrid combinations, testing of inbred lines per se is also important for several reasons. First, seedling vigor is indispensable in field establishment of inbred lines during seed increases and hybrid seed production. Second, it is important to assess the seed production capability of inbred lines that would be used in hybrid production. A low-yielding inbred line is not desirable in hybrid production. Third, there are specific traits to emphasize in lines that would be used as female or male in hybrid combinations. For example, the male parent should be slightly taller, flower 2-3 days earlier, and produce more pollen than the female parent. The potential female parent, on the other hand, should silk uniformly and produce high yield as line per se.

Inbred-line evaluation is an important component of the maize program at OAU-Ife. Nearly all generations of inbreeding are evaluated in one form or another. Because of limited seed supply, most inbred trials are conducted in single-, 2-row or, in a few cases, 4-row plots. Rows are usually 5m long and spaced 0.75m apart with 0.25m between hills when planting is at one seed/hill, or 0.50m for two plants/hill; approximately 53,333 plants/ha in either case. All trials are kept weed-free through pre-plant application of herbicide plus manual weeding as necessary during the growing season. Fertilizer is usually applied at the rate of 180 kg N, 90 kg P_2O_5 and 90 kg K_2O per ha. The randomized complete-block design with two or three replicates was used in most trials, although lattice designs were used for trials involving large number of lines, particularly at the early generations (S_1 or S_2) of inbreeding.

Field trials of inbreeding lines started in 1980 and have been a normal practice in the Program since then. In a study involving 111 S_3 lines from several sources, grain yield ranged from about 0.1 to 1.7 t/ha with a mean of 0.6t/ha (Table 5). Most other traits similarly showed wide ranges.

Table 5. Means, standard errors (s.e.) and ranges for grain yield and agronomic traits of S_3 lines developed from several source populations and evaluated at Ile-Ife, 1982.

Trait	Mean	±s.e.	Range	Heritability FARZ 27	Heritability TZSR-W
Grain yield, t/ha	0.60	0.332	0.1—1.7	0.59	0.68
Emergence percentage	65.43	10.260	28.6—92.8	0.90	0.58
Number of ears/plot	6.57	3.090	6.5—20.0	0.70	0.43
Plant height, cm	139.04	12.970	91.1—174.5	0.75	0.70
Ear height, cm	60.93	7.138	40.8—90.4	0.74	0.81
Days to tassel	61.08	1.530	46.5—67.0	0.77	0.83
Days to anthesis	63.37	1.897	51.5—68.5	0.67	0.71
Days to silk	66.44	2.452	55.5—73.5	0.74	0.67
Pollen production, g	7.99	3.500	0.8—27.3	0.64	0.87
Ear length, cm	12.17	1.323	7.1—19.4	0.68	0.77
Ear diameter, cm	3.40	0.346	2.5—4.2	0.49	0.64
Cob diameter, cm	2.38	0.387	1.5—3.3	0.56	0.42
Kernel depth, cm	0.51	0.173	0.3—0.8	0.12	0.00
Weight/300 kernels, g	43.77	9.958	26.0—61.5	0.24	0.00
Shelling percentage	64.8	9.092	43.1—76.5	—	—
Kernel moisture, %	10.3	1.439	6.2—14.7	—	—

Among the 111 lines in this study, 38 and 35 were derived from FARZ 27 and TZSR-W, respectively. Heritability estimates for the traits of these two populations were computed and are shown in Table 5. Apart from kernel depth and 300-kernel weight that were poorly heritable, most traits showed moderate-to-high heritability estimates.

Many traits had significant correlation with grain yield of the S_3 lines. Ear number per plot had the largest positive correlation while ASI had the largest negative correlation with grain yield (Table 6). Most yield components, plant and ear heights, and pollen production had significant positive correlation with yield. Emergence traits, most of the tassel traits and grain moisture at harvest had no significant relationship with grain yield in this set of material.

In another study, 27 S_1 lines extracted from TZSR-W-1 and their S_4 counterparts were evaluated in yield trials conducted in two locations in1984. The objective was to determine to what extent S_4 performance could be predicted from the S_1. For most of the traits, significant mean squares were observed for each source of variation. Of particular interest was the S_1 vs. S_4 comparison and this was significant for all the traits assayed in the study (Table 7). This indicated that significant differences occurred in the expression of the traits between the two generations.

Table 6. Coefficients of linear correlation (r-value) between grain yield and agronomic traits for 111 S_3 lines developed from several source populations and evaluated at Ile-Ife, 1982.

Trait	r-value	Trait	r-value
Emergence %	-0.01	Number of days to silk	-0.20
Emergence index	0.21	Pollen production, g	0.44**
Emergence rate index	0.03	ASI	-0.50**
Plant height, cm	0.58**	Number of ears per plot	0.79**
Ear height, cm	0.45**	Ear length, cm	0.41**
Tassel branch number	0.19	Ear diameter, cm	0.67**
Tassel height	0.40**	Cob diameter, cm	0.57**
Tassel branch length, cm	0.20	Kernel depth, cm	0.24
Tassel weight, g	0.31*	Kernel row number	0.16
Number of leaves at flowering	0.37**	Kernel weight, g	0.49**
Number of days to tassel	0.05	Kernel moisture, %	0.07
Number of days to anthesis	-0.02	Shelling percentage	0.41**

*,** Significant at 0.05 and 0.01 level of probability, respectively.

Table 7. Means for grain yield and agronomic traits of 27 S_1 lines extracted from TZSR-W-1 maize population and their S_4 counterparts evaluated in two locations in 1984.

Trait	Mean of S_1	Mean of S_4	S_4 as %S_1	F-test
Plant height, cm	203.5	180.8	88.83	**
Ear height, cm	97.7	93.5	95.64	**
Days to tassel	55.3	57.4	103.76	**
Days to anthesis	59.0	60.0	101.66	**
Days to silk	60.8	62.2	102.44	**
Ear number per plot	14.7	13.0	88.59	*
Ear length, cm	71.0	65.8	92.73	**
Ear diameter, cm	19.9	18.9	94.63	*
300 kernel weight, g	65.6	71.2	108.59	*
Grain yield, t/ha	3.2	1.8	56.33	**

*,** Significant S_1 vs. S_4 mean squares at 0.05 and 0.01 level of probability, respectively

For many of the traits, however, the differences between the S_1 and S_4 means were small. Apart from grain yield that decreased at the S_4 to about 56% of the S_1, expression of all traits at the S_4 changed by about 2-12% (Table 7). One would, therefore, expect that S_1 performance would reasonably predict the performance of the lines at the S_4 generation.

Correlation analysis was done to determine the relationship between the performance of the lines at the S_1 with that at the S_4. Correlation coefficients of the traits at each of the two generations were also computed. The results are summarized in Table 8. Only ear number and ear length of S_1 had significant positive correlation with grain yield at the S_1 generation. Ear number, ear length and ear diameter of S_4 had significant positive correlation with grain yield of S_4. On the other hand, number of days to tassel and anthesis of the S_4 lines had significant negative correlation with grain yield of S_4. Similarly, plant and ear heights, days to anthesis, ear diameter and 300 kernel weight of S_1 had significant positive correlation with their S_4 counterparts. None of the correlation coefficients between S_1 traits and S_4 grain yield reached significant level.

Table 8. Correlation coefficients for grain yield and agronomic traits of 27 inbred lines extracted from TZSR-W-1 maize population at the S1, S4 and the S1 vs. S4 generations.

Trait	Correlation coefficients of			
	S_1 trait vs. S_1 yield	S_1 trait vs. S_4 yield	S_4 trait vs. S_4 yield	S_1 trait vs. S_4 trait
Plant height, cm	0.11	-0.24	0.26	0.38*
Ear height, cm	0.00	-0.29	0.29	0.42*
Days to tassel	-0.09	-0.11	-0.59*	0.35
Days to anthesis	0.17	-0.25	-0.39*	0.49**
Days to silk	-0.31	0.03	-0.19	-0.32
Ear number per plot	0.73**	0.16	0.77**	-0.01
Ear length, cm	0.51**	-0.21	0.43*	0.33
Ear diameter, cm	0.15	0.13	0.40*	0.53*
300 kernel weight, g	-0.01	0.01	0.22	0.40*
Grain yield, t/ha	1.00	0.03	1.00	0.03

The results of these correlation studies led us to reach the following conclusions:

i. Some agronomic traits tend to be correlated with grain yield within but not between generations of inbreeding.
ii. Some agronomic traits in one generation of inbreeding tend to be correlated with their counterparts in another generation.
iii. Ear number is the primary determinant of grain yield of inbred lines, followed by ear components, especially ear length.

Based on the results of our studies, several inbred lines were released into the Nationally Coordinated Inbred Trials evaluated in Ibadan, Ikenne and Ile-Ife in 1985 and 1986. The lines were coded FE followed by a number; for example, FE 001, FE 007, etc.

COMBINING ABILITY OF INBRED LINES: The final worth of an inbred line is judged by its performance in hybrid combinations. Evaluation of inbred lines to identify those with good combining ability is much more complex than developing the lines per se. For nearly one century of hybrid maize research and development, maize breeders all over the world have continually investigated means of improving the methodology of inbred-line evaluation in hybrid combinations. Breeders coined two terms to describe combining ability: general combining ability (GCA) and specific combining ability (SCA). GCA is the ability of a line to produce high yield in combination with any other line. SCA, on the other hand, is applicable to lines that perform well in combination with some lines but not with others.

There are several methods for evaluating the combining ability of lines, including the topcross test, diallel cross, and the line x tester cross. The three methods, plus the new method proposed by Fakorede (1982) and described earlier herein, have been used extensively in our Program.

The topcross test. The topcross test involves crossing inbred lines to an open-pollinating variety (OPV) and evaluating the resulting hybrids in field trials. Because an OPV is a broad-base tester, the topcross test measures GCA and is, therefore, useful in eliminating lines that have poor combining ability. Indeed, breeders often use the topcross test to evaluate early generation inbreds, such as S_1 and S_2 so that undesirable lines are identified and eliminated from the inbreeding process forthwith.

Topcross seeds are produced in isolated crossing blocks by alternating four rows of inbred lines with two of the OPV tester. The test lines, which serve as the female parents, are detasseled before anthesis so that pollen comes only from the OPV tester, which serves as the male parent. The male rows are harvested several days before the topcross hybrid seed are harvested from the female rows.

Our approach to the evaluation of inbred lines in hybrid combinations has been to topcross S_3 and/or S_4 lines to a population followed by single-cross tests for lines selected on the basis of their performance in the topcross test. The first set of topcrosses in our Program contained 40 entries produced in 1980 and evaluated at Ile-Ife in 1981, using two dates of planting. A more extensive topcross yield trial was conducted in 6 and 4 locations in 1982 and 1983, respectively; a total of 10 random environments in the rainforest ecological zone of southwest Nigeria (Table 9). A total of 35 entries, consisting of 21 topcross hybrids (TCH), 7 varietal hybrids (HYB) and 7 OPVs were evaluated in the trials (Adeyemo and Fakorede, 1986). The TCH and HYB seeds were produced in 1981 second season.

Table 9. Mean grain yield, ear number per plot and grain weight per ear of maize topcross hybrids and checks evaluated in 10 environments in the rainforest ecology of southwest Nigeria, 1982-83.

S/N	Environment	Planting Date	Grain yield, t/ha	Ears/plot (max. = 21)*	Grain wt, g/ear
		1982			
1	Univ. T & R Farm, Ife	14 April	7.1	20.5	145.9
2	Univ. Com. Farm, Ife	30 April	5.5	16.0	140.1
3	Ekiti-Akoko ADP, Ikole-1	22 April	7.5	19.6	155.7
4	Ekiti-Akoko ADP, Ikole-2	2 May	6.8	16.9	158.5
5	Ekiti-Akoko ADP, Ikare	22 April	6.8	23.3	118.2
6	CAC Grams, Efon-Alaye	29 April	2.4	12.5	74.6
		1983			
7	Univ. T & R Farm, Ife	4 May	5.1	15.3	134.9
8	Univ. Com. Farm, Ife	16 May	4.4	13.7	128.7
9	Ekiti-Akoko ADP, Ikole-1	18 May	5.0	14.7	142.7
10	Ekiti-Akoko ADP, Ikare	8 July	2.2	11.1	78.3

*A maximum of 21 ears was expected per plot, assuming one ear per plant.

Analysis of variance revealed highly significant differences among the environments and genotypes (Table 10). G x E interaction was also significant for grain yield, ear number, grain weight per ear and some other traits. There were highly significant differences for grain yield within each of the three groups of genotypes. Both TCH and HYB had significant interaction with the environment. The contrasts (TCH + HYB) vs. OPV and TCH vs. HYB were significant.

Relative to the OPVs, the hybrids were higher yielding and produced better-filled ears, with no appreciable differences in maturity and plant height (Table 11). Yield advantage of TCH and HYB over OPV was 12.8 and 21.3%, respectively.

Table 10. Mean squares from the analysis of variance for grain yield (t/ha), ear number per plot and grain weight per ear (g) of maize topcross hybrids (TCH), variety hybrids (HYB) and open-pollinating varieties (OPV) evaluated in 10 environments in the rainforest ecology of southwest Nigeria, 1982-83.

		Mean squares		
Source of variation	df	Grain yield, t/ha	Ear number per plot	Grain weight per ear, g
Environment (E)	9	361.96**	1507.63**	92184.00**
Rep in E	20	6.38	82.31**	2952.00**
Genotype (G)	34	14.09**	64.19**	3347.24**
OPV	6	35.00**	121.02**	10109.66**
HYB	6	8.78**	20.64	3441.67**
TCH	20	5.65**	29.51*	2415.25**
OPV vs. (HYB + TCH)	1	70.89**	308.88**	6540.09**
TCH vs. HYB	1	25.29**	93.34**	1000.20
G x E	305	2.80**	18.09**	643.36**
OPV x E	54	2.69	21.16**	956.78**
HYB x E	54	3.40**	17.87	467.04
TCH x E	180	2.68*	15.71	567.07
OPV vs. (HYB + TCH) x E	9	5.96**	44.97**	1125.07*
TCH vs. HYB x E	9	3.61	21.85	864.00
Error	680	2.15	13.90	570.66
Total	1049			
C.V., %		27.9	22.8	18.8

*,** Significant F-test at 0.05 and 0.01 level of probability, respectively.

Table 11. Means for grain yield and agronomic traits, and correlation coefficients (r-values) between grain yield and the agronomic traits of maize topcross hybrids (TCH), variety hybrids (HYB) and open-pollinating varieties (OPV) evaluated in 10 environments in the rainforest ecology of southwest Nigeria, 1982-83.

Trait	TCH	HYB	OPV	r-value
Grain yield, t/ha	5.3 a	5.7 b	4.7 c	—
Ear number per plot	16.4 a	17.2 b	15.3 c	0.81**
Ear number per plant	0.9 a	0.9 a	0.8 a	0.54**
Plant height, cm	202.6 a	209.4 b	201.9 a	0.61**
Ear height, cm	110.5 a	111.0 a	109.8 a	0.33*
Number of days to silk	58.4 a	58.1 a	59.2 a	-0.24
Grain weight per ear	128.4 a	130.9 a	122.7 b	0.75**
Kernel row number	14.2 a	14.1 a	13.9 b	0.68**
Ear length, cm	16.4 a	16.6 a	16.2 a	0.56**
Ear diameter, cm	4.5 a	4.6 a	4.4 a	0.73**
Cob diameter, cm	2.9 a	2.9 a	2.9 a	0.64**
Kernel depth, cm	8.4 a	8.5 a	8.1 b	0.52**
300 kernel weight, g	77.8 a	79.4 a	78.1 a	0.22
Kernel moisture at harvest, %	19.4 a	19.3 a	19.2 a	0.12
Shelling percentage	77.6 a	77.3 a	76.1 b	0.19

[a] Means with the same letter along a row are not significantly different at 0.05 probability level using LSD.

*,** Significant r-values at 0.05 and 0.01 level of probability, respectively.

Most of the traits assayed in the study had positive correlation with grain yield, the significant r-values ranging from 0.52 for kernel depth to 0.81 for ear number (Table 11). However, stepwise multiple regression of grain yield on the 12 other traits in the study produced the equation:

$Y = 1.261 + 0.362 + 0.043X_2$; $R^2 = 0.98$.

Evidently, ear number (X_1, $r^2 = 0.66$) and grain weight/ear (X_2, $r^2 = 0.32$) explained almost all of the variation in grain yield of the entries. All of the 12 traits together explained 99% of the yield variation.

Adeyemo and Fakorede (1990) performed the stability analysis of the 35 genotypes in this study and found that several topcross hybrids were adapted to environments supporting high yield. Some OPVs and variety hybrids also demonstrated stable, high-yield performance.

Results obtained in all other trials of topcross hybrids generally corroborate those reported above thus leading us into some definite conclusions useful in the hybrid program in Nigeria.

i. Hybrids have greater productivity potential than OPVs under similar management regimes.
ii. Ear number per unit land area and grain weight per ear are primary determinants of yield per hectare and may be emphasized in breeding programs.
iii. The topcross test is quite effective in eliminating inbred lines that perform poorly in hybrid combinations.
iv. Location effects accounted for the largest proportion of the total variance in hybrid yield trials; therefore, a large number of locations should be sampled for yield trials to identify outstanding hybrids.

Information from the topcross hybrid trials was particularly relevant at that point in time in the development of hybrids in Nigeria for several reasons.

First, there was an urgent need for experimental evidence to substantiate the on-going debate as to the advantages of hybrids over OPVs in Nigeria. Our results, along with those obtained by IITA and NCRI maize breeders, provided conclusive evidence to support the argument in favor of hybrids.

Second, we needed to convince policy makers to provide financial support for hybrid development nationwide. The Technical Committee of the Green Revolution Program, floated by the Federal Government, was strongly in favor of hybrid maize development for Nigeria. Under the Chairmanship of Chief (Dr) S.B. Aribisala, this Committee had, in 1982 recommended to the Federal Government that funds be provided to IITA to develop hybrids for Nigeria within three years. This Committee needed to be convinced that the national scientists were equally up to the task.

Third, the Federal Ministry of Science and Technology (FMST) was at that time establishing and actively supporting the Nationally Coordinated Research Programs, one of which was the Nationally Coordinated Maize Research Program (NCMRP). The Ife Maize Program obtained financial support from the NCMRP for some of its activities. Results from our studies, along with those of others, were presented at the annual meetings of the NCMRP at which top government officials of the FMST were present. It is gratifying that the results from our studies adequately justified the investment into hybrid maize research.

Four, *pari pasu* with the development of hybrids for Nigeria farmers between 1982 and 1985, the Federal Government set up a Committee to draft the National Seed Decree. Among other items in the terms of reference, the Committee was to make recommendations to the Federal Government on the type of hybrid to release for farmers and the type seed enterprise (private, public or joint private-public) to adopt nationwide. Information on the potential productivity of hybrids was much needed to properly address these issues and the results of our studies were available for this purpose.

The diallel cross. All possible crosses among a set of parental lines are referred to as diallel cross. Griffing (1956) described four types of diallel cross from which breeders may obtain estimates of GCA and SCA effects and or variances; that is:

- one set of F_1's, which is obtainable as ½n(n-1), where n= number of parental lines;
- one set of F_1's plus the parental lines which is obtainable as n+[½n(n-1)];
- F_1's plus the reciprocals, which is obtainable as n(n-1);
- all possible crosses, including reciprocals and the parental lines, which is obtainable as n^2.

Depending on how the parental lines are selected, each diallel method may be analyzed using one of two models. In Model I, the random model, it is assumed that the parental lines are a random sample from a base population. In that case, variances may be obtained from the diallel cross and extrapolated to the base population. In Model II, the fixed model, the parental lines have been selected and are, therefore, fixed. Only genetic effects specific to the set of lines may be obtained from the analysis of the diallel cross. Most diallel studies in maize have used only one set of F_1's and Model II analysis.

Breeders usually evaluate the combining ability of lines in yield trials conducted in several locations and or years, often regarded as environments. Most such studies report the interaction of GCA and SCA with environments, but fail to show the mechanics for obtaining the interactions. Common biometrical genetic textbooks, including those by Mather and Jinks (1971), Singh and Chaudhary (1979) and Hallauer and Miranda Fo (1981), also fail to give the method of estimation. Therefore, Ajala and Fakorede (1986) developed a simple algebraic method for estimating GCA, SCA and their interaction with years and locations. The method was illustrated with a set of 45 F_1's and their 10 parental lines involved in a diallel cross. The materials were evaluated at the Teaching and Research Farm and the Commercial Farm of the University in1982 and 1983 in 3-replicate experiments. Analysis of variance for the combining ability is summarized in Table 12.

As expected, mean squares for all of the main effects in the study were significant. Significant GCA mean squares indicate that the parental lines were different in their ability to perform well in crosses with the other lines. Similarly, significant SCA mean squares indicate that the lines will combine differently with the same set of specific lines. GCA and SCA mean squares also indicate the relative importance of additive to non-additive gene actions. In this study, the GCA sum of squares was 7.2 times as large as SCA sum of squares. There was, therefore, a preponderance of additive gene action in this set of inbred lines. Apart from GCA x year interaction, the combining ability mean squares did not interact significantly with the environments (Y, L, and Y x L) in this study. This is desirable because specific, high-yielding hybrids identified in the study would be stable in their performance when grown in environments similar to those sampled in the study.

Table 12. Combining ability ANOVA for grain yield of 55 maize genotypes including 10 parents and 45 F_1's from a diallel cross, evaluated in two locations for two years.

Source of variation	Degrees of freedom		Mean squares
	value	computational formula	
Year (Y)	1	y-1	2.4
Location (L)	1	l-1	284.8**
Y x L	1	(y-1)(l-1)	61.8**
Replication in YL	8	ly(r-1)	7.1**
Genotype (G)	54	g-1	23.8**
Parents	9	n-1	7.3**
Crosses	44	n(n-1)/2	8.3**
GCA	9	p-1	17.0**
SCA	35	p(p-3)/2	6.1**
Parents vs crosses	1		845.1**
Genotype x Y	54	(g-1)(y-1)	2.0*
Parents x Y	9	(n-1)(y-1)	1.3
Crosses x Y	44	[n(n-1)/2](y-1)	2.1*
GCA x Y	9	(p-1)(y-1)	3.6*
SCA x Y	35	[p(p-3)/2](y-1)	1.5
(Parents vs crosses) x Y	1		0.8
Genotype x L	54	(g-1)(l-1)	2.0*
Parents x L	9	(n-1)(l-1)	1.6
Crosses x L	44	[n(n-1)/2](l-1)	1.7
GCA x L	9	(p-1)(l-1)	2.7
SCA x L	35	[p(p-3)/2](l-1)	1.4
Parents vs crosses) x L	1		9.8**
Genotype x Y x L	54	(g-1)(y-1)(l-1)	1.1
Parents x Y x L	9	(n-1)(y-1)(l-1)	0.9
Crosses x Y x L	44	[n(n-1)/2](y-1)(l-1)	1.0
GCA x Y x L	9	(p-1)(y-1)(l-1)	0.3
SCA x Y x L	35	[p(p-3)/2](y-1)(l-1)	1.3
(Parents vs crosses) x Y x L	1		5.7
Error	432	ly(r-1)(g-1)	1.5
Total	659	rlyg-1	4.1

y, l, g, r, represent years, locations, genotypes, and reps, respectively.
*.**Significant F-test at 0.05 and 0.01 level of probability, respectively.

The line x tester cross. The diallel cross is quite effective in evaluating inbred lines for combining ability 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, ignoring reciprocals, the number of hybrids to be evaluated soon becomes too large to handle as *n* increases. For example, if $n = 25$, one would evaluate 300 hybrids, but if $n = 40$, the number of hybrids to evaluate escalates to 780.

The line x tester cross is a way of reducing the number of hybrids to evaluate without losing information on the combining ability of the lines being evaluated. In this method, some lines serve as female (*f*) parents while the others are the male (*m*) parents. The resulting *f* x *m* hybrids are evaluated in yield trials from which the GCA due to males and GCA due to the females are obtained. The male x female interaction is the estimate of the SCA for the *m* + *f* inbred lines.

In 1984, 18 selected S_4 lines from FARZ 27 were used as female parents unto which each of 8 selected S_4 lines from TZSR- were crossed as male parents to produce a total of 144 hybrids. The hybrids were evaluated in 1985 and 1986 while the 28 lines were advanced to the S_5 and S_6. Based on the performance of the hybrids, 10 lines were selected and used in another line x tester study with 10 lines from IITA. Both the F_1's and the reciprocals were produced and evaluated in yield trials at the OAU-Ife T & R Farm in 1987 and 1988. The mean squares for male GCA, female GCA, SCA, reciprocal effects and their interactions with environments were significant for grain yield and several agronomic traits. The inbred lines with the best GCA ans SCA were identified from the trials. IITA lines produced higher grain yield when used as female rather than male parents.

Two important recommendations emanated from the study. (i) elite lines should be tested in reciprocal crosses to determine whether they are better as male or female parents of hybrids; (ii) for higher grain productivity, the lines from IITA should serve as female parents whenever IITA lines are involved in crosses with Ife lines.

Newly proposed method. Using the method described by Fakorede (1982), 7 selected S_3 lines from each of FARZ 27, TZSR-W and FARZ 34 were used to produce S_3 x S_3 intra- and inter-population hybrids. The intra-population hybrids were diallel crosses while the inter-population hybrids were line x tester crosses. We produced 21 hybrids (diallel crosses) among the lines from each population and 49 hybrids for lines from each pair of populations. The resulting 210 S_3 x S_3 hybrids, along with the three populations per se and the three population hybrids as checks, were evaluated at the T & R Farm and the Commercial Farm of the University, and the IAR&T Research Farm at Ikenne in 1984.

Combining ability ANOVA for grain yield showed significant F-tests for all sources of variation (Table 13). The sum of squares attributable to SCA was larger than those for the GCA of the grain yield performance of the three inter-population hybrids. This was expected because, as observed by earlier workers (Sprague and Tatum, 1942; Sprague and Eberhart, 1977), SCA tends to be more important than GCA in crosses involving inbred lines that have undergone selection.

Table 13. Combining ability ANOVA for grain yield (t/ha) of three sets of S_3 line x line inter-population maize hybrids evaluated in three locations in 1984.

		Mean squares		
Source of variation	Df	Pop A x B[1]	Pop A x C	Pop B x C
Entries	49	0.647**	0.514**	1.167**
Pop cross vs. S_3 crosses	1	5.473**	3.801**	24.012**
S_3 crosses	48	0.547**	0.446**	0.691**
Lines from first population	6	1.286**	0.978**	1.840**
Lines from second population	6	1.371**	0.767**	0.813**
Interaction	36	0.286**	0.305**	0.479**
Pooled error	288	0.122	0.005	0.189

[1] Pop A = FARZ 27, Pop B = TZSR W, Pop C = FARZ 34.

**Significant F-test at 0.01 level of probability.

On the average, the population crosses yielded nearly 2 t/ha more than the populations per se. For the inter-population hybrids, 33, 31, and 14 line x line crosses were higher yielding than the FARZ 27 x TZSR-W, FARZ 27 x FARZ 34, and TZSR-W x FARZ 34 population crosses, respectively. Based on the results of this study, 40 hybrids (16 inter- and 24 intra-population line x line crosses) were selected and their S_5 x S_5 crosses were evaluated in 1986. Three of the 40 S_5 x S_5 crosses were selected and the S_6 x S_6 single-cross hybrids were submitted as FE 86001, FE 86002, and FE 86003 into the Nationally Coordinated Maize Trials in 1987 and 1988. Meanwhile, some other promising new hybrids were in the pipeline, four of which were submitted to the Coordinated Trials in 1989 and 1990 as FE 87201, FE 87202, FE 87203, and FE 87204.

Prediction of hybrid performance. Maize breeders often desire to know whether the performance of hybrids can be predicted from inbred traits or from the performance of topcross hybrids of early generation inbreds. We carried out some studies to obtain information on this subject. Correlation coefficients between the performance of S_1 lines and the performance of the lines as S_3 and S_4 TCH were very low, in most cases not reaching statistically significant level (Table 14). Similar results were obtained when S_3 line performance was correlated with S_3 and S_4 TCH of the same lines (Table 14).

Table 14. Coefficients of correlation of inbred line performance with the performance of the lines in topcrosses.

	S_1 line trait with				S_3 line trait with	
Trait	S_3 TCH trait	S_3 TCH yield	S_4 TCH trait	S_4 TCH yield	S_3 TCH trait	S_3 TCH Yield
Grain yield, t/ha	0.06	—	-0.32*	—	0.27*	—
Ear number	0.00	-0.11	0.07	-0.23	0.39**	0.31*
Ear length, cm	-0.02	0.12	-0.23	-0.19	0.02	0.10
Ear diameter, cm	0.25	0.00	0.12	0.27*	0.01	0.16
Grain moist., %	0.10	0.08	-0.02	0.20	0.04	0.03
Shelling %	0.10	0.11	0.44**	-0.20	0.07	0.30*
Days to silk	0.17	-0.07	0.31*	0.11	0.14	0.18
Plant height, cm	—	—	—	—	-0.32**	0.09
Ear height, cm	—	—	—	—	0.02	0.12

*,**Significantly different from zero at 0.05 and 0.01 level of probability, respectively.

Fakorede and Ajala (1986) [illegible] the relative performance of 10 inbred lines at the S_2 and S_5 generations as lines per se and in hybrid combinations (diallel cross). In each generation, both GCA and SCA mean squares were significant for grain yield and several agronomic traits. Relative ranking of the lines for GCA effects at the S_2 was generally maintained at the S_5, but relative ranking of hybrids for SCA effects changed considerably between generations. The preponderance and relative stability of GCA effects suggest that good inbreds can be selected as from the S_2 generation. To identify the best single-cross hybrids, however, the selected lines must be tested in specific hybrid combinations at the desired generation of inbreeding.

In a complementary report, Ajala and Fakorede (1988) obtained phenotypic as well as genetic correlation coefficients between:

i. S_2 inbred line traits and their $S_2 \times S_2$ hybrid counterparts;
ii. S_5 inbred line traits and their $S_5 \times S_5$ hybrid counterparts;
iii. S_2 inbred line traits and their $S_5 \times S_5$ hybrid counterparts;
iv. $S_2 \times S_2$ hybrid traits and their $S_5 \times S_5$ hybrid counterparts.

Generally, none of the S_2 and S_5 line traits could be used to predict the $S_5 \times S_5$ hybrid yield. Similarly, only two of the $S_2 \times S_2$ hybrid traits had significant correlation with $S_5 \times S_5$ hybrid yield, but the r^2 associated with the traits was about 20%. We concluded that hybrid yield performance could not be predicted from inbred line traits, or crosses of the lines made in early generations.

Performance of FE hybrids in the Nationally Coordinated Maize Variety Trials (NCMVT). Mean grain yield of the varieties in the 1987-88 and 1989-90 NCMVT are summarized in Tables 15 and16, respectively.

Table 15. Grain yield (t/ha) and rank of white hybrids in the 1987-88 NCMVT summarized for groups of locations.

	Group 1*		Group 2		Group 3		Group 4	
Variety	Yield	Rank	Yield	Rank	Yield	Rank	Yield	Rank
8505-3	5.23	1	4.47	1	4.51	2	3.60	7
FE 86001	5.10	2	3.39	9	3.67	8	4.53	3
8321-18 - Chk-1	4.79	3	4.13	4	4.70	1	4.94	2
8505-2	4.52	4	4.17	2	3.68	7	4.42	4
IK 83 TZSR-W-1 Chk-2	4.51	5	3.56	5	4.24	3	3.39	8
8505-9	4.45	6	3.52	6	3.84	6	3.30	9
8505-3	4.29	7	4.16	3	3.86	5	5.65	1
FE 86002	4.17	8	3.49	7	3.95	4	3.80	6
FE 86003	3.50	9	3.44	8	3.63	9	3.90	5
LSD 0.05	0.56		0.75		0.65		NS	

*Group 1 = Ibadan, Ife, Mokwa; Group 2 = Amakama, Funtua, Badeggi, Lanlate;
Group 3 = Benin, Uyo; Group 4 = Bagauda

The 1987-88 national trials contained 4 hybrids from IITA, 3 from Ife and 2 check varieties — one hybrid and one OPV. In most cases, differences between FE hybrids and IITA hybrids were not statistically significant. Both groups of hybrids interacted with the environments used in the study. Similar results were obtained in the 1989-90 trials, which contained 4 hybrids from IITA, 4 from Ife and 5 OPV (Table 16). The FE hybrids compared favorably with IITA hybrids and the OPVs for plant height, ear height and maturity, as measured by days to silk (Table 17). The FE hybrids were deliberately selected for reduced height and high grain yield. The selection was effective because two of the FE hybrids were the shortest in the trial.

Table 16. Grain yield (t/ha) of white OPVs and hybrids in the 1989-90 NCMVT evaluated in seven locations.

Variety	Badeggi	Bagauda	Ibadan	Ife	Ilora	Mokwa	Zaria	Mean
8516-12	1.51	1.79	2.77	3.75	3.11	4.78	6.10	3.40
TZB-SR	1.19	2.18	3.14	3.21	2.89	3.88	6.26	3.25
FE 87203	0.82	2.13	3.46	2.95	3.39	3.83	6.14	3.25
8505-3	1.05	1.89	3.18	3.17	3.34	3.69	5.97	3.18
DMR-LSR-W	0.70	2.04	3.11	2.54	3.33	3.25	5.86	2.99
8321-21	0.86	2.52	2.92	2.01	2.87	3.39	6.05	2.95
Pop 25-SR	0.60	2.18	3.32	2.79	2.36	3.27	5.60	2.88
FE 87202	0.99	1.16	3.09	3.08	2.86	3.06	5.51	2.82
FE 87204	1.04	1.41	3.01	2.83	3.39	3.23	4.61	2.79
FE 87201	1.17	1.41	2.55	2.58	3.02	3.20	5.40	2.76
8321-18	0.59	2.04	2.45	2.82	3.31	3.18	4.88	2.75
TZPB-SR	1.42	0.73	3.06	2.14	2.21	3.61	5.89	2.72
TZSR-WY	0.88	1.94	2.94	2.59	2.29	3.20	5.02	2.69
LSD 0.05	0.50	1.36	0.43	0.97	1.32	0.90	0.97	0.92
CV, %	34	35	10	24	31	18	12	23

Performance of hybrids in farmers' fields. Because of the urgency of getting hybrid maize across to farmers, there was a felt need among maize scientists for new paradigms in technology transfer. Transfer of the hybrid maize technology to Nigerian farmers was done using both conventional and non-conventional extension approaches.

Table 17. Mean plant height, ear height and number of days to silk for white OPVs and hybrids in the 1989-90 NCMVT.

Variety	Plant height, cm	Ear height, cm	Days to silk
8516-12	204	94	60
TZB-SR	208	107	63
FE 87203	201	98	59
8505-5	200	100	60
TZPB-SR	204	98	63
8321-21	199	94	60
Pop 25 SR	194	96	60
DMR-LSR-W	191	90	61
FE 87201	181	90	60
FE 87204	198	97	61
TZSR-W-1	199	100	63
8321-18	193	92	61
FE 87202	186	95	60
LSD 0.05	11.5	8.3	1.3

Hybrid maize technology was taken to the farmers, not only by extensionists, but also by research scientists as well as any other person interested in maize development in Nigeria. Field days sponsored by the Nigerian government and organized by the Nigerian NARES in collaboration with IITA, greatly facilitated the rapid adoption of hybrid maize.

During the first 1-2 years of the introduction of hybrids, all national agricultural extension agencies together conducted over 3000 mini-kit trials all over the country (Adenola and Akinwumi, 1993). The agencies included the National Accelerated Food Production Project (NAFPP), Agricultural Development Projects (ADPs) and the National Agricultural Extension and Research Liaison Services (NAERLS). Hybrid demonstration plots were sited in farmers' fields, near farm market places, highways, secondary schools, university farms, home gardens and in other places where people showed interest.

Hybrid productivity in farmers' fields was well monitored by Sasakawa Global 2000 (SG 2000) in four savanna States: Kaduna, Katsina, Kano and Jigawa. In these States, hybrids were, on the average 80-105% higher yielding than OPVs (Table 18) and cost-benefit analysis (Table 19) showed that net income of farmers growing hybrids more than doubled the income of those growing OPVs (Arokoyo and Omotayo, 1997). Net income of hybrid maize farmers in the SG2000 villages was ₦26,000 - ₦40,000 per hectare in 1995.

Sasakawa-Global 2000 (SG-2000), an international NGO, also promotes technology transfer for maize in Nigeria, including a package of good quality hybrid seed, appropriate planting time, and adequate dose and application of the right type of fertilizers.

A participatory extension approach is used. This approach includes farmer-managed demonstration plots, called management training plots (MTPs), regular farm visits, and provision of production inputs on credit to the participating resource-poor small-scale farmers. Details of this approach have been well documented in earlier reports (Arokoyo and Omotayo, 1997; Auta and Akpoko, 1997; Auta *et al.*., 2001). Some of the findings are summarized in Tables 20 and 21. This approach has been so successful that SG-2000 has been invited by the Federal government to extend the approach to all parts of Nigeria.

Table 18. Grain yield of hybrids and OPVs in Nigerian farmers' field in 1994 and 1995 (Adapted from Valencia *et al.*, 1997).

	1994	1995
Area, ha.	60	105
Range in yield, t/ha	1 - 8	2 – 8
Mean yield of hybrids, t/ha	3.9	4.7
Mean yield of OPVs, t/ha	1.9	2.6
% increase of hybrids over OPVs	105	80

Table 19. Cost-benefit analysis of maize production in Nigeria, 1994 and 1996 (Adapted from Arokoyo and Omotayo, 1997).

	Hybrid	OPV
1994		
Gross returns per ha. $	182	102
Total cost per ha., $	93	59
Net returns per ha, $	89	43
% increase over OPV	107	
1996		
Gross returns per ha., $	678	
Total cost per ha., $	256	
Net returns per ha., $	422 (Range: $327 - $506).	

Table 20. Number of villages and farmers, land area cultivated and grain yield of SG-2000 farmers compared with other farmers in Kaduna State, 1993-97 (Auta *et al.*, 2001).

Year	Number of		Area (ha)	Average yield (t/ha) of	
	villages	farmers		SG-2000 farmers	Other farmers
1993	9	98	58.4	3.8	1.89
1994	27	344	187.2	2.0*	2.17
1995	13**	398	63.5**	5.4	2.65
1996	58	1700	234.5	5.6	2.14
1997	NA	1901	250.2	4.8	2.60

Source: SG-2000 records.

*Poor yield recorded due to army-worm attack

**A Number of villages and farmers dropped due to cancellation resulting faulty plot measurement.

***A number of farmers were disqualified due to non-compliance with recommended practices.

NA – Not Available

IMPACT OF HYBRIDS ON NIGERIAN AGRICULTURE. Fakorede *et al.* (2001b) examined the impact of hybrid maize on Nigerian agriculture. First, the productivity potential of maize varieties has been improved. Overtime, the percent increase of the best initial commercial white and yellow hybrids over the best OPVs decreased (Table 22). This is an indication that maize populations that perform equally well with or better than the initial hybrids are now available. Thus, the productivity potential of Nigerian maize varieties has been greatly improved. New hybrids extracted from these improved populations are 20-46% higher yielding than the best commercial hybrids presently available (Table 23).

Table 21. Area, number of farmers, grain yield, production costs and incomes for Maize MTPs farmers in five Zones of Kaduna State, 1997.

Zone	Area (ha)	Total number of farmers	Yield range, t/ha	Average yield t/ha
Lere	155.45	622	2.3-9.3	5.6
Maigana	21.25	85	2.6-8.5	5.5
NAERLS	37.25	149	1.8-7.4	4.2
Samaru Kataf	15.00	60	1.7-6.9	4.1
Birnin Gwari	21.25	85	2.8-6.7	4.7

	Costs and income			
	Area (ha)	Total cost of production, US$	Average gross income, US$	Average net income, US$
Lere	155.45	452	1,142	690
Maigana	21.25	422	1,135	713
NAERLS	37.25	297	859	563
Samaru	15.00	352	844	493
Birnin Gwari	21.25	408	960	552

Table 22. Mean grain yield of the best commercial hybrids and the best OPV checks in field trials conducted from 1984 to 1995 (Menkir *et al.*., 1999).

Year	No. of locations	Hybrid yield (t/ha)	Yield of best OPV (t/ha)	% increase of hybrid over best OPV
White hybrids				
1984	7	6.3	4.9	29
1985-89	104	5.2	4.3	21
1993	13	5.0	4.2	19
1994	10	5.0	5.1	-2
1995	6	6.1	6.1	0
Yellow hybrids				
1987	6	6.2	5.4	15
1990	14	4.7	4.0	18
1993	13	4.5	4.0	12
1994	5	5.6	5.8	-3
1995	5	5.8	5.9	-2

Table 23. Mean grain yield of newly developed IITA hybrids evaluated in 1996 (Menkir *et al.*, 1999).

Hybrid	Mean yield, t/ha	% over check
9607-1	6.3	20
9607-5	7.7	46
9607-7	6.8	28
9607-8	7.4	40
Oba Super 1 (check)	5.3	
LSD.05	1.2	

One important impact of hybrid maize is the dramatic shift in production from the rainforest and forest-savanna transition zones (that used to be the "maize belt" of Nigeria) to the northern Guinea savanna (NGS) and mid-altitude savanna (MAS) zones.

NCRI had done varietal development and extensive evaluation in five ecological zones: Ibadan (forest), Amakama-Umudike (forest with acid soil), Kabba (forest-savanna/southern Guinea savanna), Mokwa/Samaru (southern/northern Guinea savanna) and Riyom (mid-altitude savanna) (Fajemisin, 1978). Each ecology had formidable constraints that the national program could not single-handedly overcome because of lack of funds, facilities and personnel. Some of the problems were ecology specific diseases (such as highland rust and blight incited by organisms different from those which incite lowland rust and blight), maize streak virus that could not be inoculated artificially, *Striga*, borers and weevils. Maize breeders developed germ plasm tolerant of these constraints. Much of this germplasm served as the base population for the extraction of inbred lines for hybrid production. The introduction of hybrids actually catalyzed the rate of adoption of maize in the savanna zones. Within a decade, hybrid maize had displaced sorghum (the traditional crop) in much of this ecological zone.

Second, total land area under maize and total production have increased tremendously. Third, commercial seed companies have been established and the use of improved seed has become more widespread. These two points were discussed more elaborately by Fakorede *et al.* (2001b), who concluded that the success of hybrid maize in Nigeria was attributable to:

the initial financial support of the federal government complemented by backup financial support from IITA;

the strong collaboration between IITA and the Nigeria NARES;

extensive and large number of on-farm demonstrations, field days and training courses during the initial years of the project;

production of high quality seed by seed companies;

continuous research to sustain the program.

The greatest problems faced by farmers in adopting hybrid maize were bottlenecks created by government policies, non-availability or exorbitant prices of fertilizers, inadequate seed supply and delay by seed companies in making hybrid seed available in time for planting.

Despite these problems, which in any case are being solved by the relevant government and private agencies, hybrid maize has been a success in Nigeria and OAU-Ife has been an important contributor to the success.

Many graduate and undergraduate students have been exposed in varying degrees to the art of maize breeding, especially through thesis research projects. In most cases, the undergraduate project students work with the breeder for about one year. The graduate students usually work more closely and for longer periods of time with the breeder than the undergraduate students, about 2-4 or more years, depending on the degree in view. Many of our former students are holding positions of responsibility in universities, national and international research institutes, government offices, parastatals, and the organized private sector.

PRESENT AND FUTURE THRUST

The hybrid component of the Ife Maize Program presently works collaboratively with maize scientists at IITA and in the West and Central Africa sub-region to solve several maize production constraints in the sub-region. The major constraints are drought, the parasitic weed *Striga hermonthica* (Del.) Benth (Scrophulariaceae), low soil nitrogen, and corn borers. Maize researchers in the sub-region have organized themselves into a network, the West and Central Africa Collaborative Maize Research Network (WECAMAN) with the Coordination Office based in Côte d'Ivoire. For about 20 years, the USAID has provided financial support for WECAMAN. More recently, UNDP and IFAD have provided additional financial support through the Africa Maize Stress (AMS) Project. With IITA as the Executing Agency, WECAMAN has been a highly effective network and its impact in revolutionizing maize production in the sub-region has been well recognized. The Network has developed, and national programs have released, many technologies for farmers in the sub-region. *Striga* and or drought tolerant early and extra-early maize varieties, that have made it possible to grow maize profitably in marginal areas, such as the Sahel and the northern fringes of the Sudan savanna are among the technologies developed by the Network (Badu-Apraku and Fakorede, 2001; Badu-Apraku *et al.*, 1997).

Research to overcome the production constraints, including identifying and removing the causes of the yield gap between research and farmers' fields, will continue in the future (Fakorede *et al.*, 2001a). Conventional maize breeding as well as molecular approaches will be used in solving the constraints. Our efforts in the near future will also be directed towards genetic improvement of the nutritional level of maize. The quality protein maize (QPM) developed by maize breeders in Ghana and is now available in Nigeria will be improved. Maize with high levels of the essential micro-nutrients will also be given high priority in our breeding program.

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