Progress from reciprocal recurrent selection in two early-maturing maize composites

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Abstract

Two early-maturing maize (*Zea mays* L.) composites, TZE COMP 3 and TZE COMP 4, are undergoing improvement by reciprocal recurrent selection (RRS) at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Fifty random S_1 lines from each of the original (C0) and the two improved cycles (C1 and C2) of selection were evaluated at Ikenne in 1998 and 1999 and at Zaria in 1999. The objective was to determine the progress from two cycles of selection. Response to selection for grain yield was 10.4% per cycle in TZE COMP3 and 5.7% in TZE COMP4. Selection also increased days to 50% silking, ear height, and plant height by 1.18 to 3.76% per cycle, but reduced plant and ear aspects. Genetic variances among S_1 lines for grain yield and other agronomic traits were significant (P <0.05). Broad sense heritability estimates were high (h^2 = 0.41 to 0.88) with little variation across cycles for most of the traits. These results indicate that RRS was effective in improving grain yield and other traits without reducing genetic variance. Thus, it is possible to make further progress from selection for grain yield and other traits in these composites. Coefficients of genetic correlation of grain yield with plant and ear aspects were negative. However, genetic correlation of grain yield with days to 50% silk, ear height, and plant height were positive in both composites, suggesting that gains from selection for grain yield was related to changes in these traits.

Résumé

Deux composites précoces de maïs (Zea mays L.), TZE COMP 3 et TZE COMP 4, sont en amélioration par la sélection recurrente réciproque (SR8) à l'institut international d'agronomie tropicale (IITA), Ibadan Nigéria. 50 lignées aléatoires S1 de chaque composite original (C0) et deux cycles améliorés (C1 et C2) ont été évalués à IKENNE en 1998 et 1999 et à Zaria en 1999. L`objectif était de déterminer le progrès de deux cycles de sélection. La réponse à la sélection du rendement en grain a été de 10,4% par cycle dans TZE COMP3 et 5,7% dans TZE COMP4. La sélection a prolongé les jours à 50% de floraison, la hauteur des épis et la hauteur des plants ont été de 1,18 à 3,76% par cycle de maïs avec une réduction des aspects des plants et des épis. La variance génétique entre les lignées S1 pour le rendement en grain et d'autres caractères agronomiques a été significative (P<0,05). L`héritabilité estimée dans le sens large a été haute (h^2 = 0,41 à 0,88) avec une faible variation entre les cycles pour beaucoup de caractères. Ces résultats indiquent que le RRS a été efficace dans l'amélioration du rendement en grain et d'autres caractères sans réduire la variance génétique. Ainsi, il est possible de faire plus de progrès à partir de la sélection pour le rendement en grain et d'autres caractères dans ces composites. Les coefficients de correlation génétique du rendement en grain avec les aspects de la plante et de l'épis sont négatives. Cependant, la correlation génétique du rendement grain avec les jours à 50% de floraison la hauteur des épis et des plants sont positives dans les deux composites, ceci suggère que les gains à partir de la sélection pour le rendement en grain est lié aux changements de ces caractères.

Introduction

Maize (*Zea mays L.*) is one of the five most important crops in West and Central Africa (WCA) accounting for 7 to 70% of the total cereal production (Manyong et al. 1996). Production of maize has expanded considerably in many West African countries. This has been made possible by the adoption of improved varieties identified from international trials coordinated by the International Institute of Tropical Agriculture (IITA), the Semi-Arid Food Grain Research and Development (SAFGRAD) project, and the West and Central Africa Collaborative Maize Research Network (WECAMAN) (Menkir and Kling, 1999). Development of early and extra-early maturing varieties in recent years has also enhanced the expansion of maize production into the drier areas of the savanna where the characteristic short rainy season had prevented its cultivation (Manyong et al. 2000). There is also high demand for early maize in the forest zone because it allows farmers to market the early crop as green maize at prime price. Furthermore, early maize provides farmers in different ecological zones with flexibility in date of planting and it is the crop most suitable for filling the hunger gap after a long dry period (Menkir and Kling 1999).

To satisfy the need for improved early-maturing varieties, IITA developed several populations from various sources of germplasm. The limitation in the number of breeders working on maize at IITA prompted the adoption of the comprehensive breeding system (CBS) proposed by Eberhart et al. (1967) to consolidate the gains achieved in several populations and to integrate population improvement with hybrid development activities. The CBS involves the formation of breeding population from diverse sources of germplasm and the application of reciprocal recurrent selection (RRS) scheme. The expected products of CBS are superior open-pollinated varieties, varietal crosses, inbred lines and hybrids. In Africa, this system has been successfully used in Kenya (Eberhart et al. 1967; Darrah et al. 1978; Eberhart et al. 1991) and Cameroon (Everett et al. 1994).

Two early-maturing composites, TZE Comp 3 and TZE Comp 4 were used in the CBS. These composites have gone through two cycles of reciprocal recurrent selection (RRS) using S_1 testcross progeny as the selection unit (MIP, 1996). The progress from selection based on inter-population testcrosses of S_1 lines shows that RRS has been effective in improving the composites with mid-parent heterosis of 4% for C1 and 7% for C2 relative to the original populations (Menkir and Kling 1999). However, the progress from selection based on the performance of S_1 *per se* had not been studied. This information is useful for the evaluation of the potential of the two composites as sources of productive inbred lines for the development of hybrids and synthetics.

This study was, therefore conducted to evaluate the S_1 lines *per se* for (i) changes in means and genetic gain from selection for grain yield and other agronomic traits, and (ii) changes in heritability and genetic correlation between grain yield and other agronomic traits.

Materials and Methods

Two broad based early-maturing maize composites, TZE Comp 3 and TZE Comp 4, identified from a combining ability study (MIP 1996) were used for the study. TZE Comp 3 was developed by crossing selected S_1 lines from TZESR-W C_3 to DMR-ESR-W while TZE Comp 4 was formed by crossing EV8430-SR to Ikenne (1) 8149-SR. The two composites have undergone two cycles of RRS for improved grain yield, resistance to foliar diseases and other desirable agronomic traits using the reciprocal S_1 selection scheme. In each selection cycle, 500 to 1000 S_1 lines derived from each composite were evaluated for agronomic traits. Selection of S_1 lines for recombination was based on yield potential, resistance to foliar diseases, ear rot, stalk rot and root lodging of testcross progenies. A base index was used to identify the best 40–50 S_1 lines for recombination to form the next cycles. Five seasons (two seasons per year) were needed to complete one cycle of selection for each composite. Details of the RRS procedure are reported in MIP Annual Report (1996).

In 1997, 50 random S_1 lines derived from each cycle of selection (C_0, C_1 and C_2) of the two composites were sib-mated to increase seeds for evaluation. Evaluation of the S_1 lines was conducted in three environments (Ikenne 1998, Ikenne 1999, and Zaria 1999). A total of 300 S_1 lines (50 lines x 2 composites x 3 cycles) were divided into 10 equal sets; each set contained 5 lines from each cycle of each composite. A set consisted of five randomly selected S_1 lines from each cycle of each composite. Each set was planted in a randomized complete block design with two replicates in each of the three environments. The S_1 lines were planted in single row plots, 5 m long with 75 cm between rows and 25 cm within a row. Fertilizer and field management practices recommended for optimum maize production were used for each environment.

The number of days from planting till 50% of the plants had incipient silk extrusion in each plot was recorded as days to silk.

Plant and ear heights were measured in cm as the distance from the base of the plant to the first tassel branch and the node bearing the upper ear, respectively. Plant aspect was rated on a scale of 1 to 5 based on overall plant type, where 1 = excellent plant type and 5 = poor plant type. Ear aspect was also scored on a 1 to 5 scale, where 1 = clean, large, uniform and well-filled ears and 5 = ears possessing undesirable features. All ears harvested from each plot were weighed and representative ear samples were shelled to determine percent moisture. Grain yield was computed from ear weight (EWT, kg/m^2), adjusted to 15% moisture content (MOIST) and 80% shelling percentage (SHELL), using the following formula:

Grain yield ($Mg\ ha^{-1}$) = EWT*[(100-MOIST)/85]*(10000*SHELL)

Data were subjected to the analysis of variance (ANOVA) using the General Linear Model procedure (GLM) for randomised complete block design SAS (SAS Institute, 1995). ANOVA was computed for each selection cycle of the two composites. Environments, S_1 lines (hereinafter referred to as genotypes), and genotype x environment interaction were considered as random factors in determining the expected mean squares for the analysis. Genotype x environment interaction mean square was used as the denominator in the F-test for significant genotypic effects. Response to selection was calculated by regressing means of genotypes averaged over environments on the cycles of selection. Percentage gain per cycle was obtained by dividing the linear regression coefficient by the intercept multiplied by 100 (Hallauer and Miranda 1988). Genetic variances for the traits in each cycle of selection were estimated from the combined ANOVA by equating the observed mean squares with the expected mean squares. Broad-sense heritability was estimated as the ratio of the genetic variance to phenotypic variance on progeny mean bases. Standard errors for the estimates of genetic variance and heritability were computed using the method described by Hallauer and Miranda (1988). Genetic correlation between grain yield and other traits were calculated from variance and covariance estimates by using the formula of Falconer and Mackey (1996). Standard errors of genetic correlation values were computed based on the method of Mode and Robinson (1959).

Results and Discussion

Average grain yield of S_1 lines across the three environments was 3.03 $Mg\ ha^{-1}$ for TZE Comp 3 and 3.17 $Mg\ ha^{-1}$ for TZE Comp 4. Mean grain yield in the test environments were considerably wide ranging from 2.37 $Mg\ ha^{-1}$ at Ikenne in 1998 to 4.12 $Mg\ ha^{-1}$ at Zaria for TZE Comp 3 and from 2.39 at Ikenne in 1998 to 4.26 Mg ha^{-1} in Zaria for TZE Comp 4. Mean grain yield increased with selection in the two composites (Table 1).

Significant (P<0.01) linear increase in grain yield was detected after two cycles of selection (Table 2). The realised gain due to selection for grain yield was 10.4% for TZE Comp 3 and 5.7% for TZE Comp

4. Therefore, RRS has been effective in improving grain yield of the composites. The gains obtained in this study compare favorably with the average gains of 2 to 7% per cycle obtained for RRS programs conducted in other countries (Walter *et al.*, 1991; Keeratinijakal and Lamkey, 1993; Holthaus and Lamkey 1995; Menz and Hallauer, 1997).

Table 1. Means for grain yield and some agronomic trait of S_1 lines derived from the original and two selection-derived populations of TZE Comp 3 and TZE Comp 4 evaluated in three environments.

		Cycle			
Traits	Composite	0	1	2	±s.e.
Grain yield (Mg ha^{-1})	TZE Comp 3	2.7	3.1	3.3	0.05
	TZE Comp 4	3.0	3.1	3.4	0.06
Days to 50% silk	TZE Comp 3	51.7	53.1	53.5	0.14
	TZE Comp 4	52.8	53.0	54.1	0.13
Ear height (cm)	TZE Comp 3	61.1	67.2	65.5	0.63
	TZE Comp 4	59.1	62.4	63.3	0.66
Plant height (cm)	TZE Comp 3	149.7	156.6	154.9	0.84
	TZE Comp 4	146.9	152.8	157.9	0.91
Plant aspect (1-5)	TZE Comp 3	2.7	2.4	2.3	0.03
	TZE Comp 4	2.6	2.3	2.3	0.03
Ear aspect(1-5)	TZE Comp 3	3.0	2.9	2.8	0.03
	TZE Comp 4	2.8	2.8	2.7	0.03

Days to 50% silk increased significantly ($P < 0.05$) from cycle 0 to 2 by 1.8 and 1.3 days in TZE Comp 3 and TZE Comp 4, respectively. Gain per cycle for days to 50% silk in TZE Comp 3 was 1.65% and 1.18% for TZE Comp 4. In practical terms silking was delayed by about one and half days in the second cycle relative to the original cycle of selection in the two composites. This is presently negligible, but if the trend continues in later cycles of selection, the earliness of the two composites would gradually be lost.

Table 2. Linear response and percentage gain per cycle of reciprocal recurrent selection for grain yield from TZE Comp 3 and TZE Comp. 4 as measured by S_1 lines evaluated in three environments.

	Response per cycle of selection			
	TZE Comp 3		TZE Comp 4	
Traits	Mean	%	Mean	%
Grain yield(Mg ha^{-1})	0.29±0.05**	10.38	0.17±0.05**	5.73
Days to 50% silk	0.86±0.89**	1.65	0.62±0.19**	1.18
Ear height (cm)	2.23±0.48**	3.58	2.07±0.49*	3.48
Plant height (cm)	2.64±0.64**	1.75	5.53±0.66**	3.76
Plant aspect (1-5)	-0.16±0.02**	-5.97	-0.12±0.02**	-4.70
Ear aspect(1-5)	-0.12±0.02**	-4.06	-0.07±0.02**	-2.34

*, ** Significant at p=0.01 and p=0.05 levels, respectively.

Increased grain yield in these composites was associated with increased ear and plant heights (Table 2). On the other hand, the scores for plant and ear aspects decreased significantly (P <0.01) with selection in the two composites. These results corroborate those obtained by Menkir and Kling (1999) for the testcrosses of lines from the two composites.

Genetic variances among S_1 lines for grain yield, days to 50% silk, ear height, plant height and plant aspect of the selection cycles of both composites were significantly different from zero (P < 0.05) for each selection cycle (Table 3).

Table 3. Estimates of genetic variance (±s.e.) for grain yield and some agronomic traits across three environments for S_1 lines derived from the original and two improved cycles of TZE Comp 3 and TZE Comp 4.

Traits	Composite	Cycle of selection		
		0	1	2
Grain yield (Mg ha^{-1})	TZE Comp 3	0.28±0.09**	0.25±0.08**	0.27±0.09**
	TZE Comp 4	0.30±0.10**	0.23±0.09**	0.28±0.10**
Days to 50% silk	TZE Comp 3	2.68±0.77**	4.36±1.13**	2.67±0.68**
	TZE Comp 4	2.57±0.69**	1.50±0.44**	1.99±0.58**
Ear ht (cm)	TZE Comp 3	53.49±14.78**	42.48±12.90**	39.10±12.61**
	TZE Comp 4	63.74±17.00**	39.80±12.91**	38.55±12.12**
Plant ht (cm)	TZE Comp 3	84.31±23.50**	90.43±25.41**	120.00±32.90**
	TZE Comp 4	90.14±25.26**	147.78±38.79**	91.49±26.09**
Plant aspect	TZE Comp 3	0.09±0.02**	0.07±0.03**	0.06±0.05**
	TZE Comp 4	0.06±0.02**	0.06±0.02**	0.05±0.02**
Ear aspect	TZE Comp 3	0.07±0.03**	0.03±0.01*	0.05±0.02**
	TZE Comp 4	0.08±0.03**	0.07±0.02**	0.05±0.02*

*, ** Significant at P = 0.05 and P = 0.01, respectively.

Genetic variance estimates of the two composites showed 3.5 to 78.3% reduction from cycle 0 to 2 for all the traits except plant height, which increased. The slight difference in the genetic variance as a result of selection for grain yield implied that there is adequate genetic variance for future improvement of the two composites. However, the drastic reduction in genetic variance of grain yield between C1 to C2 for TZE Comp 3 and C0 to C1 for TZE Comp 4 were unexpected, because a fairly large number of S_1 lines (40–50) were recombined to form each cycle of selection. Menkir and Kling (1999) in an S_1 x S_1 testcross evaluation involving the two composites made similar observation. Similar reductions in genetic variance of S_1 lines after the initial two or three cycles of selection have been reported in other studies; for example, in BSSS after three cycles of RRS (Walter et al. 1991).

Heritability estimates for grain yield, days to 50% silk, ear height and plant height were significantly (P < 0.01) high (h^2 > 0.6) in all the selection cycles indicating that further selection would be effective (Table 4).

Table 4. Broad-sense heritability estimates (± s.e.) for grain yield and some agronomic traits across three environments for S_1 lines derived from the original and two improved cycles of TZE Comp 3 and TZE Comp 4.

Traits	Composite	Cycle of selection 0	1	2
Grain yield ($Mg\ ha^{-1}$)	TZE Comp 3	0.74±0.20	0.69±0.29	0.69±0.20
	TZE Comp 4	0.61±0.20	0.60±0.21	0.64±0.20
Days to 50% silk	TZE Comp 3	0.79±0.20	0.87±0.20	0.88±0.20
	TZE Comp 4	0.84±0.20	0.77±0.19	0.78±0.19
Ear height (cm)	TZE Comp 3	0.81±0.20	0.75±0.20	0.71±0.20
	TZE Comp 4	0.84±0.19	0.70±0.19	0.72±0.20
Plant height (cm)	TZE Comp 3	0.80±0.19	0.80±0.20	0.82±0.20
	TZE Comp 4	0.80±0.19	0.85±0.19	0.81±0.20
Plant aspect (1-5)	TZE Comp 3	0.69±0.85	0.54±0.21	0.56±0.21
	TZE Comp 4	0.55±0.20	0.60±0.20	0.56±0.21
Ear aspect (1-5)	TZE Comp 3	0.58±0.21	0.41±0.21	0.55±0.21
	TZE Comp 4	0.68±0.20	0.70±0.14	0.50±0.21

Heritabilities for days to 50% silk and plant height of C_2 were similar to or higher than those of C_0 for TZE Comp 3 while other traits had smaller heritability estimates after two cycles of selection. Reductions in heritability estimates were also observed for days to 50% silk, ear height and ear aspect after two selection cycles in TZE Comp 4 (Table 4). The overall changes in heritability estimates with selection followed trends similar to changes in genetic variance estimates. Schniker and Lamkey (1993) and Menkir and Kling (1999) have also shown that changes in heritability parallel those of genetic variance.

Grain yield had positive genetic correlation coefficients with days to 50% silk, ear height and plant height (Table 5). This implies that:

Table 5. Genetic correlation (±s.e.) between grain yield and and some agronomic traits across three environments for S_1 lines derived from the original and two improved cycles of TZE Comp 3 and TZE Comp 4.

Traits	Composite	Cycle 0	1	2
Days to 50% silk	TZE Comp 3	0.66±0.08	0.28±0.12	0.18±0.13
	TZE Comp 4	0.19±0.13	0.23±0.12	0.49±0.10
Ear ht (cm)	TZE Comp 3	0.56±0.09	0.64±0.08	0.69±0.08
	TZE Comp 4	0.55±0.09	0.40±0.11	0.70±0.07
Plant ht (cm)	TZE Comp 3	0.66±0.07	0.77±0.05	0.61±0.09
	TZE Comp 4	0.65±0.08	0.55±0.08	0.72±0.06
Plant aspect	TZE Comp 3	-0.99±0.00	-0.65±0.09	-0.73±0.08
	TZE Comp 4	-0.92±0.02	-0.73±0.07	-0.56±0.11
Ear aspect	TZE Comp 3	-0.45±0.15	-0.65±0.12	-0.54±0.13
	TZE Comp 4	-0.92±0.12	-0.94±0.01	-0.75±0.08

increase in grain yield with selection would result in taller plants and increased ear height. Consequently, efforts must be made to select plants with lower ear and plant heights in future cycles of selection.

The trend in the genetic correlation for days to 50% silk indicated reduction in magnitude with selection, although this trend was significant ($P < 0.05$) only at cycles 0 and 1 for TZE Comp 3. Such reduction in magnitude indicates that more of the gains in selection for grain yield should be expected to be independent of the changes in days to 50% silk. In contrast, genetic correlation coefficient increased with selection for ear height, but did not follow any definite pattern for plant height. Grain yield had negative genetic correlation with plant and ear aspects (Table 5). Therefore, selection based on low rating for these traits would lead to increased grain yield.

Conclusions

From the results of this study, we conclude that:

1. There was increase in mean grain yield, plant height, ear height, and days to 50% silk after two cycles of reciprocal recurrent selection in TZE Comp 3 and TZE Comp 4 maize composites. Plant and ear aspects decreased with selection.
2. Genetic variances and heritability estimates for grain yield and five other traits of the S_1 lines were sufficiently large to allow good response to further selection in the two composites.
3. Genetic correlation coefficients of grain yield with days to 50% silk, ear height and plant height were positive whereas those of grain yield with plant and ear aspects were negative.

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