Utilization of Genetic Components and Heritability of Physiological Traits in Female Inbred Parents in Developing Hybrid and Synthetic Maize Varieties

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Abstract. Conventionally, parental inbred selection has been based on the combining ability of male parents, utilizing diallel cross design, Comstock and Robinson's Design I or Design II. Those designs in maize require methodical crossing of a number of male and female parents and 3-4 plantings before one is enabled to identify males with good combining ability in the diallel design, or tester males in Design II. On the other hand, selecting for females with good combining ability is rather more straightforward since one actually measures the advantages in terms of the physiological traits shown in the crossed progenies as compared to those of their female parents. This study was done in 2005 and 2006 to lay a strong foundation for a breeding program utilizing selected inbred females to develop superior hybrid and synthetic (open-pollinated) progenies. In 2005, our objectives included (1) developing an appropriate unbiased method of statistical analysis in selecting females with good combining ability; (2) testing 10 female inbred populations for their combining abilities through a bulked-pedigree method; (3) deriving 10 single-cross F_1 and 10 reciprocal hybrid progenies; and (4) developing 5 synthetic progenies by intermating the 5 selected good-combining females. All hybrid and synthetic progenies were tested in 2006. The study resulted in (1) modified diallel analysis fit for testing good-combining females; the tests of inbreds, diallel crosses and synthetic progenies indicated a significant relationship between general combining ability and cross population means, and the synthetic progenies may be useful in predicting superior inbreds suitable for good-combining females; (2) the inbred populations showed high interpopulation variability which may simplify selection for certain desirable traits; and (3) the values for $\hat{\sigma}^2M$ (maternal) and $\hat{\sigma}^2NM$ (nonmaternal) measured a similar importance at >1 se and 2 se; $\hat{\sigma}^2M$ being indicative of the presence of a maternal effect. The maternal effect for productivity was not proved.

Keywords: Maize, hybrid, synthetic, good-combining female

Introduction

Selection of parental inbred lines is the most important part of a plant breeding program aimed at identifying superior hybrids and synthetic progenies (Fehr 1987). Parental inbred selection has conventionally been based on the combining ability of males, utilizing diallel cross design and Comstock and Robinson's Design I or Design II. Those designs in maize involve methodically crossing a number of male and female parents and 3-4 plantings before one is enabled to identify good-combining males in the diallel design, or tester males in Design II (Hallauer and Miranda 1981). On the other hand, selecting for females with good combining ability is rather more straightforward since one actually measures advantages in terms of physiological traits in the crossed progenies as compared to those of their female parents (Hikam 2003). Previous studies employing diallel-cross design have indicated nonsignificancies between F_1 cross progenies and their reciprocals when maternal effects were not assumed (Sudrajat 2002). However, Supandi (2005) reported significant $\hat{\sigma}^2A$ and $\hat{\sigma}^2D$, and concurrently, maternal effect. A problem arose in developing appropriate an analysis of variance and the concurrent expected mean-squares which should take the parental inbreds and progenies, ie, F_1 hybrids, reciprocals and open-pollinated (synthetics) into consideration.

Our study, therefore, intended to (1) develop an appropriate unbiased statistical analytical method for selecting good-combining females; (2) test 10 female inbred populations for their combining abilities in a bulked-pedigree method; (3) derive 10 single-cross F_1 and 10 reciprocal hybrid progenies; and (4) develop five synthetic progenies by intermating the five selected good-combining females. This was accomplished in 2005. In 2006, we tested all the hybrid and synthetic progenies developed.

Materials and Methods

Plant materials

The study was done in 2005 and 2006 in the red-yellow podzolic at the State Polytechnic of Lampung in Bandar Lampung. In 2005, five S_6 inbreds developed by Hikam (2003), UL1.04, UL1.06, UL2.03, UL3.01 and UL4.01, were mated following a diallel cross design (Griffing 1956). The cross resulted in three populations: the five inbreds, ten F_1 crosses and their ten reciprocals. A fourth population was developed by intermating the inbreds which resulted in synthetics. In 2006, all the developed populations were tested for their vegetative and productive performance.

Field design and measurement

The plots were preplant treated with glyphosate and 2,4D herbicides at 2 L ha^{-1} 7 days prior to tilling. Planting density was about 71 400 plants ha^{-1} (spacing 0.7 m between rows and 0.2 m within a row). In 2005, the plots were set up to accommodate diallel-cross and open-pollinated matings. The progeny populations that were obtained are presented in Table 1. The seeds were harvested, and bagged and tagged accordingly. In 2006, the plots were prepared in a randomized complete-block design (Steel and Torrie 1981) with three replications. Open-pollinated seeds were bulked with 500 seeds of each to form the synthetics population prior to planting. The plots were fertilized with urea, SP 36 and KCl at the rate of 300 kg ha^{-1}, 150 kg ha^{-1} and 150 kg ha^{-1}, respectively. The urea was split-applied with 100 kg ha^{-1} at day 7 and 200 kg ha^{-1} at day 30; whereas SP 36 and KCl were applied all at day 7.

On anthesis, ten sample plants from each plot were self-pollinated. The self-pollination was so prepared as to completely protect the ear from cross contamination (Hikam 2003). Paper bags were used to cover the tassels and ears of the sample plants; the tassels were covered 24 hours before pollination and the ears were were covered before silk emerged. The tassel bags were used to harvest pollen which were then pollinated to the ear of the same plant. The 2-3 cm top husk was cut 24 hours before pollination to permit the silk to grow at the same length. The ear was covered again after pollination with the tassel bag.

The parameters measured were: (1) plant height (cm); (2) leaf number; (3) ear length (cm); (4) ear diameter (cm); (5) ear weight (g per ear); (6) number of kernel rows per ear; and (8) productivity (kg of dried kernels m^{-1} at 15.5 % moisture).

Data analysis

The proposed model of analysis of variance for diallel-cross design which takes open-pollinated progeny populations into consideration is presented in Table 1. Variance components and narrow-sense heritabilities, and their respective standard errors were calculated following Hallauer and Miranda (1981; not shown). The values of variances and heritabilities were tested for significance at 95% and 99% confidence levels.

Results and Discussion

Mean-squared analyses

The mean-squared values derived from the analyses of variance (Table 2) indicated differences at Pd"0.01 as well as Pd"0.05 for various sources of variation although leaf number and above-ear leaves indicated differences at smaller numbers of sources compared to the rest. Interested readers may look at Table 2 and Table 3 simutaneously.

Parental inbreds, open-pollinated, cross and reciprocal

The differences ($P \leq 0.01$ or ≤ 0.05) for parental inbreds indicated that at least one inbred differed from the other four. The differences among inbreds would assure better hybrid and synthetic performances when recombined due to heterosis (Fehr 1987). This finding is rather consistent with the differences in open-pollinated, cross and reciprocal sources, except ear position and ear number in open-pollinated populations, and ear diameter in reciprocated populations.

Parents vs cross and open-pollinated vs cross

Differences ($P \leq 0.01$ or ≤ 0.05) for parent vs cross which indicated realized heterosis existed for plant height and kernel row. Differences ($P \leq 0.01$ or ≤ 0.05) for open-pollinated vs crossed progeny existed for plant height, leaf number, ear length, and kernel row.

Combining ability, maternal and nonmaternal effect

General combining ability (GCA, additive effect is prominent) was significant (P≤0.01 or ≤0.05) for plant height, ear length, ear diameter and kernel row. Specific combining ability (SCA, dominant and epistatic effects are prominent) was significant (P≤0.01 or ≤0.05) for plant height, ear length, kernel row, ear weight and productivity. Coexistence of GCA and SCA for plant height and ear length were of similar magnitude, except for kernel row where GCA >SCA.

Analyses of genetic variances, heritabilities and combining abilities

Data in Table 3 indicate that $\hat{\sigma}^2D$ was more important than $\hat{\sigma}^2A$, suggesting that some particular crosses were expected to perform better than average. This result confirmed the fact that the inbreds used in our study were derived from three different pedigrees (Hikam 2003). The values for $\hat{\sigma}^2M$ and $\hat{\sigma}^2NM$ measured similar importance at >1 se and 2 se, $\hat{\sigma}^2M$ being indicative of the presence of a maternal effect. Unfortunately, we did not prove maternal effect for productivity.

Table 1. Proposed model of analysis of variance for diallel-cross design, taking open-pollinated progeny population into consideration.

Source of variation	Df	Mean squared	Expected mean squared
Replicate	(r-1)	MS_1	
Entry	$(n^2 + p)-1$	MS_2	
Parental inbred	(n-1)	MS_{21}	
Open-pollinated	(p-1)	MS_{22}	
Parent vs cross	1	MS_{23}	
OP vs cross	1	MS_{24}	
Cross	n(n-1)-1	MS_{25}	
GCA	(n-1)	MS_{251}	
SCA	n(n-3)/2	MS_{252}	
Reciprocal	n(n-1)/2	MS_{253}	
Maternal	(n-1)	MS_{2531}	

Table 2. Mean-squared values of analyses of variance of measured variables.

Source of variation	df	Plant height	Leaf number	Ear length	Ear diameter	Kernel row	Ear weight	Productivity
Replicate	2	374.34*	1.12	4.07	0.02	0.84	292.8	34989**
Entry	29	1612.03**	7.03	12.53**	0.46**	5.39**	1262.51**	8539
Parental inbred	4	6033.63**	1.26	31.98**	0.79**	10.68**	4772.14**	36813**
Open-pollinated (OP)	1	33 907.15**	13.67	157.04**	3.84**	15.61**	25 039.95**	730133**
Parent vs cross	1	422.8*	0.05	6.29	0.00005	7.59**	455.76	2545
OP vs cross	4	646.02**	25.31*	9.11**	0.105	4.58**	282.79	8243
Cross	19	1054.23**	5.15	10.47**	0.515**	5.01**	862.80**	25157**
GCA	4	1281.18**	0.57	19.11**	0.69*	13.62**	518.13	15108
SCA	5	2484.41**	9.07	9.98**	0.48	2.78*	1769.69**	51597**
Reciprocal	10	248.36*	5.02	7.26**	0.46	2.69**	547.21*	15957*
Maternal	4	249.67*	4.56	4.74	0.52	2.84*	243.34	7097
Nonmaternal	6	247.49*	5.32	8.94**	0.42	2.58*	754.79**	21864
Error	58	91.21	7.93	1.94	0.19	0.82	228.79	6671

* and ** indicate significant differences at P≤0.05 and ≤0.01, respectively.

Table 3. Values of genetic variances ($\acute{o}^2$), narrow-sense heritabilities (h^2_{NS}), combining abilities, and genetic coefficients of variation (CV_g).

Measurement	Plant height	Leaf number	Ear length	Ear diameter	Kernel row	Productivity
Xbar	185.69	13.59	16.44	3.80	13.11	471.21
$\acute{o}^2$e	91.21	7.93	1.94	0.19	0.82	6671.32
$\acute{o}^2$P	1980.81*	-2.22	10.01*	0.20*	3.29*	10 047.40*
Se[1]($\acute{o}^2$P)	1161.19	0.54	6.16	0.15	2.06	7096.39
$\acute{o}^2$OP	11 271.98**	1.91	51.70*	1.22*	4.93*	241 154.00*
se($\acute{o}^2$OP)	9228.36	3.75	42.74	1.05	4.25	198 717.54
$\acute{o}^2$C	321.01**	-0.93	2.84**	0.11**	1.40**	6162.18**
se($\acute{o}^2$C)	108.59	0.72	1.08	0.05	0.52	2619.61
$\acute{o}^2$GCA	132.22	-0.82	1.91	0.06	1.42	937.46
se($\acute{o}^2$GCA)	246.63	0.49	3.68	0.13	2.62	2935.84
$\acute{o}^2$SCA	797.73*	0.38	2.68*	0.10*	0.65*	14 975.47*
se($\acute{o}^2$SCA)	442.69	1.69	1.78	0.09	0.50	9202.34
$\acute{o}^2$R	78.58*	-1.46	2.66*	0.14*	0.94*	4643.17*
se($\acute{o}^2$R)	51.38	1.25	1.49	0.10	0.55	3313.78
$\acute{o}^2$M	15.85*	-0.34	0.28*	0.03*	0.20*	42.61
se($\acute{o}^2$M)	14.51	0.30	0.28	0.03	0.16	427.49
$\acute{o}^2$NM	26.05*	-0.44	1.17**	0.04*	0.29*	2532.19*
Se($\acute{o}^2$NM)	15.61	0.38	0.56	0.03	0.16	1374.98
$\acute{o}^2$A	528.88	-3.27	7.63	0.22	5.69	3749.85
Se($\acute{o}^2$A)	986.50	1.98	14.72	0.53	10.49	11 743.36
$\acute{o}^2$D	3190.93*	1.52	10.72*	0.39*	2.61*	59 901.88*
se($\acute{o}^2$D)	1770.77	6.75	7.13	0.35	1.99	36 809.37
h^2NS	13.88	-52.94	37.61	27.82	62.36	5.33
se(h^2NS)	25.89	32.04	72.54	66.74	114.96	16.70
$\acute{o}^2$Ph	3811.02*	6.18	20.29	0.80	9.12	70 323.05*
se($\acute{o}^2$Ph)	2773.93	10.17	22.20	0.91	12.63	49 770.74
CVg(%)	5.14	20.72	8.47	11.47	6.91	17.33

[1] se = Standard error.

* and ** indicate that $\acute{o}^2$g and h^2_{NS} were different from zero at >1 and 2 se, respectively.

Conclusions

1. The modified diallel analysis was found suitable for testing good-combining females. The tests of inbred, diallel-cross and synthetic progenies indicated a significant relationship between the general combining ability and the cross-population means, and the synthetic progenies may be useful to predict superior inbreds suitable for good-combining females.
2. The inbred populations showed a high interpopulation variability, which may simplify selection for certain desirable traits.
3. The values for $\acute{o}^2$M and $\acute{o}^2$NM measured similar importance at >1 se and 2 se, $\acute{o}^2$M being indicative for the presence of maternal effect. Maternal effect for productivity was not proved.

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