Theoretical and Applied Genetics 47, 271-274 (1976)

Cytoplasmic Effects on Quantitative Characters in Maize (*Zea mays* L.)

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Summary. The investigations were carried out with ten genetically diverse maize varieties and all possible crosses between them, including reciprocals, at two agro-climatically different locations in Punjab (India). The materials were studied in a split-split plot design with plant population level of 59200, 74000 and 98700 plants per hectare. The variances due to reciprocal cross effects were significant for plant height, ear height and ear girth in the pooled analysis and the effects were quite consistent over plant population levels and locations. The data on days to silk were recorded only at one location and highly significant reciprocal effects were observed. The cytoplasmic effects, however, did not depend on the cytoplasm alone but also on the interaction of genotype with cytoplasm. The reciprocal effects were more distinct in early × late combinations of varieties than in early × early or late × late combinations. Early parents when used as female tended to reduce plant and ear height and days to silk, indicating a common developmental pathway for these three traits. Since the cytoplasmic effects for these characters were not associated with significant effects on yield, the results can be of practical significance. The cytoplasmic effects for days to silk were maintained even in the F_2 and backcrosses. These findings encourage the use of particular cytoplasm in developing early maturing varieties.

Introduction

The role of cytoplasmic effects in the inheritance of quantitative characters in maize has been reported by many workers in the recent past. Singh (1965), Crane and Nyquist (1967), Bhat and Dhawan (1971) and Kalsy and Sharma (1972) reported that the interaction between cytoplasm and nuclear genes is important in character expression. Fleming et al. (1960) demonstrated that choice of the female parent in a double cross hybrid may effect yield. Therefore, a sequence of parents showing beneficial cytoplasmic effects is important for taking advantage of cytoplasm-gene interactions.

The present investigation was planned to study the effect of cytoplasm on the expression of some important plant characteristics in inter-varietal crosses involving diverse indigenous and exotic heterozygous varieties at different plant densities and to examine the consistency of effects for silking days in the F_2 and backcross generations.

Materials and Methods

The material for the study consisted of ten open-pollinated populations and all possible crosses between them, including reciprocals. Of the 10 parent varieties, five, viz. Partappura Local (V_1), Bhodipur Yellow Local (V_2), Bassi Local (V_3), ((J_1 × Sathi) × Sathi)-#$_4$ (V_4) and Argentina Syn. A(V_5), were early maturing and the remaining five, viz. Vijay (V_6), JML-22(V_7), JML-27(V_8), Caribbean Flint Composite (V_9) and ((A_1 × Atigua Gr.I-12-#) × J_1) -#$_4$(V_{10}), were late maturing. The investigations were conducted at two agro-climatically different locations in the Punjab (India), Ludhiana and Gurdaspur. The soil at Ludhiana is poor sandy loam, whereas that at Gurdaspur is clay loam of high fertility. Three row spacings, 75, 60 and 45 cm, were used, keeping plant-to-plant spacing at 22.5 cm. This produced 59200 (P_1), 74000 (P_2) and 98700 (P_3) plants per hectare. The experimental design was split-split plot with plant densities in the main plot. The straight and reciprocal crosses were put in the sub-sub plots and sub-sub plots consisted of two rows. In each sub plot, the outer two rows were treated as non-experimental to avoid intergenotypic competition, as the populations differed greatly in height, vigour and duration.

The data were recorded on ten randomly selected competitive plants for the characters, grain yield per plant, 500-grain weight, ear length, ear girth, plant height and ear height. The observations on days to silk were recorded on a line basis at Ludhiana only. To study the consistency of cytoplasmic effects, four crosses, $V_1 \times V_7$, $V_2 \times V_7$, $V_2 \times V_8$ and $V_3 \times V_6$, and their reciprocals, were again produced and advanced to F_2 generation during spring, 1972. Some backcrosses, $(V_1 \times V_7)V_7$, $(V_3 \times V_6)V_6$, $(V_7 \times V_1)V_7$ and $(V_6 \times V_3)V_6$, were also attempted. Early maturing parents were sown later than the late maturing parents so as to synchronize the flowering of early and late varieties and to ensure random selection of the plants from the parent varieties when making the crosses. These 20 cultures (F_1, F_2 and backcross) were grown during kharif, 1972, at Ludhiana in randomised block design with four replications in 2-rows per plot. The spacing was 75 cm from row to row and 22.5 cm from plant to plant. The data were recorded only for days to silk. Data could not be recorded for other characters as the crop was severely lodged because of rain and very strong and gusty winds at the grain development stage.

The analysis for split plot design was carried out separately for the two locations following Kempthorne (1967). The combining ability analysis was carried out according to Griffing (1956) using model 1, method 1.

Table 1. Analysis of variance for reciprocal cross effects

Source		d.f.	Mean squares						
			Grain yield per plant	500-grain weight	Ear length	Ear girth	Plant height	Ear height	Days to silk
Ludhiana									
P_1	r.c.e.	45	21.79	15.49*	0.18	0.18*	36.83**	45.63**	1.70**
	Error	198	18.82	10.03	0.19	0.15	11.26	20.59	0.76
P_2	r.c.e.	45	21.88	11.29	0.22	0.18	20.90*	37.67**	1.34**
	Error	198	18.06	12.64	0.18	0.17	12.94	19.88	0.78
P_3	r.c.e.	45	19.45	12.91*	0.24	0.17	30.63**	25.98*	1.36**
	Error	198	42.55	7.93	0.17	0.15	12.93	17.93	0.65
Gurdaspur									
P_1	r.c.e.	45	41.17*	18.90	0.08	0.16*	33.63**	42.33**	--
	Error	99	23.61	22.30	0.07	0.10	12.59	17.57	--
P_2	r.c.e.	45	28.25	23.44	0.10	0.16	32.79**	40.09**	--
	Error	99	22.04	19.01	0.08	0.13	11.64	20.94	--
P_3	r.c.e.	45	18.42	24.07*	0.11	0.11	33.30**	25.20*	--
	Error	99	14.51	14.34	0.09	0.11	11.32	14.24	--
Pooled									
r.c.e.		45	9.23	6.14	0.07	0.05*	17.07**	21.42*	
r.c.e. × pop.		90	3.63	1.91	0.03	0.01	1.92	2.75	
r.c.e. × loc.		45	3.13	3.12	0.03	0.02	9.85*	3.49	
r.c.e. × pop. × loc.		90	2.96	2.31	0.02	0.01	0.25	2.07	
Error		891	7.28	4.79	0.05	0.03	5.30	4.92	

P_1, P_2 and P_3 refer to 59200 plants, 74000 plants and 98700 plants per hectare, respectively.
* and ** Significant at 5 and 1 per cent respectively.

Results and Discussion

The variance due to reciprocal cross effects (r.c.e.) was significant for plant height, ear height and days to silk under all the environments studied (Table 1). For grain yield, grain weight and ear girth, the variation due to r.c.e. was significant only in some of the environments, while for ear length, r.c.e. variances were invariably non-significant. The pooled analysis revealed significant r.c.e. variance for plant height, ear height, ear girth and days to silk, and Table 2 shows the reciprocal cross effects for these characters. The numbers of crosses showing significant reciprocal effects were six, thirteen, sixteen and five for ear girth, plant height, ear height and days to silk, respectively.

The interactions of r.c.e. with population levels, locations and second order interactions were not significant except in the case of r.c.e. × location for plant height. This indicated that the relative magnitude of the reciprocal effects of the different cross combinations did not vary much over the environments. Reliable inferences can, therefore, be made for the reciprocal effects using data from only a few environments. Crane and Nyquist (1967) found that the reciprocal effects were modified by interaction with environments, but this result referred to yield, a character greatly influenced by environment. Kalsy and Sharma (1972) compared reciprocal differences in varietal hybrids at two locations and found that the effects were less consistent for a character like yield than for days to silk.

The existence of cytoplasmic differences has been reported by Singh (1965) for yield, ear height, plant height, ear length, days to silk, number of ears per plant and moisture at harvest, by Bhat and Dhawan (1969) for grain yield, maturity, plant height and ear height, and by Kalsy and Sharma (1972) for yield per plant, days to silk, plant height, ear height, ear length, ear girth and 100-grain weight. In the present study, r.c.e. effects were important for ear girth, plant height, ear height and days to silk.

Table 2. Cytoplasmic effects pooled over the plant densities and locations

Cross	Ear girth	Plant height	Ear height	Days[1] to silk
$V_1 \times V_2$	0.07	-3.49*	-4.32**	0.00
$V_1 \times V_3$	0.10	-2.80	-1.27	-0.61
$V_1 \times V_4$	0.01	0.10	3.60*	0.11
$V_1 \times V_5$	0.20	2.48	3.00	0.94
$V_1 \times V_6$	0.08	-3.36*	-3.52*	-0.67
$V_1 \times V_7$	0.34**	-0.79	-2.95	-1.39*
$V_1 \times V_8$	-0.14	-1.57	-1.47	-1.06
$V_1 \times V_9$	-0.34**	-4.18*	-7.92**	-0.39
$V_1 \times V_{10}$	-0.04	-1.16	-2.54	-1.00
$V_2 \times V_3$	0.14	0.99	1.56	0.39
$V_2 \times V_4$	0.12	-0.18	2.12	-0.44
$V_2 \times V_5$	0.16	-1.45	-1.12	-0.72
$V_2 \times V_6$	-0.12	1.36	3.08*	0.17
$V_2 \times V_7$	-0.17	-4.93**	-5.93**	-1.33*
$V_2 \times V_8$	-0.16	-8.45**	-7.93**	-2.28**
$V_2 \times V_9$	-0.11	-2.07	-0.59	0.22
$V_2 \times V_{10}$	0.05	0.61	-0.33	-0.17
$V_3 \times V_4$	0.12	1.83	1.72	0.28
$V_3 \times V_5$	-0.09	-0.96	-0.72	0.28
$V_3 \times V_6$	-0.08	-5.89**	-5.49**	-1.88**
$V_3 \times V_7$	0.13	-1.64	-3.86*	0.28
$V_3 \times V_8$	-0.31**	-3.30*	-5.56**	-0.17
$V_3 \times V_9$	0.02	0.60	0.84	-0.17
$V_3 \times V_{10}$	0.02	-3.60*	-4.13**	-0.88
$V_4 \times V_5$	0.10	-1.04	0.39	0.33
$V_4 \times V_6$	-0.01	-2.13	-1.96	-0.28
$V_4 \times V_7$	-0.13	0.27	-0.31	-0.00
$V_4 \times V_8$	-0.21	0.60	-1.31	-0.17
$V_4 \times V_9$	-0.04	-3.45*	-4.88**	-0.22
$V_4 \times V_{10}$	-0.26*	-3.41*	-1.52	-0.11
$V_5 \times V_6$	0.03	-2.01	-1.52	0.50
$V_5 \times V_7$	0.01	-0.33	-2.43	0.06
$V_5 \times V_8$	0.05	0.85	-1.75	0.22
$V_5 \times V_9$	-0.02	-0.96	-1.03	-0.11
$V_5 \times V_{10}$	0.11	-1.54	-2.63	-1.78**
$V_6 \times V_7$	0.28*	3.37*	0.65	-0.33
$V_6 \times V_8$	0.02	3.14	3.73*	-0.44
$V_6 \times V_9$	0.36**	-7.67**	-5.68**	-0.61
$V_6 \times V_{10}$	-0.03	-2.17	5.67**	0.06
$V_7 \times V_8$	0.19	1.55	1.00	-0.28
$V_7 \times V_9$	-0.12	1.70	2.71	1.06
$V_7 \times V_{10}$	-0.03	-3.88*	-4.54**	-1.11
$V_8 \times V_9$	0.14	1.04	1.83	0.78
$V_8 \times V_{10}$	-0.16	-3.00	-1.64	-0.61
$V_9 \times V_{10}$	-0.21	0.95	1.07	0.00
S.E. ±	0.12	1.63	2.21	0.60
C.D. (5%)	0.23	3.19	3.06	1.17
C.D. (1%)	0.31	4.21	4.02	1.55

* and ** Significant at 5 per cent and 1 per cent, respectively.
[1] Ludhiana location only.

Perusal of the estimates of r.c.e. revealed that the reciprocal effects were more pronounced in early × late combinations. Out of ten early × early combinations, the number of hybrids, showing significant r.c.e. for ear girth, plant height, ear height and days to silk was zero, one, two and zero, respectively. Of 25 early × late combinations, the corresponding numbers of hybrid combinations showing significant effects were four, nine, ten and five, respectively; and out of 10 late × late combinations, it was two, three, four and zero, respectively. The parents showing significant specific reciprocal effects were genetically diverse. The role of diversity of the parents in the expression and manifestation of quantitative differences for agronomic characters as influenced by specific cytoplasmic effects has also been emphasized by Fleming et al. (1960), Dhawan and Paliwal (1964) and Singh (1965). In all the crosses showing significant effects, the early parent as female reduced plant height and ear height as well as days to silk. This may be because of the common developmental pathway for these three characters.

Even though many significant reciprocal effects were observed and some of the varieties were quite consistent in showing reciprocal effects, with many of the other genotypes, particularly when the crosses involved early × late combinations, the reciprocal effects did not just depend on the cytoplasm but depended more on the interactions of genotypes with cytoplasm. This is in agreement with the studies of Crane and Nyquist (1967) and Bhat and Dhawan (1971).

The desirable cytoplasmic effects of early maturing varieties appear to be of practical significance as these were not associated with a significant effect on yield. The significant reduction in plant and ear height and days to silk had no associated effect on grain yield. The combinations having significant r.c.e. values for all these three traits were $V_2 \times V_7$, $V_2 \times V_8$ and $V_3 \times V_6$. Another outstanding combination was $V_1 \times V_6$, which was significantly shorter than $V_6 \times V_1$ in plant and ear height, and earlier in maturity though not significantly. Yield was also higher than in the reciprocal and it outyielded all other combinations under high plant density at Ludhiana.

Maternal effects in F_1's, if present, are confounded with cytoplasmic effects but such effects are eliminated in further generations. For the practical exploitation of r.c.e. in breeding superior composite varieties, these effects must be maintained in subsequent generations. Therefore, the r.c.e. for days to silk were also studied in the F_2 generation and backcrosses. The results showed that all the cross combinations studied had significant reciprocal differences in all the generations (Table 3) and the magnitude of the differences was almost the same in F_2 and the

Table 3. Mean values of F_1, F_2 and backcross generations for days to silking

Cross	F_1		F_2	Backcross with late parent as male
$V_1 \times V_7$	54.25**		53.50*	55.00*
$V_7 \times V_1$	56.25		55.25	56.75
$V_2 \times V_7$	53.50**		52.25**	-
$V_7 \times V_2$	55.75		55.00	-
$V_2 \times V_8$	53.00**		53.50*	-
$V_8 \times V_2$	55.75		55.00	-
$V_3 \times V_6$	55.25**		52.75**	52.50**
$V_6 \times V_3$	58.00		54.75	55.00
C.D.(5%)		1.53		
C.D.(1%)		2.00		

* and ** Significant at 5 and 1 per cent, respectively.

backcrosses as in F_1. The continuity of cytoplasmic effects in F_2 has also been reported by Crane and Nyquist (1967), although their results were lower in magnitude. Examination of the results presented by Bhat and Dhawan (1971) revealed that the magnitude of reciprocal effects in the backcross generations was almost the same as in F_1 crosses. This continuity of the r.c.e. over the generations indicates the possibility of taking advantage of the cytoplasm for developing early maturing, short statured varieties.

Received September 26, 1975
Communicated by R. Riley

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