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Serial Analysis of Combining Ability in Diallel and Fractional Diallel Crosses in Linseed

I. J. Anand and **B. R. Murty**

Division of Genetics, Indian Agricultural Research Institute, New Delhi

Summary. An analysis of the nature of the gene action for seven characters influencing productivity and wide adaptation in *Linum usitatissimum* L. was undertaken in this investigation over three seasons based on diallel and fractional diallel crosses, among a set of ten genetically diverse parents. Estimation of combining ability and the nature of genotype-environment interactions for the above characters was also examined.

A comparison of the means of the parents and hybrids over three environments showed positive heterosis for height, number of tillers, fruit-bearing branches and capsules per plant while negative heterosis was observed for flowering time. The remaining two characters viz., height at branching and seeds per five capsules showed little differences due to mutual cancellation of the components of heterosis.

A serial analysis of combining ability over three seasons using Griffing's model (1956) has revealed significant seasonal effects on the estimates of combining ability effects. Additive gene action was found to be predominant in most of the characters although non-additive variation due to s.c.a. was equally prominent for fruit-bearing branches and capsules per plant. On the basis of g.c.a. for all the characters, M. 10 and N. 55, both Peninsular types were the best followed by N.P. (R.R.) 45 and Mohaba Local.

In the fractional diallel analysis the relative estimates g.c.a. and s.c.a. were similar for $s = 9$ and 7. However, there was overestimation in favour of s.c.a. when s was reduced to 3. The serial analysis of fractional diallel had confirmed the results of full diallel. Significant genotype × environment interactions for flowering time, height, height at branching, fruit-bearing branches and capsules per plant were observed in this analysis also. The results have indicated that reduction of the diallel to a fraction with $s = n/2$ would vitiate the order and precision of estimates of combining ability.

The analysis of genotype × environment indicated that the pattern of interactions among the parents of different geographical groups was not similar but varied with the character under study. Considerable interactions were observed for capsules per plant, fruit-bearing branches and flowering time in that order respectively. A comparison of the parental and hybrid populations for the degree of interaction for all the characters had revealed that heterozygosis might not at all be directly related to the degree of homeostasis. Actually, heterozygotes were found to show more interactions than homozygotes for flowering time, height at branching and tiller number and lower interactions for the other four characters. Significant seasonal effect on the degree of heterosis for vegetative as well as reproductive characters was observed in a majority of F_1's with variable degree of dominance.

The advance under selection for yield in linseed in India has not reached the expectations on the basis of predictions from the performance of early generations. Strong negative association between some of the yield components, genetic slippage due to unpredictable successive environments, and the loss of genes for productivity with intensive selection for disease resistance under poor soil fertility could be some of the causes (Jeswani and Murty, 1963).

However adequate information on the role of genotype-environment interactions is not available in this crop. It has also been reported that general combining ability is least influenced by such interactions in maize and tobacco (Rojas and Sprague, 1952; Matzinger, Mann and Cockerham, 1962). A serial analysis of combining ability of main effects and interaction components of genetic variation in a number of diallel crosses between parents chosen on the basis of genetic diversity might give an idea of the nature and magnitude of such interactions. This will also help to examine the changes in the estimates of combining ability over seasons. The results of such a study in diallel and fractional diallel sets are reported in this paper.

Materials and Methods

The experimental material used in the present investigation comprised of a set of ten varieties, chosen on the basis of their genetic diversity as measured by D^2-statistic. Amongst these, three were exotics, three Peninsulars from Deccan Peninsula, three Indo-Gangetics from Indo-Gangetic plains, and the tenth a derived line adapted to both Indo-Gangetic and Peninsular regions as reported in an earlier paper (Murty and Anand, 1966). The three exotics were used as donors for rust resistance at the Division of Genetics, Indian Agricultural Research Institute, New Delhi, in India.

The parental varieties which were selfed for several generations previously, were crossed in all possible combinations in the years 1963, 1964 and 1965 so as to make a complete diallel set without reciprocals. The 45 F_1 hybrids thus obtained in each year were sown along with parents in a randomised complete block design with three replications in the following winter season. The spacing was 12 inches between rows and four inches within rows of ten feet length.

Five plants were selected at random in each row and observation on seven characters related to productivity i.e. flowering time (recorded as the number of days from the date of sowing to the opening of first flower), height (measured in centimeters from the base to the tip of the main tiller at maturity), height at branching (measured in centimeters at the time of maturity), tiller number, fruit-bearing branches, capsules per plant and seeds per five capsules were taken.

The estimates of general and specific combining ability effects and analysis of variance for combining ability was done on the fixed effects model described by GRIFFING (1956).

Fractional diallel sets corresponding to $s = 9, 7, 5$ and 3 were formed from the full diallel sets and the data on the above characters were analysed for the first two seasons. The sampling and analysis of fractional diallels followed the procedure outlined by KEMPTHORNE and CURNOW (1961). Pooled analysis of full and fractional diallels over three different seasons was carried out.

Results

A comparison of the means of the parents and hybrids over the three environments revealed that the hybrids showed positive heterosis for height, number of tillers, fruit bearing branches and capsules per plant while negative heterosis was observed for flowering time. The remaining two characters viz., height at branching and seeds per five capsules showed little hybrid vigour due to mutual cancellation of the components of heterosis.

A combined analysis was done for the full diallel without reciprocals based on individual plant observations for the three seasons, to examine the nature of genotype × environment interactions (Table 1). The variation amongst the hybrids was larger than that among the parents except for the character seeds per five capsules. The differences between parents and hybrids pooled over environments were substantially high for almost all the characters except seeds per five capsules, indicating marked heterosis. Significant seasonal effects with interactions due to genotypes × years were indicated for all the characters. The interaction of hybrids × years was more than that of parents × years for flowering time, height at branching and number of tillers, while it was the opposite for the remaining characters. Therefore, heterozygosity did not appear to be related to the magnitude of these interactions. The interaction of (Parents vs. hybrids) × years was significant for six characters indicating that heterotic effects varied with seasons. Actually, heterosis was found to be maximum in the most favourable season in 1964 to 1965.

The pooled analysis of combining ability of the three seasons is given in Table 2. The variations due to general and specific combining ability and their interactions with years were significant. The seasonal effects on both general and specific combining ability

Table 1. *Pooled analysis of variance of a set of crosses and parents over three seasons 1964—66*

Source	D.F.	Mean sum of squares						
		Flowering time	Height	Height at branching	Number of tillers	Fruit bearing branches	Capsules per plant	Seeds per capsule
Replications	6	811.25	898.75	293.58	206.77	37312.97	175370.50	60.82
Populations	54	3518.46**	5809.80**	3095.93**	171.95**	18435.50**	191667.77**	136.53**
Parents	9	1363.03**	3878.40**	1397.86**	84.54**	8819.16*	119743.66**	159.40**
Hybrids	44	3729.84**	6084.25**	3449.63**	190.05**	20816.29**	210607.50**	134.88**
Par. vs. Hyb.	1	13617.00**	11116.00**	2816.70**	162.18 N.S.	237.00 N.S	5710.00 N.S	4.20 N.S.
Error (A)	324	158.08	188.54	234.82	34.19	3602.44	25853.32	34.77
Years	2	24021.50**	14643.50**	7845.40**	2084.25**	1733493.00**	20351915.00**	768.00**
Years × Populations	108	786.78**	511.31**	373.39**	84.91**	9736.18**	88735.74**	78.15**
Parents × years	18	643.65**	579.14**	210.75 N.S.	52.57**	15752.56**	139120.50**	118.09**
Hyb. × years	88	824.65**	469.34**	397.32**	90.20**	7434.10**	67181.02**	70.91**
Par. vs. Hyb. × year	2	408.60**	1737.70**	783.83*	143.14**	56880.45**	583680.50**	37.12 N.S.
Error (B)	1980	74.71	67.33	184.58	22.33	2499.90	19764.76	22.70
Total	2474							

* Significant at 5% level. — ** Significant at 1% level. — N.S. Not significant

Table 2. *Pooled diallel analysis for combining ability over three seasons in linseed*

Source	D.F.	Flowering time	Height	Height at branching	Number of tillers	Fruit bearing branches	Capsules per plant	Seeds per capsule
G.C.A.	9	395.10**	688.17**	342.03**	12.89**	744.00**	8579.72**	10.33**
S.C.A.	45	14.81**	17.30**	14.15**	2.01**	342.83**	3395.42**	1.58**
Years	2	24021.50**	14643.50**	7845.50**	2084.25**	1733493.00**	20351915.00**	768.00**
G.C.A. × Years	18	523.06**	779.80**	385.83**	21.81**	1624.57**	18450.66**	19.64**
S.C.A. × Years	90	52.16**	39.87**	35.26**	7.01**	945.59**	8519.91**	5.96**
Error	1980	1.66	1.50	4.10	0.50	55.55	439.22	0.50

** Significant at 1% level. — G.C.A. = General combining ability. — S.C.A. = Specific combining ability

Table 3. *Pooled estimates of general combining ability effects of ten parents of linseed over three seasons*

Parents		General combining ability effects						
		Flowering time	Height	Height at branching	Number of tillers	Fruit bearing branches	Capsules per plant	Seeds per five capsules
1. N.P. 12	(G)	5.08	−4.83	−2.06	0.46	−1.27 N.S.	−8.28 N.S.	0.31 N. S.
2. N. 55	(P)	−4.05	−5.76	−5.09	−0.21 N.S.	6.24	13.81	−1.14
3. M. 10	(P)	−6.37	−7.05	−5.76	1.40	8.21	23.11	−0.94
4. Mayurbhang	(G)	−2.52	−3.16	−2.47	−0.32 N.S.	−1.51 N.S.	−3.76 N.S.	0.48
5. Afghanistan-2	(E)	7.18	5.38	1.57	0.87	8.35	38.59	1.30
6. Wada	(E)	−3.29	17.56	11.32	−2.50	−17.79	−59.84	1.44
7. A. 17-1-1	(E)	11.05	5.74	6.98	−0.08 N.S.	3.01 N.S.	5.99 N.S.	0.12 N.S.
8. N.P. (R.R.) 9	(G,P)	−1.87	−1.80	−1.11	−0.19 N.S.	−6.09	−14.49	0.06 N.S.
9. N.P. (R.R.).45	(G)	−0.96	−4.93	−2.10	0.49	3.10	14.59	−0.92
10. Mohaba local	(P)	−4.32	−1.13	−1.27	0.07 N.S	−2.24 N.S	−9.72 N.S.	−0.72
S.E. ĝi		0.35	0.33	0.55	0.19	2.04	5.73	0.19
S.E. (ĝi−ĝj)		0.52	0.49	0.82	0.28	3.04	8.55	0.28

N.S. = Not significant. — G: Indo-Gangetic; P: Peninsular; E: Exotic; G.P: Suitable for both Gangetic and Peninsular regions.

were considerable. Predominantly additive gene action was indicated for flowering time, height, height at branching, fruit-bearing branches and capsules per plant. Variation due to specific combining ability was also large for fruit-bearing branches and capsules per plant. The pooled estimates of general combining ability effects (g.c.a.) for the ten parents are given in Table 3. M. 10 was the best combiner for all the characters except seeds per five capsules, followed by N. 55, N.P. (R.R.) 45 and Mohaba Local. Afghanistan-2, which resembles a flax type had a high combining ability for fruit-bearing branches and capsules per plant but highly non-synchronous in tillering and poor in plant type and total seed yield. Thus, the best combiners are mostly Peninsular types.

The pooled estimates for specific combining ability effects (s.c.a.) over three different environments are presented in Table 4. It was interesting that crosses involving late parents showed high specific combining ability towards late flowering, whereas crosses with high specific combining ability for early flowering, had either one or both the parents with general combining ability towards earliness. The estimates of specific combining ability were not consistent for the other characters although the performance of some crosses agreed with the expectations on the basis of general combining ability of their parents, thus giving an indication that non-allelic interactions may not be important and prediction of performance on the basis of general combining ability would be generally valid.

In general, a comparison of specific combining ability effects had shown that the performance of the crosses M. 10 × Mohaba Local, Wada × Mohaba Local, M. 10 × N.P. (R.R.) 45, Afghanistan-2 × N.P. (R.R.) 45, Mayurbhang × N.P. (R.R.) 9, N. 55 × A.17-1-1 and Mayurbhang × A.17-1-1 were exceptionally good. These crosses had one or more Peninsular types or derivatives from them as parents. Thus, the Peninsular material would appear to be promising for exploiting both general and specific combining abilities.

Fractional Diallel Analysis of Combining Ability

The analysis of variance of partial diallel pooled over two environments was done for all the seven characters for the cases $s = 9, 7, 5$ and 3 (Table 5). For full diallel, s takes the value of $(n-1)$, where n is the number of parents.

The variation due to g.c.a. among the parents was significant in both the years for flowering time, height and height at branching for all values of s, confirming the results of full diallel that gene action was predominantly additive for these characters, except two (i.e. number of tillers and fruit bearing branches).

The pooled estimates of g.c.a. effects for fractional diallel indicated changes in the order of general combining ability effects for all the characters when *s* was reduced to 3 and the relative values of g.c.a. were overestimated consequently.

The results obtained from the serial analysis of fractional diallel were in agreement with the results obtained from the serial analysis of full diallel. The average variance $\widehat{(gi\text{-}gj)}$ increased by more than ten times as *s* decreased from nine to three indicating that it is not feasible to reduce the fraction of the diallel with *s* less than *n*/2.

Variation due to s.c.a. effects with environments were also significant for all values of *s* for all the characters. The variance ratio specific combining ability × year was less than general combining ability × year for flowering time, height, height at branching and seeds per 5 capsules, when $s = 9$ and 7 but rapidly went on increasing when *s* decreased to 5 and 3.

Discussion

The present study, which was undertaken to examine the nature of gene action and to study the magnitude of genotype × environment interactions

Table 4. *Pooled estimates of specific combining ability effects over three seasons*

Cross	Flowering time	Height	Height at branching	No. of tillers	Fruit bearing branches	Capsules per plant	Seeds per five capsules
P1×P2	0.00	−2.87	−3.67	−0.65	−2.63	19.46	−0.26
P1×P3	−0.14	−1.50	0.38	1.69	3.71	−25.88	1.53
P1×P4	2.40	−1.93	−1.26	−0.45	6.77	14.60	0.27
P1×P5	−0.67	1.43	−2.20	0.29	12.79	69.09	−1.17
P1×P6	−2.04	2.84	−1.63	0.78	19.81	42.70	0.91
P1×P7	−2.19	1.52	0.55	−0.29	−9.08	−13.47	−1.27
P1×P8	−3.11	4.25	0.96	−0.41	14.26	−0.97	−1.38
P1×P9	0.76	1.49	−0.26	0.47	11.46	46.15	−2.68
P1×P10	2.89	1.65	3.10	0.16	18.38	−50.50	−0.40
P2×P3	0.94	−1.42	2.11	1.22	1.93	2.78	−0.91
P2×P4	−3.64	−1.74	−2.14	0.46	3.62	16.83	1.75
P2×P5	7.74	2.06	−0.97	−2.31	−3.75	−11.64	−0.51
P2×P6	−4.35	1.42	0.21	2.21	4.68	14.98	−0.35
P2×P7	3.86	3.41	−0.65	2.14	35.62	96.86	0.00
P2×P8	0.88	3.25	2.36	−0.31	2.40	13.80	−1.19
P2×P9	4.02	1.54	−1.51	−0.77	15.66	43.84	−1.20
P2×P10	−3.19	−1.12	0.13	0.72	−6.06	3.57	−1.03
P3×P4	0.67	−2.15	−1.84	0.12	−14.20	−57.51	0.15
P3×P5	3.48	1.89	2.47	−1.02	−7.05	−23.81	−0.76
P3×P6	−2.61	−1.26	−3.76	−0.35	−8.16	− 8.08	1.17
P3×P7	6.23	4.72	3.70	−1.12	−5.20	−10.96	1.42
P3×P8	0.54	1.49	−0.85	1.24	−7.31	21.61	0.46
P3×P9	0.37	5.81	0.80	2.35	28.92	98.36	0.17
P3×P10	−2.40	−0.79	−1.62	0.74	20.59	63.24	−2.07
P4×P5	−1.94	0.76	1.85	0.92	2.29	15.25	0.37
P4×P6	−1.75	1.43	−1.62	−0.69	−8.52	−17.58	0.31
P4×P7	−0.28	6.26	0.96	1.80	33.79	77.55	−2.07
P4×P8	−2.12	−2.97	−1.83	0.19	28.01	83.92	−0.81
P4×P9	−3.36	−1.30	−0.42	−0.71	−13.52	−44.56	−0.83
P4×P10	1.25	−3.84	−2.97	−1.36	3.67	2.95	0.64
P5×P6	1.63	−0.92	−1.00	1.00	6.75	17.00	−1.71
P5×P7	−1.96	−3.49	1.59	1.60	4.59	14.59	−0.79
P5×P8	−0.79	−0.33	1.49	−0.86	−5.30	−20.63	1.66
P5×P9	−4.18	7.43	0.40	0.86	18.22	95.20	1.34
P5×P10	9.14	9.38	5.22	1.92	6.07	3.96	1.03
P6×P7	−4.37	4.77	4.40	−0.39	10.03	49.71	1.74
P6×P8	3.46	−4.33	−3.50	1.84	−3.41	14.16	0.82
P6×P9	−3.90	−3.43	−4.40	0.52	7.58	12.42	−0.88
P6×P10	−4.30	7.33	−0.29	0.76	20.51	70.90	−1.40
P7×P8	−1.33	−1.40	−0.45	−0.73	−1.91	−10.08	0.19
P7×P9	−2.50	−6.22	−4.24	0.03	−3.00	−19.97	0.05
P7×P10	−1.14	−6.22	−4.24	0.03	6.17	18.03	0.18
P8×P9	−1.01	1.63	−0.48	0.60	14.52	41.74	1.73
P8×P10	2.33	−2.80	−2.54	−0.09	12.87	26.81	−0.44
P9×P10	4.76	4.34	15.60	1.15	1.32	−9.07	1.72

P1 — N.P. 12; P2 — N. 55; P3 — M.10; P4 — Mayurbhang; P5 — Afghanistan — 2; P6 — Wada; P7 — A. 17—1—1; P8 — N.P. (R.R.) 9; P9 — N.P. (R.R.) 45; P10-Mohaba local

Table 5. *Partial Diallel Analysis of Combining Ability pooled over two seasons for some characters in Linseed*

Source	D.F.	Flowering time				Height				Height at branching			
		$s = 9$	7	5	3	9	7	5	3	9	7	5	3
Replication	4	91.31	69.23	72.25	22.56	153.04	120.77	50.15	71.55	54.82	42.62	31.94	47.66
G.C.A.	9	273.77**	244.25**	168.86**	112.95**	561.73**	314.99**	205.69**	156.49**	236.96**	123.96**	78.85**	50.77**
S.C.A.	35	175.01**	213.93**	241.06**	459.61**	348.69**	298.15**	310.79**	606.27**	138.39**	104.83**	116.55**	219.14**
Year	1	6961.50**	5011.70**	3489.70**	2315.47**	4410.90**	3697.60**	3398.70**	1884.20**	1493.44**	1092.11**	926.54**	666.41**
G.C.A. × Y	9	459.72**	373.12**	271.55**	205.38**	617.01**	369.27**	255.44**	202.30**	278.40**	162.57**	117.76**	77.74**
S.C.A. × Y	35	330.61**	344.75**	399.27**	639.70**	445.02**	420.44**	417.83**	622.28**	182.38**	157.56**	181.17**	274.50**
Error	176	40.52	38.35	38.39	37.07	48.89	48.17	27.51	17.33	22.20	21.04	15.57	14.66

Table 5 (contd.)

Source	D.F.	No. of tillers				Fruit bearing branches			
		9	7	5	3	9	7	5	3
Replication	4	9.89	10.90	5.71	2.68	7180.65	5459.98	7103.57	2547.67
G.C.A.	9	1.89 N.S.	1.78 N.S.	1.47 N.S.	1.76 N.S.	495.30 N.S	424.46 N.S	341.52 N.S	496.12 N.S
S.C.A.	35	4.02 N.S.	4.70 N.S.	5.50*	9.65**	1936.25 N.S	2040.43 N.S	2771.69**	4758.79**
Year	1	8.50 N.S.	7.66 N.S.	3.74 N.S.	5.52 N.S.	416713.60**	313756.80**	241105.20**	153479.10**
G.C.A.×Y	9	4.37 N.S.	3.94 N.S.	4.03 N.S.	6.36 N.S.	2053.26 N.S	1556.72 N.S	1664.65 N.S	1702.11 N.S
S.C.A.×Y	35	12.05**	12.24**	14.92**	24.35**	5881.60**	6155.78**	8245.55**	11093.07**
Error	176	3.71	3.49	3.67	4.56	1396.60	1470.67	1215.46	1219.58

Table 5 (contd.)

Source	D.F.	Capsules/plant				Seeds/5 capsules			
		9	7	5	3	9	7	5	3
Replication	4	30608.75	24683.90	39345.92	11670.65	1973.25	13.77	14.26	14.23
G.C.A.	9	7589.15 N.S	6554.95 N.S	6360.94 N.S	6519.18 N.S	47.69 N.S	4.01 N.S	3.40 N.S	1.19 N.S
S.C.A.	35	20273.87**	20220.22*	28124.64**	50832.25**	42.55 N.S	8.67**	9.27**	8.14**
Year	1	4607569.00**	3615425.00**	2757559.00**	1546770.00**	2357.38**	2.75 N.S	2.82 N.S	8.04 N.S
G.C.A.×Y	9	19566.91 N.S	14957.55 N.S	15946.55 N.S	16687.56 N.S	150.67*	19.16**	17.53**	9.65*
S.C.A.×Y	35	52315.64**	54036.19**	74249.42**	101619.31**	123.31*	27.14**	31.33**	35.40**
Error	176	10680.99	11667.72	9335.72	9401.65	71.16	4.40	4.83	4.20

G.C.A. = General combining ability S.C.A. = Specific combining ability.

in crosses between parents chosen on the basis of diversity has yielded valuable information. The pooled estimates of combining ability in full diallel have shown that general combining ability was the predominant component for all the characters under study, although variation due to specific combining ability was also significant. It was interesting that interactions of g.c.a. × years were considerably larger than s.c.a. × years, contrary to the reports by ROJAS and SPRAGUE (1952) in maize, MATZINGER, MANN and COCKERHAM (1962) in tobacco and KAMBAL and WEBSTER (1965) in *Sorghum*. Such divergence in results could be due to the bias in the estimates of combining ability in the presence of maternal and reciprocal effects. Such effects were found to be present in linseed (ANAND and MURTY, under publication). This would be of interest in choosing the maternal parent for developing material with wide adaptation.

In the fractional diallel analysis, the relative estimates of general and specific combining ability were similar for $s = 9$ and 7 but were substantially biased in favour of s.c.a. when $s = 3$. Similar changes took place in the interaction components also. Therefore, it would appear that limitations on the diversity of parental material and the number of lines included in the diallel could result in incorrect conclusions that g.c.a. is more stable over environments than s.c.a.

The ordering of parents for g.c.a. effects also changed with reduction in the size of the fractional diallel. Since the characters examined are major yield components, it will be desirable to choose the parental material and number of crosses on the basis of diversity. The best combiners for a majority of the characters are M. 10 and N. 55 and are better than the best rust resistent types available. This would indicate the nature of selection in the past may have some effect on the combining ability inspite of diversity of their parentage.

Genotype × Environment Interactions

The data on this aspect had revealed that the pattern of interactions among the parents of different geographical groups was not similar but varied with the character under study. The characters most susceptible to such interactions were capsules per plant, fruit-bearing branches and flowering time in the descending order. Tiller number and seeds per five capsules had shown limited interactions over seasons. The differences among the hybrids were magnified for capsules per plant, fruit-bearing branches and seeds per five capsules as compared to the parents. Although the seasonal effects were substantial, the parents vs. hybrids comparisons were not significant for four out of the seven characters indicating specific interactions between some parents in both the positive and negative directions.

A comparison of the interactions of parents × years and hybrids × years has revealed that the heterozygotes have shown more interactions than the homozygotes for flowering time, height at branching and tiller number and lower interactions for the other four characters. The interactions of parents vs. hybrids × years were substantial for all the characters, thereby indicating that environment could substantially alter the relative performance of parents and hybrids. Therefore there did not appear to be any association between heterozygosity and the capacity of stable performance over different environments. Thus the past history of selection of each character rather than heterozygosity would appear to determine the homeostatic mechanism contrary to that reported by LERNER (1954), HIESEY (1963) and GRIFFING and LANGRIDGE (1963). It is likely that the diversity between parents within the population would be more important for the stability of performance as observed by PFAHLER (1965) in self-pollinated crops like oats. ALLARD and WORKMAN (1963) had considered the optimal conditions might reduce the differences in fitness between homo- and heterozygotes. While this could be true under domestication by man to a considerable degree, the differences in the seasonal conditions in the present study were large enough that the observed results could only be explained on the basis of diversity of the population. Genetic diversity rather than heterozygosity *per se* might be important for the limited genotype × environment interactions not associated with heterozygosity. Compensatory mechanisms might limit any advantage of the heterozygote in the enzyme activity as observed by ROWE and ANDREW (1964). Therefore, it would appear possible to get pure breeding lines by selection for low interactions with environments. The possibility of limited interactions for some characters indirectly influencing yield had indicated that yield improvement would be possible with selection for those traits, particularly in the early growth phase. The results of FINLAY (1963) could also be interpreted on the basis of diversity between the populations responsible for wide adaptation. Among the components of environment, seasonal changes are highly unpredictable and cannot be controlled. As observed in barley by RASMUSSEN and LAMBERT (1961) and in lima bean by ALLARD and WORKMAN (1963), the variety × year components are large. Therefore, it would be useful to try several environments comparable to the seasonal effects. Variety × year component was reported to be the principal one in rice by NEI (1960) and in upland cotton by AL-JIBOURI *et al.* (1958). However, as pointed out by MATZINGER, MANN and COCKERHAM (1962), the factors which cause differential varietal response are not those which occur in all years at one location. Therefore, greater significance should be attached to the genotype × year × location component by increasing the number of locations in two seasons. Such a testing over a wide range was successful in indentifying superior genotypes for hybridization and production of F_1's and selection of inbreds in self- and cross-pollinated crops like wheat, barley, maize and *Sorghum* and could be equally useful in linseed.

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Zusammenfassung

Über einen Zeitraum von drei Vegetationsperioden wurde mit einem Material von 10 genetisch verschiedenen Eltern anhand von vollständigen und unvollständigen Diallelkreuzungen die Genwirkung bei 7 die Ertrags- und Anpassungsfähigkeit von *Linum usitatissimum* L. beeinflussenden Merkmalen geprüft. Außerdem wurde die Kombinationseignung dieser Merkmale und die Genotyp-Umwelt-Interaktion untersucht.

Ein Vergleich der Durchschnittswerte der Eltern und Hybriden an drei verschiedenen Anbauorten ergab positive Heterosis bezüglich der Merkmale Höhe, Anzahl der Triebe, samentragende Zweige und Kapseln je Pflanze, negative Heterosis wurde dagegen bezüglich des Merkmals Blütezeit beobachtet. Die restlichen zwei Merkmale, Höhe der Verzweigung und Samenansatz von je 5 Kapseln, zeigten infolge gegenseitiger Aufhebung der Heterosiskomponenten geringe Unterschiede.

Eine dreijährige Reihenanalyse hinsichtlich der Kombinationseignung nach dem Modell von GRIFFING (1956) ergab einen signifikanten Einfluß des Anbaujahres auf die Schätzung der Kombinationseignung. Bei den meisten Merkmalen konnte auf additive Wirkung der Gene geschlossen werden, obgleich nichtadditive Wirkung als Folge von spezieller Kombinationseignung bei den Merkmalen fruchtende Sprosse und Kapseln je Pflanze ebenso ausgeprägt war. Hinsichtlich der allgemeinen Kombinationseignung für alle untersuchten Merkmale erwiesen sich die beiden Halbinsel-Sippen, M 10 und N 55, als die besten, gefolgt von P.P. (R.R.) 45 und Mohaba Local.

In den unvollständigen diallelen Analysen waren die relativen Schätzungen für allgemeine und spezielle Kombinationseignung für $s = 9$ und 7 ähnlich. Wenn s jedoch auf 3 reduziert wurde, ergab sich eine Überschätzung der speziellen Kombinationseignung. Die Reihenanalysen des unvollständigen Diallel-Versuchs bestätigten die Ergebnisse des vollständigen Diallel-Versuchs. Auch in diesem Fall wurden signi-

fikante Genotyp-Umwelt-Interaktionen bezüglich Blütezeit, Höhe, Verzweigungshöhe, fruchtende Sprosse und Kapseln je Pflanze beobachtet. Die Ergebnisse deuteten an, daß eine Verringerung des Diallel-Versuchs auf einen Teil mit $s = n/2$ die Reihenfolge und Genauigkeit der Schätzung der Kombinationseignung beeinträchtigen würde.

Die Analyse der Genotyp-Umwelt-Interaktion zeigte, daß die Art der Interaktion bei den Eltern verschiedener geographischer Gruppen nicht gleich war, sondern je nach dem untersuchten Merkmal variierte. Beträchtliche Interaktionen wurden für die Merkmale Kapseln je Pflanze, fruchtende Sprosse und Blütezeit — in dieser Reihenfolge — beobachtet. Ein Vergleich der Eltern- und Hybridenpopulationen bezüglich des Grades der Interaktion hat bei allen Merkmalen ergeben, daß Heterozygotie durchaus nicht unmittelbar mit dem Grad der Homeostasis in Beziehung zu stehen braucht. Tatsächlich wurde gefunden, daß Heterozygote bezüglich Blütezeit, Verzweigungshöhe und Zahl der Triebe größere Interaktionen und für die anderen 4 Merkmale geringere Interaktionen als Homozygote zeigen. Bei der Mehrzahl der F_1-Nachkommen wurde sowohl für die vegetativen wie reproduktiven Eigenschaften ein signifikanter Einfluß des Anbaujahres mit verschiedenem Dominanzgrad auf den Grad der Heterosis beobachtet.

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Dr. B. R. Murty,
Division of Genetics, Indian Agricultural
Research Institute
New Delhi 12 (India)