Theor. Appl. Genet. 60, 339-343 (1981)

Combining Ability Analysis over Environments in Diallel Crosses of Linseed (*Linum usitatissimum* L.)*

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Summary. This paper reports on combining ability studies for yield and its component traits in diallel crosses involving ten ecogeographically and genetically diverse linseed (*Linum usitatissimum* L.) cultivars in the F_2 generation over three locations. The general combining ability (GCA) and specific combining ability (SCA) mean squares were significant at all three locations for all traits. Combined analysis over locations showed the same trend of significance. The ratio of GCA to SCA mean squares was significant for all the traits in individual location analysis as well as in combined analysis. This indicated the predominant role of additive gene effects in the inheritance of these characters. The GCA mean squares were several times larger than SCA mean squares for all the traits, indicating the presence of considerable magnitude of additive genetic variance and the additive × additive components of the epistatic variance. Consequently, effective selection should be possible within these F_2 populations for all characters. Significant genotype-location and GCA-location interactions indicated that more than one test location is required to obtain reliable information. The inexpensive and reliable procedure used for making the choice of parents was the determination of breeding values of the parents on the relative performance of their F_2 progeny bulks.

Key words: Plant breeding – Quantitative genetics

Introduction

Successful breeding programmes result from maximum assembly of favourable genes. It is necessary to have knowledge of the genetics of the population (s) being handled by the breeder before effective breeding programmes can be developed. The breeder, therefore, needs methods which can provide reliable information about the nature of gene action present in his material.

Investigators are often compelled to use lower plant densities than those used in commercial production and to limit testing to one location. Studies of combining ability may be facilitated by testing in the F_2 generation, in which there is usually ample seed, if F_2 performance is closely related to F_1 performance. Diallel crosses have been used extensively to determine the combining ability of parents (in F_1 and F_2 generations) but very limited information is available on the effects of different environments on the magnitude of general and specific combining ability and their interactions with environments. Objectives of our investigations were to make diallel crosses among linseed (*Linum usitatissimum* L.) parents and to study subsequent F_2 generations over three environments.

Materials and Methods

Ten genetically diverse parental genotypes were crossed in a diallel mating design, excluding reciprocals. These included seven Indo-gangetic types (R-17, Mukta, Neelum, T 397, T 603, K_2 and NPRR-9), two Peninsular types (S-36 and 46-10), and one exotic type (EC 1387). The parents and F_1 generation were studied during the winter in 1978 at the Agricultural Research Station, Badnapur. The combining ability analysis in the F_1, generation was reported previously (Patil 1980).

In the F_2 generation, evaluations were made in three environments (locations): Research Farm of the Botany Department, Marathwada Agricultural University, Parbhani; Agricultural Research Station, Badnapur, and Sorghum Research Station, Parbhani. The soils at the Botany Department Farm and Agricultural Research Station, Badnapur were deep black cotton soil whereas at the Sorghum Research Station the soil was saline. The experiment at the Agricultural Research Station, Badnapur, was irrigated about 35 days after sowing.

Experimental design was a randomized complete block with three replications. Each F_2 progeny included four rows, whereas each parent included one row. Row length was 3 m and the plants

* Part of the thesis submitted by the senior author in partial fulfillment of the requirements for the Ph. D. degree of the Marathwada Agricultural University, Parbhani, 431 402, India

0040-5752/81/0060/0339/$ 1.00

in each row were spaced 15 cm with a between row distance of 30 cm. Data collected from each row on an individual plant basis were subsequently reduced to progeny means for statistical analysis. The combining ability analysis for each location was carried out following Model 1 and Method 2 described by Griffing (1956). Combined analysis over locations for combining ability and their interactions with locations for Model 1 Method 2 was conducted by the method described by Singh (1973).

Results and Discussion

The combining ability mean squares for the five characters for each individual location are presented in Table 1 and the analysis of variance for combining ability combined over three locations is presented in Table 2. General combining ability (GCA) and specific combining ability (SCA) mean squares for yield and its component traits (viz., number of tillers per plant, number of capsules per plant, 1000 seed wt (g), yield per plant, and days to 50% flowering) were significant for each location. The ratio of GCA to SCA mean squares was significant for all characters for all locations, indicating the predominance of additive gene effects in the genetic control of these traits. These results were similar to those obtained earlier from the F_1 data (Patil 1980). Anand and Murty (1969) in linseed and Shehata and Comstock (1971) in flax also reported substantial additive gene effects for different characters.

Combined analysis of variance of combining ability over three locations revealed that GCA and SCA mean squares were significant for all characters. Although SCA mean squares were significant for all characters, most of the total genetic variability for each character was associated with GCA as shown by the greater magnitude of GCA mean squares. General combining ability mean

Table 1. Pertinent portion of the analysis of variance for combining ability for yield and components of yield in the F_2 generation at three locations

Source of variation	Location	d.f.	No. of tillers/ plant	No. of capsules/ plant	1000 seed wt (g)	Yield/ plant (g)	Days to 50% flowering
GCA	L_1	9	5.08[b]	800.18[b]	1.10[b]	0.95[b]	181.07[b]
	L_2		6.68[b]	952.78[b]	1.38[b]	1.46[b]	181.81[b]
	L_3		2.21[b]	79.77[b]	0.48[b]	0.26[b]	91.77[b]
SCA	L_1	45	1.01[b]	43.56[b]	0.13[b]	0.10[b]	9.77[b]
	L_2		1.14[b]	45.26[b]	0.17[b]	0.13[b]	11.57[b]
	L_3		0.44[b]	14.69[b]	0.27[b]	0.05[a]	4.26[b]
Error	L_1	108	0.47[a]	40.71	0.14	0.07	2.68
	L_2		0.58	42.84	0.18	0.09	0.84
	L_3		0.37	14.43	0.09	0.02	0.39
GCA/SCA	L_1		5.03	18.37	8.46	9.50	18.53
	L_2		5.86	21.05	8.11	11.23	15.71
	L_3		5.02	5.43	1.77	5.20	21.54

[a,b] Significant at p = 0.05 and 0.01, respectively

Table 2. Pertinent portion of the analysis of variance for combining ability for yield and components of yield combined over three locations

Source of variation	d.f.	No. of tillers/ plant	No. of capsules/ plant	1000 seed wt (g)	Yield/ plant (g)	Days to 50% flowering
GCA	9	12.94[b]	1468.94[b]	1.82[b]	2.25[b]	437.66[b]
SCA	45	1.89[b]	58.45[b]	0.25[b]	0.19[b]	19.51[b]
Locations	2	84.09	267.78	2.83	55.27	474.70
GCA × Location	18	0.52	181.90[b]	0.57[b]	0.22[b]	8.49[b]
SCA × Location	90	0.35	22.53	0.16[b]	0.05	3.05[b]
Error	324	0.47	32.65	0.12	0.06	1.30
GCA/SCA		6.85	25.13	7.28	11.84	22.43

[b] Significant at p = 0.01

Table 3. Estimates of general combining ability effects for yield and yield components in the F_2 generation at three locations

Sr. No.	Parents	No. of tillers/plant				No. of capsules/plant			
		L_1	L_2	L_3	Combined	L_1	L_2	L_3	Combined
1	K-2	0.166	0.524[b]	0.239	0.310[b]	–5.584[b]	–6.251[b]	–1.972	–4.602[b]
2	R-17	0.098	0.306	0.053	0.153	14.284[b]	18.622[b]	5.486[b]	12.797[b]
3	Mukta	–0.208	–0.148	–0.361[b]	–0.239[a]	–4.668[b]	–4.604[a]	–2.063[a]	–3.772[b]
4	T-603	–0.702[b]	–0.879[b]	–0.584[b]	–0.722[b]	–1.857	–1.885	–1.426	–1.723
5	Neelum	–0.736[b]	–0.916[b]	–0.456[b]	–0.702[b]	–6.618[b]	–6.666[b]	–0.705	–4.193[b]
6	EC-1387	1.060[b]	1.102[b]	0.742[b]	0.968[b]	–8.312[b]	–8.701[b]	–0.101	–5.705[b]
7	T-397	–0.868[b]	–1.080[b]	–0.355[b]	–0.768[b]	1.682	1.437	0.989	1.369
8	NPRR-9	0.016	0.028	0.188	0.077	–6.705[b]	–6.512[b]	–3.437[b]	–0.552[b]
9	46-10	0.846[b]	0.708[b]	0.448[b]	0.667[b]	5.601	3.196	–0.607	2.730[b]
10	S-36	0.329	0.355	0.086	0.257[b]	12.158[b]	11.364[b]	2.426[a]	8.649[b]
S.E.	(gi) ±	0.187	0.207	0.164	0.104	1.747	1.802	1.040	0.903
S.E.	(gi-gj) ±	0.279	0.311	0.246	0.161	2.604	2.772	1.550	1.346

Sr. No.		1000 Seed Weight				Yield/plant				Days to 50% flowering			
		L_1	L_2	L_3	Combined	L_1	L_2	L_3	Combined	L_1	L_2	L_3	Combined
1		–0.007	–0.036	–0.119	–0.054	–0.261[b]	–0.238[b]	–0.076[a]	–0.192[b]	2.728[b]	1.494[b]	1.711[b]	1.978[b]
2		0.141	0.187[a]	–0.282[a]	0.015	0.556[b]	0.766[b]	0.252[b]	0.525[b]	–2.939[b]	–3.089[b]	–2.428[b]	–2.818[b]
3		0.123	0.203[a]	0.242[a]	0.189[a]	0.013	0.010	0.074[a]	0.032	–0.133	–0.311	–0.733	–0.393
4		0.050	0.016	0.123	0.063	–0.138	–0.085	–0.021	–0.081[a]	–0.106[a]	–4.200[b]	–2.067[b]	–3.457[b]
5		0.546	0.516[b]	0.023	0.361[b]	–0.110	–0.090	0.179	–0.007	1.839[b]	1.744[b]	1.767[b]	1.783[b]
6		–0.539[b]	–0.692[b]	–0.170	–0.467[b]	–0.308[b]	–0.457[b]	–0.225[b]	–0.330[b]	8.589[b]	8.439[b]	5.794[b]	7.607[b]
7		–0.224[b]	–0.255[b]	–0.019	–0.166[b]	0.069	0.060	–0.004	0.042	–3.661[b]	–3.783[b]	–1.956[b]	–3.133[b]
8		–0.340[b]	–0.290[b]	0.252[a]	–0.126[a]	–0.198[a]	–0.237[b]	–0.118[b]	–0.184[b]	1.839[b]	3.328[b]	2.267[b]	2.478[b]
9		0.093	0.120	0.203	0.139[a]	0.034	0.124	0.148	0.120[b]	–1.717[b]	–1.256[b]	–2.039[b]	–1.670[b]
10		0.158	0.231[a]	–0.252[b]	0.046[a]	0.412[b]	0.395[b]	0.087[b]	0.298[b]	–2.439[b]	–2.367[b]	–2.317[b]	–2.374[b]
S.E.	(gi) ±	0.077	0.080	0.118	0.181	0.070	0.080	0.031	0.031	0.448	0.250	0.270	0.178
S.E.	(gi-gj) ±	0.118	0.122	0.176	0.077	0.109	0.122	0.054	0.054	0.669	0.374	0.254	0.268

[a,b] Significant at P = 0.05 and P = 0.01, respectively

squares were several times greater than SCA mean squares for all traits. Therefore, the magnitude of additive genetic effects and the additive × additive components of the epistatic variance, if present, must be considerable for each character. Consequently, effective selection should be possible within these F_2 and subsequent populations for all the characters. Both GCA and SCA showed significant interaction with locations for 1000 seed weight and days to 50% flowering. The GCA-location interaction was significant for number of capsules per plant and yield, but nonsignificant for number of tillers per plant. The interactions were greater for GCA. Similar results have been reported in different crop species (Matzinger et al. 1959; Liang 1967; Paroda and Joshi 1970). This suggests that the additive effects were no more stable over environments than the dominance effects. However, Shehata and Comstock (1971) reported differential interactions of GCA – location and SCA – location for seed yield and its components under different plant densities in F_2 flax populations.

The parents generally showed a similar pattern of general combining ability effects at all locations (Table 3). Parents R-17, S-36, and 46-10 were good general combiners for yield and for number of capsules per plant. Parents EC 1387, 46-10, and K_2 were good general combiners for number of tillers per plant, whereas, Neelum and Mukta were good combining parents for 1000 grain weight. Significant and negative GCA effects for days to 50% flowering were observed in six different parents. These results are in agreement with those reported earlier from F_1 data in this material (Patil 1980). The per se performance of parents and GCA effects as expressed in the performance of their F_2 progenies is shown in Table 4. The strong association between GCA effects from the F_1 and F_2 generations for the five characters studied, suggests that F_2 populations can effectively be used for the identification of good general combiners. Bhullar et al. (1979) reported that F_2/F_3 generations gave better predications than those from the F_1 generation. The repeatability of GCA estimates over environments and the availability of better estimates from F_2 generations indicated that it may be advisable to study combining ability in linseed in the F_2 generation rather than F_1 generation. The significant genotype-location and combining ability mean square-location interactions indicated that more than one test location is required to get reliable information.

The results of this study support earlier work which showed that in autogamous crops, additive gene effects and additive × additive epistasis can be exploited in developing promising pure lines because these components are fixable. Thus, selection of parents on the basis of GCA effects, as suggested by Jensen (1970) and Redden and Jensen (1974) in cereal breeding, may also be promising in linseed breeding programmes. Further, this study indicates that an inexpensive and reliable procedure for making a choice of

Table 4. Mean performance of parents and their F_2 progenies combined over three locations

Progenies	No. of tillers/plant	No. of capsules/plant	1000 seed wt. (g)	Yield/plant (g)	Days to 50% flowering
1	2	3	4	5	6
Parents					
K_2 (1)	7.54	41.62	7.07	1.74	63.56
R-17 (2)	9.60	89.36	6.79	2.95	55.00
Mukta (3)	7.62	49.71	7.38	2.21	58.89
T-603 (4)	8.10	53.21	7.11	1.79	51.78
Neelam (5)	6.59	47.00	7.36	2.15	65.44
EC-1387 (6)	8.35	37.17	6.10	1.18	72.33
T-397 (7)	6.15	60.36	6.95	2.49	53.89
NPRR-9 (8)	7.09	46.22	6.39	1.72	62.00
46-10 (9)	8.96	63.03	7.09	1.89	56.78
S-36 (10)	8.66	64.89	7.18	2.91	58.44
F_2 progenies					
1 × 2	8.59	62.62	6.95	2.67	58.44
1 × 3	7.47	49.07	7.30	1.94	59.89
1 × 4	7.31	56.21	6.83	2.22	52.78
1 × 5	7.62	51.61	6.40	2.08	61.33
1 × 6	9.28	40.68	5.78	1.38	67.44
1 × 7	7.92	52.08	6.89	1.93	55.67
1 × 8	8.45	50.40	6.81	1.99	61.33
1 × 9	8.68	62.67	7.32	2.39	54.89
1 × 10	9.36	56.80	7.26	1.98	58.67
2 × 3	6.89	61.87	7.09	2.74	51.89
2 × 4	6.28	68.61	6.78	2.72	51.22
2 × 5	7.70	60.98	7.60	3.02	56.33
2 × 6	9.97	70.43	6.78	2.65	58.56
2 × 7	6.36	67.17	6.56	2.71	50.56
2 × 8	7.43	56.41	7.11	2.47	56.89
2 × 9	8.85	79.33	7.06	2.33	53.44
2 × 10	9.62	78.04	7.00	3.45	52.67
3 × 4	6.26	49.23	7.32	2.20	54.22
3 × 5	6.75	48.97	7.55	2.12	58.22
3 × 6	8.76	53.85	6.77	2.65	64.33
3 × 7	7.85	55.57	6.66	2.24	55.67
3 × 8	7.58	42.44	6.91	1.72	62.11
3 × 9	8.18	52.64	7.02	1.90	54.67
3 × 10	8.20	62.30	7.21	2.80	50.33
4 × 5	5.68	48.41	7.29	2.06	55.11
4 × 6	9.12	47.42	6.91	1.81	65.67
4 × 7	5.56	57.35	6.37	2.24	48.56
4 × 8	8.07	47.12	7.02	1.96	62.89
4 × 9	6.68	49.90	7.36	1.91	50.56
4 × 10	6.24	69.26	6.98	2.68	47.78
5 × 6	7.25	46.20	6.95	1.86	67.33
5 × 7	6.24	50.76	7.89	2.21	55.89
5 × 8	6.59	50.93	7.19	1.98	56.56
5 × 9	9.44	61.88	7.76	2.41	57.56
5 × 10	7.17	56.87	7.31	2.25	56.00
6 × 7	8.29	58.85	6.26	1.89	61.33
6 × 8	9.32	48.10	6.46	1.84	70.00
6 × 9	9.62	53.19	6.29	1.93	64.44
6 × 10	9.36	59.10	6.30	2.02	61.33
7 × 8	7.33	53.49	6.42	2.35	57.00
7 × 9	8.11	53.83	6.86	1.86	53.66

Table 4. (continued)

Progenies	No. of tillers/ plant	No. of capsules/plant	1000 seed wt. (g)	Yield/plant (g)	Days to 50% flowering
1	2	3	4	5	6
F_2 progenies					
7 × 10	6.89	67.23	6.54	2.46	50.22
8 × 9	9.32	55.90	7.15	2.28	56.22
8 × 10	8.72	56.76	6.95	2.12	56.56
9 × 10	8.27	68.28	6.99	2.35	54.89
S.E. ±	0.562	4.666	0.284	0.200	0.933

parents is the determination of the breeding value of the parents by the relative performance of their F_2 generation progeny bulks.

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Received April 15, 1980
Communicated by A. Kahler

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Book Reviews

Gunther, F.A.; Davies Gunther, J. (eds.): Residue Reviews. Residues of Pesticides and other Contaminants in the Total Environments, Ed. Vol. 74, 75, 76. Berlin-Heidelberg-New York: Springer 1980. 138/189/218 pp. 23/50/30 figs. 33/35/24 tabs. Hard bound DM 49.–/54.–/54.–.

Vol. 74 of Residue Reviews contains 3 comprehensive papers, 'Molybdenum in the environment', by W.M. Jarrell, A.L. Page and A.A. Elseewi dealing with the following topics: production and uses of Mo; natural occurences in minerals, rocks, soils and waters; Mo in plant, animal and human nutrition, its essentiality, toxicity and factors influencing Mo uptake by plants; sources of Mo enrichment in the environment, soils, waters, atmosphere and management of high-Mo wastes. In the review 'Fate of polychlorinated biphenyls (PCBs) in soil-plant systems' by D. Pal, J.B. Weber and M.R. Overcash the following aspects are given: chemical structure, production and use, distribution, toxicity and historical perspective; microbial decomposition and stability in soils including rates and metabolites; photodecomposition, volatilization, soil adsorption, leaching and run-off, including water solubilities and octanol partition coefficients; plant uptake, effects and metabolism of PCBs in plants and factors affecting the behavior in soil-plant systems. Analytical methods for dealing with special fungicides are reviewed in brief in the paper 'Fungicides for gray-mold control: A critical review of analytical methods for formulation and residue analysis' by A. Del Re, P. Fontana, G.F. Marchini et al. TLC, spectrophotometry, HPLC, GLC, other techniques and, in some cases, polarography and paper chromatography are discussed for the following compounds: Captan, Folpet, Captafol and Chlorothalonil; Benomyl, MBC, Thiophanate, Thiophanate-methyl and Thiabendazole; Dichlorfluanid and Tolylfluanid; Carboxin and Oxycarboxin; 3,5-Dichloroaniline derivatives; Sclex, Dimethachlon, Vinclozolin and Sumisclex; Dichlone; Tridemorph; Pyrazophos; Pyridinitrile; sec-Butylamine; Triforine.

Vol. 75 of Residue Reviews is dedicated to the Research Conference and Workshop on minimizing occupational exposure to pesticides, held on February 19-21, 1980 at Tucson, Arizona, USA. Fourteen papers and summaries and recommendations of the conference are given (Chairman F.A. Gunther, Vice-Chariman G.W.