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Performance of three-way crosses in groundnut

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ABSTRACT

A set of 3-way crosses made in groundnut (*Arachis hypogaea* Linn.) to a line × tester design using 6 single crosses as female and 10 diverse genotypes as male parents were evaluated for early-stage characters and yield components. The variance of general combining ability was higher than that of specific combining ability for yield components while the reverse was true for early-stage characters. Of the 52 3-way crosses, 8 failed to set seed and 8 were heterotic for pod and seed yield or test weight or shelling percentage. Plants transgressing the better parent for yield components up to 370% on the average were recovered in the F_2 generation. Crosses that produced F_2 selections having more pods than 'Robut 33-1', a national check, were often found to be heterotic in the F_1. The general combining ability of parents based on early-stage characters was as good as that based on all the characters. Desired parents could hence be chosen on the basis of an evaluation of 3-way or multiple crosses of higher order in the same season.

Most of the attempts at breeding for yield initiate from single crosses in groundnut (*Arachis hypogaea* Linn.). But there is a need to broaden the initial genetic base when the progress so made in self-pollinated crops like wheat (Fajersson, 1963) and triticale (Zillinsky and Borlaug, 1971) is noted.

In the process of widening the initial genetic base, 3-way crosses are the next logical step to 2-way cross. This paper reports therefore the performance of 3-way crosses based on a number of characters spanning the entire growth phase of groundnut.

MATERIALS AND METHODS

Two sets of diallel crosses involving 15 and 10 parents were studied in detail earlier (Arunachalam *et al.*, 1982, 1984). The parents of the 15-parent diallel were divergent for yield components and those of the 10-parent diallel for resistance to rust and leaf spots, Hence, 6 crosses from the 15 × 15 diallel cross were chosen as female parents and 10 parents of the 10 × 10 diallel cross as males. The single crosses used as females were made afresh and mated to the 10 male parents in a line × tester design. Eight crosses failed to set seed, giving finally 52 crosses for evaluation (Table 1).

The F_1 generation of the 3-way crosses was raised in a completely randomized-block design with 2 replications at Rajendranagar, Hyderabad during the rainy season of 1980. Observations were recorded on the following characters :

Early phase : Flowering time (FT); seedling height (SH) in cm; number of leaves (NL); leaf area (LA) in dm^2; and specific leaf weight (SL).

Yield components : Weight of mature pods (PW); weight of kernels from mature pods (KW); recovery percentage (RP) = 100 × number of mature pods/[number of (mature pods + immature pods + aerial pegs)]; 100-kernel weight (TW); and shelling percentage (SP).

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Table 1. Information on parents of three-way crosses

Parent	15×15 diallel cross			3-way cross	Parent	10×10 diallel cross	3-way cross
	Female gca	Male gca	sca	gca		gca	gca
Female					*Male*		
'Argentine' × 'MH 2'	H	L	H	H	'Chico'	L	H
'GAUG 1' × 'MK 374'	L	H	L	H	'Chalimbana'	H	L
'M 13' × 'NC Ac 1107'	H	H	H	L	'EC 76446 (292)'	H	L
'MH 2' × 'NC Ac 2731'	L	L	L	L	'Makulu Red'	L	L
'NC Ac 1107' × 'MH 2'	H	L	L	L	'Manipintar'	H	L
'Robut 33-1' × 'GAUG 1'	H	L	L	L	'PI 259747'	L	H
					'PI 298115'	H	L
					'NC Ac 17090'	L	H
					'87/4/7 (2)'	L	L
					'Robut 33-1'	H	H

The crop suffered due to severe incidence of pests and diseases. Though attempts were initially made to record data on random samples of 10 plants, plants died before harvest resulting in unequal sample sizes. Individual plant data were analysed following Kempthorne (1957) and Arunachalam (1974). Least square estimates of variances due to general combining ability (gca) and specific combining ability (sca) were obtained. The gca status of each parent and the sca status of each cross were classified to be either high (H) or low (L) on a specific set of characters following the procedures outlined by Arunachalam and Bandyopadhyay (1979).

Heterosis was computed as the percentage improvement over better parent only when the F_1 mean exceeded the better parent mean significantly in the desired direction as tested by the t-test. Since parents were not grown along with the 3-way crosses, parental means were estimated as marginal means. If the parent i was involved with parent j (j = 1, - - - k), estimate of i^{th} parental mean

$$m_i = \frac{1}{k}\sum_{j=1}^{k} \frac{Z_{ij}}{n_{ij}},$$

$$Z_{ij} = \sum_{l=1}^{n_{ij}} X_l \text{ where } X_l = \text{value}$$

of the character for the l^{th} plant and n_{ij} = number of plants on which observations were recorded for the cross, i × j. To test the difference between mean of cross i × j with m_i,

$$d = \bar{X}_{ij} - m_i \text{ where } \bar{X}_{ij} = \frac{1}{n_{ij}}\sum_{l=1}^{n_{ij}} X_l$$

It would be easy to derive the variance of d as

$$v_d = \frac{\sigma^2}{k^2}\left[\frac{1}{n_{i1}} + \frac{1}{n_{i2}} + - - \frac{(1-k)^2}{n_{ii}} + - - \frac{1}{n_{ik}}\right]$$

where σ^2 is the value of error mean square in the ANOVA of line × tester design. We note that the cross i × i in the line × tester design is between female i and a different male i. The statistic, $T = d/\sqrt{v_d}$ would follow a t-distribution with error df.

RESULTS

Four of the 6 single crosses used as

female parents of the 3-way crosses were initially chosen to be H × L crosses based on the gca status given by the 2-way cross; one each was H × H and L × L cross. At 3-way cross level, only 2 parents ('Argentine' × 'MH 2') and ('GAUG 1' × 'MK 374') retained high gca (Table 1). In a similar way, the male parents were chosen initially to represent high and low gca status (given by 2-way cross) in equal frequencies. But at the 3-way cross level, all parents changed their status except 'Makulu Red', '87/4/7(2)' and 'Robut 33-1', the former 2 retaining their low and the latter its high gca status. Thus it was clear that the gca status of a parent should be defined only in relation to the particular set of crosses in which it was a parent.

The ANOVA of combining ability indicated significant differences among female and male parents for all the component characters; the female × male interaction was significant for early-stage characters and recovery percentage only among yield components (Table 2). The estimate of variance (gca) was lower than that of variance (sca) for all early-stage characters except flowering time and mature pods, which seem to be controlled by predominant non-additive gene action. On the other hand, the direct yield components were under the influence of additive gene action. This would imply that direct selection for yield components was feasible.

Only 8 of the 52 crosses were heterotic for one or more yield components (Table 3). ('Argentine' × 'MH 2') × 'PI 259747', ('GAUG 1' × 'MK 374') × 'Chico' and ('MH 2' × 'NC Ac 2731') × 'Robut 33-1' were heterotic for pod and seed yield to the extent of 80 to 150%. They registered an average improvement of 167 to 370% over the better parent in the F_2. The other 5 crosses that were heterotic either for 100-kernal weight or shelling percentage to lower magnitudes compared with the earlier 3 crosses registered also low magnitudes of improvement over the better parent in the F_2 (Table 3). In all the crosses, the sca effect was positive, significant and high. The parents ('Argentine' × 'MH 2') and 'PI 259747' showed high and significant gca effects, in addition.

The percentage of crosses that were heterotic at least for 1 character produced by any female or male parent was not very high (Table 4). While all the crosses

Table 2. ANOVA of combining ability in 3-way crosses for 11 characters

Source	Crosses	Female	Male	Female × Male	Error	Variance (gca)	Variance (sca)
df	51	5	9	37	330		
Seedling height	20.5*	39.3*	52.3*	10.3*	5.8	1.6	2.9
Number of leaves	164.4*	286.2*	541.7*	56.4*	47.7	13.8	50.3
Leaf area	53.1*	115.6*	145.8*	22.1*	10.8	5.1	12.5
Specific leaf weight	0.35*	0.87*	0.47*	0.26*	0 07	0.03	0.04
Flowering time	62.1*	177.8*	155.1*	23.8*	13.0	8.0	2.5
Recovery %	509.9*	1397.9*	1111.9*	243.5*	165.9	58.9	30.3
Pod weight	49.1*	101.8*	75.8*	35.5	33.9	3 3	1.5
Kernel weight	15.5*	30.4*	25.0*	11.1	10.6	1.0	0.3
100-kernel weight	134.7*	311.8*	204.3*	93.8	76.5	10.8	Negative estimate
Shelling %	253.0*	309.8	444.4*	198.8	146.6	6.7	Negative estimate

*P = 0.05.

Table 3. General and specific combining ability, magnitudes of heterosis and F_1 improvement over better parent realized for yield components in 3-way crosses

Cross	Pod weight				Improvement over better parent
	Female gca	Male gca	Sca	Heterosis	
('Argentine' × 'MH 2') × 'PI 259747'	3.02*	2.72*	9.78*	148	167
('GAUG 1' × 'MK 374') × 'Chico'	—0.29	0.90	6.71*	105	180
('MH 2' × 'NC Ac 2731') × 'Robut 33-1'	—0.07	1.17	5.21*	81	300

Cross	Kernel weight				Improvement over better parent
	Female gca	Male gca	Sca	Heterosis	
('Argentine' × 'MH 2') × 'PI 259747'	1.53*	1.22*	4.80*	145	202
('GAUG 1' × 'MK 374') × 'Chico'	0.07	0.88	4.40*	131	243
('MH 2' × 'NC Ac 2731') × 'Robut 33-1'	—0.05	0.84	3.11*	92	370

Cross	100-kernel weight				Improvement over better parent
	Female gca	Male gca	Sca	Heterosis	
('MH 2' × 'NC Ac 2731') × 'Manipintar'	1.16	1.88	5.94*	31	44
('MH 2' × 'NC Ac 2731') × '37/4/7 (2)'	1.16	1.25	12.73*	62	39
('NC Ac 1107' × 'MH 2') × 'Chalimbana'	1.69	—1.82	6.50*	20	49

Cross	Shelling %				Improvement over better parent
	Female gca	Male gca	Sca	Heterosis	
('NC Ac 1107' × 'MH 2') × 'Makulu Red'	—2.34	2.40	11.65*	20	23
('Robut 33-1' × 'GAUG 1') × 'PI 298115'	—0.87	1.94	9.87*	47	39

*P = 0.05

Table 4. Percentage of 3-way crosses (produced by various parents) that were heterotic at least for one character and those that gave selections in F_3

Parent	Number of crosses	Percentage of crosses heterotic for at least one character	Percentage of crosses that gave selections in F_3
Female			
'Argentine' × 'MH 2'	8	38	100
'GAUG 1' × 'MK 374'	8	50	63
'M 13' × 'NC Ac 1107'	8	25	88
'MH 2' × 'NC Ac 2731'	9	56	89
'NC Ac 1107' × 'MH 2'	9	33	75
'Robut 33-1' × 'GAUG 1'	10	30	50
Male			
'Chico'	6	67	67
'Chalimbana'	5	60	100
'EC 76446 (292)'	4	0	75
'Makulu Red'	6	33	83
'Manipintar'	6	33	83
'PI 259747'	5	60	60
'PI 298115'	5	40	100
'NC Ac 17090'	6	17	67
'87/4/7 (2)'	5	40	20
'Robut 33-1'	4	50	75

involving the female parent ('Argentine' × 'MH 2') produced F_3 families that gave selections superior to the check in pod number, a large proportion of crosses produced by the parents ('M 13' × 'NC Ac 1107') and ('MH 2' × 'NC Ac 2731') did so. Such results were also recorded by crosses involving the male parents, 'Chico', 'PI 298115', 'Makulu Red' and 'Manipintar'. It would seem that most of the 3-way crosses produced F_3 families in which selections having more pods per plant could be recovered. It was observed that 17 of the 20 crosses (= 85%) that were heterotic for at least one character produced F_3 families in which selection for pod number could be made. Such F_3 families were observed only in 22 of the 32(= 69%) non-heterotic crosses.

The gca status of each parent given by all the 11 charaters enumerated earlier (O) was compared with that given by early-stage characters (E) or yield components (Y) alone (Table 5). The status given by E agreed with that given by O for all the female parents. Such agreement was observed for 6 out of 10 male parents. When the status given by Y was compared with that given by O, the proportion of agreement was 5/6 for female and 9/10 for male parents.

DISCUSSION

The results have shown that the gca of a parent is variable and mostly determined by the nature of the other parents with which it is combined and by the level of cross, 2-way, 3-way and so on. Hence attempts to develop high-yielding lines should profitably be made using the F_1s just tested. In other words, it may not be rewarding to follow the usual process of identifying good combining parents on one set of crosses and using them with

Table 5. Comparison of the gca status given by early-stage characters, yield components and all characters

Parent	Early-stage characters	Yield components	All characters
Female			
'Argentine' × 'MH 2'	H	H	H
'GAUG 1' × 'MK 374'	H	H	H
'M 13' × 'NC Ac 1107'	L	L	L
'MH 2' × 'NC Ac 2731'	L	L	L
'NC Ac 1107' × 'MH 2'	L	L	L
'Robut 33-1' × 'GAUG 1'	L	@	L
Male			
'Chico'	L	H	H
'Chalimbana'	L	L	L
'EC 76446 (272)'	H	L	L
'Makulu Red'	L	L	L
'Manipintar'	L	L	L
'PI 259747'	H	H	H
'PI 298115'	H	L	L
'NC Ac 17090'	H	H	H
'87/4/7 (2)'	L	H	L
'Robut 33-1'	L	H	H

H = High; L = Low; @ = Status not assignable as all the gca effects for yield components were non-significant.

other parents at a later stage to obtain combinations with good yield potential.

The type of gene action controlling yield components were similarly found to be dependent on the material used for inferring it. In the 3-way crosses we studied, additive gene action was predominant for yield components while varying results were reported in literature. Both gca and sca variances were found to be significant for yield components in various material including the F_2 by Wynne *et al.* (1975), Garet (1976) and Layrisse *et al.* (1980). Some of them reported that the magnitude of the variance due to gca was higher than that due to sca, inferring additive gene action. On the other hand, Isleib *et al.* (1978) and Mohammed *et al.* (1978) reported the presence of epistatic effects for most of the yield components. A useful strategy would thus favour immediate use of the genetic information and the material for planning the next phase of breeding.

The extent of segregation in the F_2 was hence examined. Crosses that were heterotic in the F_1 for both the yield components, pod and seed yields were found to provide segregants transgressing the better parent by up to 370% while those that were heterotic for a single yield component provided also segregants but exceeding the better parent only up to 49% (Table 3). Further, a higher frequency of crosses that was heterotic for at least one character was found to produce F_3 families from which selections exceeding the national check, 'Robut 33-1', in pod number could be obtained, when compared with non-heterotic crosses. These results confirm the earlier findings that, when early-generation selection was preferred, heterotic crosses should be given the first preference (Pungle, 1983; Arunachalam *et al.*, 1983).

Rust-resistant parents 'PI 259747' and 'PI 298115' were identified along with the earliest-maturing 'Chico' and the national check, 'Robut 33-1' to provide 3-way crosses in combination with the single-cross female parents 'GAUG 1' × 'MK 374', 'Robut 33-1' × 'GAUG 1', 'MH 2' × 'NC Ac 2731' and 'Argentine' × 'MH 2', which could usefully be searched for high-yielding derivatives in further generations.

Further, the gca status based on early-stage characters identified the status based on all the characters in most of the parents, a result relevant to making desirable multiple crosses. When a heterozygote or a single cross needs to be used as a parent of a multiple cross, it would be possible to select for their high or low gca based on early-stage characters recorded before flowering. Without losing a season, the desired parents can be chosen and desired multiple crosses made. This technique will provide a viable tool to generate complex multiple crosses as a broad initial genetic base for further breeding.

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