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SINGLE AND THREE-WAY CROSSES FOR GENERATING COMPOSITE POPULATIONS IN RAPESEED

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THE existing levels of seed and oil yield of rapeseed, *Brassica campestris* L. var. brown sarson, in India needs improvement. The lack of a well-defined and broad genetical base is one of the reasons for the slow progress. To ameliorate the situation, two approaches are feasible—(a) strengthening the genetic base of the breeding material taking into account the degree of self-incompatibility in the material, (b) plugging the existing genetic variability on to efficient systems of mating, to realise transgressive derivatives. These approaches are, however, complementary. The former can be a long time process, but the latter can be attempted after an efficient evaluation of the genetic variability. A system of mating can be recommended as a means of obtaining higher rate of yield improvement, if, on an objective evaluation of the parents and progeny, it is possible to identify methods for advancing yield with a fair amount of repeatability.

The genetic variability generated by disruptive (DR) and directional (DI) selection in *Brassica campestris* var. brown sarson offered scope to test these objectives. High yielding composite populations could be derived in this process. The result of those investigations undertaken during 1974 to 1979 at the Indian Agricultural Research Institute, New Delhi, are reported and discussed in this paper.

MATERIALS AND METHODS

Genetically variable lines generated by disruptive (DR) and directional (DI) selection from self-compatible (SC) and self-incompatible (SI) populations of *Brassica campestris* and some of their productive variants (P) in addition to the original (O) counterparts, described in Arunachalam and Katiyar (1978), formed the material. Two systems of mating, MAS 1 and MAS 2, were employed both based on line \times tester design. In MAS 1, 2 lines each from each of the five base populations that underwent disruptive selection were chosen as female parents and mated to 6 lines, chosen from the five base populations that underwent directional selection, as male parents. In MAS 2, some lines were identified from the base populations that were subjected to DR and typical plants termed, 'Original' were mated to productive variants intra-line. 11 such F_1 's were mated to each of 10 elite varieties to provide 110 three-way crosses (Table 1; Arunachalam and Katiyar, 1978).

These crosses were raised in a randomised blocks design in two replications. Data were collected on random samples of five plants on plant height, number of primary branches, number of secondary branches, length of main axis, number of siliquae on the main axis, length of siliquae and number of seeds per siliquae. The last two characters were further based on samples of five siliquae per plant.

General combining ability (GCA) and specific combining ability (SCA) effects were calculated after analysing the data on the line \times tester design for known sources of variation. Data on means of parents

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for various characters were obtained from experiments planted contiguous to the F_1 and were used to calculate heterosis over the superior parent, only when the mean of the hybrid differed significantly from that of the superior parent. The parents and crosses were classified into high (H) and low (L) categories on the basis of GCA and SCA over all component characters, following the methods outlined in Arunachalam and Bandyopadhyay (1979).

Three crosses, varying in levels of SCA and parental GCA and self-incompatibility, were identified from each of MAS1 and MAS 2. Biparental matings varying from 25 to 30 in number were effected during 1975. The progeny in each of the crosses was composited as populations in initial phase during 1976. Those six populations were carried forward along with their bulk counterparts in successive years by intermating or isolation upto their fourth phase, except the second phase where it was carried forward by open pollination. The promising populations were evaluated in isolation at their fourth phase in a few locations (Table 6).

TABLE 1

Parents, their compatibility and combining ability status

System	Female parents	CS	GS	Male parents	CS	GS
MAS 1 DR	KL 17-1	SI	H	DI KT 07	SC	L
	KL 17-2	SI	H	IARI 117	SC	L
	KL 27-1	SI	L	ASLC	SI	L
	KL 27-2	SC	H	PBST-1	SC	H
	KT 05-1	SC	H	PBST-2	SC	L
	KT 05-2	SC	H	GBS 1	SI	H
	KT 07-1	SC	L			
	KT 07-2	SC	L			
	GBS 2-1	SC	H			
	GBS 2-2	SC	H			
MAS 2	KL 17 (P×O)-1	SI	H	PUKA	—	L
	KL 17 (O×P)-2	SI	H	DC 1	—	H
	KL 27 (O×P)	SI	L	I 84-63	—	H
	KT 05 (P×O)-1	SC	H	K 1	—	H
	KT 05 (P×O)-2	SC	H	COMP. III	—	L
	KT 05 (P×O)-3	SC	L	BSH 1	—	H
	KT 07 (O×P)-1	SC	H	BS 112	—	L
	KT 07 (P×O)-2	SC	L	BS 113	—	H
	KT 07 (P×O)-3	SC	H	BS 145	—	L
	GBS 2 (P×O)-1	SC	H	BS 182	—	H
GBS 2 (P×O)-2	SC	L				

CS=Compatibility status; GS=General combining ability status; KL=Kanpur Lotni; KT=Kanpur Tora 59; PSBT=Pusa BST; PUKA=Pusa Kalyani; O=Original; P=Productive variant; ASLC=Assam Local Collection; SC=Selfcompatible and SI=Selfincompatible.

RESULTS

As expected, it was found that the sources containing general combining ability (GCA) and specific combining ability (SCA) variance were significant for all the component characters under both the systems of mating. The covariances

of combining ability between any two characters estimated on the genetic model of line \times tester design (Arunachalam, 1976) showed that the SCA components were much higher in magnitude than those of the GCA (Table 2). The uneven environment and the need for a high sample size might be responsible for non-estimability of one of those components. Conflicting direction of the covariances of GCA for many character-pairs precluded concomitant improvement in yield components by direct selection. The positive covariance of GCA between primary (PB) and secondary branches (SB) was, however, encouraging.

TABLE 2

Estimates of covariances of combining ability for yield components

		PB	SB	LM	SM
PB	MAS 1	12.8 (@)	0.9	-5.6	-10.4
	MAS 2	10.4 (0.9)	5.7	4.4	10.5
SB	MAS 1	45.8	198.6 (30.3)	-17.9	-31.9
	MAS 2	53.3	712.1 (106.9)	60.0	49.3
LM	MAS 1	33.4	122.9	166.1 (31.5)	43.8
	MAS 2	-22.9	-94.0	220.9 (27.7)	61.2
SM	MAS 1	29.0	76.1	236.8	702.9 (11.1)
	MAS 2	-31.6	-5.5	78.4	72.4 (133.5)

@=Non-estimable; values above diagonal are cov (GCA); below diagonal, cov (SCA); In diagonals upper values are var (SCA); lower var (GCA); PB=Number of primary branches; SB=Number of secondary branches; LM=Length of main axis; SM=Number of siliquae on main axis.

An analysis of the overall GCA of the parents revealed that the two DR parental lines derived from the self-compatible (SC) base populations, 'Kanpur tora 5907 (KT 5907)' and one line derived from self-incompatible (SI) population 'Kanpur lotni 27' were the only low (L) combiners as female parents (Table 1). The parental line from 'KT 5907' derived from directional selection was a low combiner as a male parent also. In all, 7 out of 10 female and 2 out of 6 male parents of MAS 1 were high (H) general combiners while 7 out of 11 female and 6 out of 10 male parents of MAS 2 were so. No association between self-incompatibility status and GCA could be observed in both the systems. When

the overall SCA status of the crosses was examined, about 65% of the total crosses in MAS 1 and 40% in MAS 2 showed low SCA. Again self-incompatibility was not associated with production of crosses with high or low SCA.

One of the relevant questions that can be asked is, given a heterotic cross, what is the probability that it will be found in a particular category, say LL? In other words, a breeder would like to give more weightage to that group which have higher chances of including heterotic crosses. Following the method given by Arunachalam and Bandyopadhyay (1979), it was observed that HL category accounted for 57% of heterotic crosses under MAS 1 and 58% under MAS 2 (Table 3). HH ranked next and contained only about half the frequency of heterotic crosses found in HL. Heterosis was insignificant under LL.

TABLE 3
Frequency of heterotic crosses under MAS 1 and MAS 2

Mating system		Combining ability status		
		HH	HL	LL
MAS 1	No. of crosses	14	34	12
	No. of heterotic crosses	2	4	1
	% heterotic crosses	28.6	57.1	14.3
MAS 2	No. of crosses	42	52	16
	No. of heterotic crosses	4	7	1
	% heterotic crosses	33.3	58.4	8.3

The base populations, from which parents were drawn for MAS 1 and MAS 2, showed differing potential for producing heterosis (Table 5). 'KL 17' (SI) and 'KL 27' (SI), used as female parent under MAS 1, ranked high in producing heterosis. 'Pusa BST 2' (SC), produced 4 out of 7 heterotic crosses as male parent, while 'IARI 117' (SC) produced none. Similar was the case under MAS 2. 'KT 5905' (SC) produced 5 of the 12 heterotic crosses as female parent followed by 'GBS 2' (SC) and KL 17 (SI). The success of the population 'KT 5907' (SC) in producing heterosis was low. Thus while SC and SI base populations could equally produce heterosis under MAS 1, SC populations had a slight edge over SI under MAS 2. Further, the relative proportion of heterotic crosses was high when one of the parent was SC and other SI (Table 4).

An evaluation of the yield potential of 6 populations (Table 6) showed that one of them (Population 1) generated from a three-way cross had a high potential for yield. This, in addition to population 4, gave an yield as high as 22 q/ha, when tested in isolation in a few locations in large plots. Though they just equalled the check at that stage, significantly superior yield is expected through further cycles of recombination.

TABLE 4
Relationship of incompatibility to heterosis

Incompatibility		Percentage of heterotic crosses	
		MAS 1	MAS 2
<i>Parents</i>			
Female	SC	8.3	11.3
	SI	16.7	10.0
Male	SC	12.5	—
	SI	10.0	—
<i>Crosses</i>			
	SI × SI	0.0	—
	SI × SC	25.0	—
	SC × SI	16.7	—
	SC × SC	4.2	—

DISCUSSION

One of the optimum strategies for improving the existing yield level in *Brassica campestris* is to generate composite populations involving a number of co-adapted, highly-fit and productive genotypes to ensure yield and guard against risks due to insects and diseases. Such a population would need to encompass a number of balanced heterozygotes (more in relational balance), if it were to sustain its yield over time. Clear and repeatable plant breeding procedures are yet to be set in perspective even for limited objectives like breeding productive composites. The investigation reported in this paper is an attempt to fill this gap.

The results brought out the utility of intra-line variants, in producing superior three-way crosses, thus emphasizing the need to restrain the urge of the plant breeders to eliminate those unlike phenotypes in the earlier cycles of breeding. In fact, intra-line variability had been the base for obtaining superior and stable yields in some of the special selection schemes like disruptive seasonal selection in rice (Tsai, Lu and Oka, 1967; Lu, Tasi, and Oka, 1967 a, b) and in brassica (Murty, Arunachalam, Doloj and Ram, 1972). While variability is not adequate for transgressing the yield of checks by intra-line hybridization alone, it was profitable to involve them in three-way combinations with elite varieties.

The DR-DI hybridization was quite analogous to negative assortative mating since the genetic characteristics of DR lines differed widely from those of DI (Arunachalam and Katiyar, 1978). Hybrids between them had a greater potential than the progeny of matings occurring in disruptive selection cycles. The performance of populations generated from 'GBS 2 × KT 5907' (of MAS 1) and 'GBS 2 (PXO) × K 1' (of MAS 2) (Table 6) add weight to these results.

Evaluating the potential of crosses on the basis of GCA, SCA, self-incompatibility and heterosis over a number of yield components, was found to be useful in identifying repeatable techniques. For instance, the best population (no. 1,

Table 6) that is now undergoing All India Trials was generated from a three-way cross from MAS 2, one of whose parents was high (H) and the other low (L) in GCA but with significant heterosis and high SCA. Identical was the case with the promising population 4 generated from a single cross from MAS 1 (Table 6) except that the cross was not heterotic. Since heterosis was manifested through high SCA and hence through dominance and dominance-based interactions, it was unlikely that these crosses would respond to direct selection or pedigree breeding. The productive populations generated from $H \times L$ crosses confirmed these observations. While, however, the utility of $H \times H$ crosses was not underscored, it was undoubtedly shown that $L \times L$ combinations with even high SCA could not generate stable and productive composites (population 6, Table 6, for example). Similar was the case with $H \times L$ crosses, with low SCA and non-significant heterosis (Population 3, Table 6) though the results need confirmation by more extensive and critical studies. Nevertheless a preferential choice of HL and HH (with more weightage to HL) over LL would itself save a large amount of time, space and labour in initial stages where a breeder has to handle necessarily a large number of potential crosses. Thus a proper system of mating (though non-traditional like MAS 1 and MAS 2) and a proper method of intensive evaluation of the basic data on a large number of component characters (regardless of their direct and immediate utility) would fetch rich dividends in breeding.

Absence of strong association between combining ability and self-incompatibility cast doubts on the use of the latter as a criterion for selection of parents for hybridisation. However, the high frequency of heterotic crosses observed in $SI \times SC$ (with no heterosis in $SI \times SI$) mating; emphasized the desirability of divergence in compatibility status for heterosis (Tables 3 and 5).

TABLE 5

Percentage of heterotic hybrids produced by different base populations used in MAS 1 and MAS 2

Base population	Compatibility status	MAS 1	MAS 2
		<i>Females</i>	
KL 17	SI	16.7	15.0
KL 27	SI	16.7	0.0
KT 05	SC	8.3	16.7
KT 07	SC	8.3	3.3
GBS 2	SC	8.3	15.0
		<i>Males</i>	
KT 07	SC	10.0	—
IARD 117	SC	0.0	—
ASLC	SI	10.0	—
PBST	SC	20.0	—
GBS 1	SI	10.0	—

TABLE 6

Performance of composite populations evolved from MAS 1 and MAS 2

Mating system	Cross	Popu- lation	Compa- tibility	Status		Hete- rosis	Yield (q/ha)				Test location	
				gca	sca		Phase				Delhi	Sirsa
							I	II	III	IV		
MAS 2	GBS 2(P×O)×K 1	1	SC	LH	H	+	14.3	17.9	23.0	16.0	22.0	14.7
	KT 05(P×O)×BSH 1	2	SC	HH	H	+	18.0	14.5	16.9	18.0		
	GBS 2(P×O)×BS 113	3	SC	LH	L	—	21.1	10.6	—	—		
MAS 1	GBS 2-1×KT 07	4	SC×SC	HL	H	—	13.3	10.8	21.5	16.0	20.3	13.1
	KL 17-2×PBST	5	SI×SC	HH	H	+	19.7	13.3	18.0	16.0		
	KL 27-1×KT 07	6	SI×SC	LL	H	—	17.7	10.9	—	—		
Check: Pusa Kalyani											23.0	15.8

+Present; —Absent

A study of the covariance of combining ability between pairs of desirable yield components pointed that selection for a few component characters could not help achieve yield advance, though the characters might be highly heritable (Table 2). This is because the component characters are working in multi-directions, in general and direct selection without proper mating cannot bring them to work unidirectionally. Even schemes like disruptive selection succeeded in this crop (Ram, Murty and Doloi, 1969) more because of the imposed negative assortative mating in every cycle than because of an *a priori* and favourable correlated response.

On the other hand, pure line breeding in self-compatible brown *sarson*, though may be a viable alternative, may not help to significantly transgress the existing yield and ensure stability against diseases and pests. An ideal way would be to pool up the transgressive segregants of SI \times SC mating and generate composite populations. Such an approach would sustain the heterozygotes along with homozygotes in balanced polymorphism over time, since, SI \times SI and SI \times SC types of matings would preserve heterozygotes while selfing and sibbing among SC plants homozygotes, in the various phases of population breeding and cycles of inter-mating for seed production. The repeatable strategy would suggest replacement of a composite by another in the pipeline in lieu of regeneration when yield levels fall below an optimum. The nature of the allogamous material including self-incompatible and self-compatible genotypes cannot facilitate the maintenance of the components of a composite population for a long time for regeneration at will.

SUMMARY

Two unconventional systems of mating using inter- and intra-line variability generated by disruptive and directional selection were examined in *Brassica campestris* var. brown *sarson* in the context of breeding high yielding composite populations. Single crosses obtained by mating lines derived from disruptive with those from directional selection, and three-way crosses, using intra-line hybrids of disruptive selection as females with elite varieties as males, provided potential initial gene pools for generating composites, some of which were superior to checks and are being tested at national level. Parents were classified as high (H) and low (L) general combiners over a number of yield components. H \times L and self-incompatible \times self-compatible single crosses provided high frequency of heterotic crosses. Besides genetic divergence, compatibility divergence added another dimension for realising heterosis. Heterotic crosses with high specific combining ability were identified to be useful to constitute initial gene pools for generating productive composite populations.

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