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CROSS-COMPATIBILITY AMONG THREE VARIETAL FORMS AND ITS IMPACT ON THE COMPONENTS OF YIELD IN OIL BRASSICA

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BRASSICA CAMPESTRIS L. includes three distinct varietal forms—brown *sarson* (BS), yellow *sarson* (YS) and *toria* (TR). While YS is purely self-compatible (SC), TR is purely self-incompatible (SI). BS, on the other hand, contains SC, SI and intermediate compatible (INT) types. Several studies on the nature and causes of self-incompatibility were made in the past. For example, self-compatibility in YS was attributed to homozygous recessive alleles independent of the S-locus (Rajan, 1958) and that in BS to considerable changes in the genetic background ensuing on selection (Qadri, Arunachalam and Murty, 1966).

The success of hybridization among the three varieties BS, YS and TR was not limited, however, by the varying degree of self-incompatibility (Sethi, Chowdhury and Sareen, 1970). High siliqua and seed set were observed in hybrids involving SC and SI forms of BS, while there was relatively poor seed set in hybrids having TR or YS as female parents and SC BS as male parents. Using SI and SC forms associated with alleles low in dominance in *Brassica oleracea*, single, double and triple cross quality hybrids were produced and widely used in practical breeding programmes (Thompson and Taylor, 1965; Watts, 1970).

It will be interesting, therefore, to assess the effect of different degrees of incompatibility on the success of inter-varietal hybridization among BS, YS and TR. It will be possible to examine in the light of such a study, the nature and degree of genetic differences that delineate these three forms. The relationship between the degree of incompatibility and combining ability, if studied on a large number of intervarietal crosses for major yield components, will also provide a wealth of information for practical plant breeding.

The present paper summarises the results, on these aspects, of such a study on 150 inter-varietal crosses and their further generations advanced by two different systems of mating–selfing and biparental mating.

MATERIALS AND METHODS

The material for the study consisted of 15 parents, three sets of five each in the three varieties—*BS:* 1-GBS II (INT), 2-Kanpur Lotni 17 (SI), 3-Kanpur Lotni 27 (SI), 4-DS 17D (SC), 5-Assam Local (SC); *YS:* 6-IB 3, 7-IB 5, 8-IB 6, 9-IB 71, 10-EP 12; *TR:* 11-T 165, 12-T 217, 13-T 244, 14-T 267, 15-T 1842, and 150 inter-varietal hybrids which were made using each of BS, YS, TR as male and female parents, thus giving 25 crosses in each of the six cross combinations—BS×YS; YS×BS—BS×TR; TR×BS—

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YS × TR; TR × YS. For convenience, we shall call BS × YS, BS × TR and YS × TR as direct and the others as their corresponding reciprocal crosses. Two F_2 families from each of these six cross combinations were selected and a total of 123 biparental progenies were obtained (Table 3). The parents, hybrids, F_2 and biparental progenies were raised in a completely randomised block design. Inter-varietal and biparental matings were made by emasculating 60 to 100 healthy flower buds selected at random from 3 to 5 plants in a row and pollinating them with the desired pollen. Selfing was done by covering 100 unopened healthy flower buds in one plant chosen at random with butter paper bags.

Data on siliqua and seed setting were collected at four stages, **SG1**—when inter-varietal crosses were made; **SG2**—when the inter-varietal crosses were selfed to get the F_2 generation; **SG3**—when biparental (BIP) matings were made; **SG4**—when the BIP progenies were selfed.

In addition, data on all the important components of yield were gathered in the 150 inter-varietal crosses in their F_1 and F_2 generation and the parents and hybrids assessed for the components of combining ability with respect to those characters.

Results

The degree of cross-compatibility was measured by the percentage of crosses in which siliqua and seed set was obtained on all the 3 to 5 plants where mating was attempted. The range of compatibility, the degree of siliqua set recorded in direct and reciprocal crosses and the average number of seeds per siliqua are only presented in Table 1 for brevity though all the 150 inter-varietal hybrids were checked for all these characters.

BS-YS combination: Only 10 out of 25 crosses were completely cross-compatible when BS was used as the female parent. It was interesting to note that DS 17D as female produced siliqua with all the YS except IB 3. On the other hand, there was siliqua set in all the crosses of the reciprocal combination, YS × BS.

Siliqua setting varied from 4 to 32 per cent. in direct and 19 to 55 per cent. in the reciprocal crosses. No relationship could be seen in siliqua setting between direct and reciprocal crosses. However, it could be observed that, whenever the siliqua set was poor in one combination, it was relatively better in its reciprocal and vice-versa (Table 1). The siliqua set was the lowest in 5 × 10 among direct crosses while a high percentage of siliqua set was obtained in 2 × 7, 4 × 8, 7 × 1, 10 × 2, 10 × 3 and 9 × 5. No direct relationship was found between average number of seeds per siliqua and the degree of siliqua set. Some crosses, which showed a high average number of seeds per siliqua (SS), were 5 × 6 (SS = 14), 7 × 1 (SS = 16) and 9 × 5 (SS = 16). Interestingly, the lowest SS was not always recorded by crosses which had the lowest percentage of siliqua setting.

On selfing the F_1's both siliqua and seed set were affected heavily and it could not be said that a cross with YS as a female parent did not show depression in siliqua and seed set unlike in inter-varietal crosses. It would be seen that, under selfing, the highest siliqua set of 23% was obtained in the direct cross, 10 × 7 and of 30% in the reciprocal, 7 × 14. An average of 15 seeds per siliqua was obtained in the cross 4 × 8 on the high side and of 2 seeds in the cross 3 × 6 on the low side.

YS-TR combination: Siliqua set was complete in YS-TR crosses when YS was used as the female parent. Only nine of the 25 crosses showed 100 per cent siliqua set when TR was used as seed parent. The siliqua set in YS-TR direct

TABLE 1

Data on some inter-varietal crosses showing the range of incompatibility

Cross	P C SG1	P R SG1	Q C SG1	Q C SG2	Q R SG1	Q R SG2	T C SG1	T C SG2	T R SG1	T R SG2
					I. BS-YS					
5 × 10	70	100	4	0	19	18	10	0	13	3
3 × 8	30	100	32	0	13	0	15	0	10	0
1 × 7	50	100	8	4	55	7	13	10	16	13
Mean	70	100	13	5	38	4	9	4	11	3
					II. YS-TR					
9 × 11	100	100	18	0	18	0	14	0	8	0
6 × 15	100	30	54	0	22	0	3	0	9	0
6 × 14	100	100	40	0	6	0	6	0	8	0
7 × 11	100	100	24	7	26	0	10	2	6	0
Mean	100	70	32	1	14	1	9	1	8	1
					III. TR-BS					
13 × 4	30	100	8	0	20	0	12	0	5	0
12 × 1	100	100	44	0	20	0	9	0	15	0
14 × 3	70	100	16	0	14	0	9	0	10	0
15 × 3	100	100	24	0	14	7	10	0	9	1
14 × 4	30	100	34	0	14	0	12	0	14	0
14 × 1	100	100	38	0	14	0	11	0	6	0
12 × 5	100	100	44	0	38	0	8	0	6	0
Mean	80	100	27	0	23	1	10	0	10	0

P=Cross-compatibility (%); Q=Siliqua setting (%); T=average number of seeds per siliqua; C=Direct cross; R=Reciprocal cross.

crosses was higher than that in BS-YS, the maximum of 54% being obtained when the parent T 1842 was used as pollen parent, and of 26 per cent when T 165 was used as seed parent. However, the maximum SS in YS-TR was 15 in 7 × 13. and the minimum 3 in 6 × 13 and 6 × 15. Again no clear relationship could be discerned between siliqua and seed set.

On selfing the F_1 hybrids, there was siliqua set only in 4 crosses (in direct or reciprocal combination), the maximum being 15 per cent in 15 × 7 and the minimum being 2 per cent in 13 × 7 and 11 × 8. The reduction in siliqua and seed set was drastic under selfing.

TR-BS combination: There was complete siliqua set in all the matings whenever BS was used as the female parent. The siliqua set in the matings with TR as female parent was comparatively less but appreciable. In many cases, the siliqua set was above 20%, the maximum of 44% having been recorded in 12 × 1 and 12 × 5. The siliqua set was the lowest (8%) in 13 × 4. The SS varied from 4 to 16, a majority of them having SS equal to 5 or more.

On selfing the F_1, there was siliqua set only in 4 crosses (1 in the direct and 3 in the reciprocal crosses). The highest depressions in siliqua and seed set were recorded by TR-BS combination, several crosses failing to set siliqua or seed under selfing.

Incompatibilitv scored at four stages: The degree of siliqua set was found to be higher when BIP matings were effected in BS-YS (Table 2), the cross, GBS II × IB 6, recording more than double the siliqua setting under BIP mating as com-

TABLE 2

The degree of incompatibility measured at four stages in 12 inter-varietal crosses

	P			Q				T			
Cross	SG1	SG3	SG4	SG1	SG2	SG3	SG4	SG1	SG2	SG3	SG4
					I. BS-YS						
1 × 8	100	70	70	18	3	42	19	11	11	4	9
2 × 7	100	90	80	24	0	29	17	7	0	5	10
8 × 4	100	80	50	26	5	32	21	17	11	5	11
9 × 3	100	100	60	30	2	34	5	19	2	6	7
					II. BS-TR						
3 × 12	100	90	40	34	0	25	3	10	0	4	7
4 × 15	100	70	90	22	0	29	7	5	0	5	8
13 × 5	30	70	70	12	0	25	5	8	0	5	6
15 × 1	70	100	10	16	0	28	7	6	0	5	2
					III. YS-TR						
7 × 13	100	90	30	26	10	32	21	15	2	4	8
8 × 14	100	50	40	24	0	29	16	13	0	3	5
11 × 10	100	90	30	10	0	35	6	10	0	4	7
13 × 8	30	100	90	10	0	29	15	7	0	5	10

pared to the stage SGI. BS-TR recorded such an increase in siliqua set only when TR was used as seed parent. In the cross, Kanpur Lotni 27 × T 217, a slight reduction in siliqua set was obtained under BIP mating. Again, in YS-TR, improvement in siliqua set was considerable in SG3 as compaed to SG1, only when TR was used as a female parent. Thus it was apparent that BIP matings increased siliqua setting without undue loss in seed set in the inter-varietal cross combination when YS or TR was used as female parent, the increase being more in the latter than in the former (Table 2).

On the other hand, a uniform decrease in the average number of seeds per siliqua was noted in SG3 when compared to SG1. Interestingly the reduction was more pronounced in the crosses where BS or TR was male parent. DS 17D × T 1842 appeared to be an exception to this trend.

A reduction in cross-compatibility in SG3 was found, in general, except IB 71 × Kanpur Lotni 27 where complete compatibility was observed in SG1 and SG3 and T 1842 × GBS II and T 244 × IB 6 where the compatibility per cent increased to 100 in SG3. However, the reduction in compatibility in SG3 was not severe.

Selfing an inter-varietal F_1 was found to affect drastically the siliqua and seed set, BS-TR combination recording complete failure in this regard. But, on selfing BIP progenies, the reduction in siliqua set was marginal in BS-YS and YS-TR combination, except IB 71 × Kanpur Lotni 27 and T 165 × EP 12 and it was severe in BS-TR combination (Table 2). However, a compensatory increase in SG4 over SG3 in the average number of seeds per siliqua was recorded in all the combinations. Such a mechanism was absent in the selfed F_1. The compensatory action between the degree of siliqua set and the average number of seeds per siliqua had offset the ill-effects of selfing the BIP progenies.

A depression in the mean values of the quantitative components—number of primary branches (PB), number of secondary branches (SB), number of siliqua on main axis (SM) and number of seeds per siliqua (SS)- was clearly observed in F_2 when compared to F_1. But the BIP progenies registered a remarkable increase in total number of branches and siliqua set without an undue loss in seed set in almost all the 12 F_2 families. Thus BIP system of mating in inter-varietal cross combinations showed its superiority despite varying degrees of siliqua and seed setting in SG1 and SG3. A comparison of the general combining ability effects of parents and the specific combining ability effects of inter-varietal crosses for those four component characters could not reveal any pattern of relationship between the degree of cross-compatibility and components of combinng ability, both in F_1 and F_2 generations (for brevity, the values of combining ability components were not shown in Table 3; see also, Amrithadevarathinam, Arunachalam and Murty, 1976).

Discussion

The results of this study showed clearly that all the inter-varietal combinations among BS, YS and TR were cross-compatible. While the combinations, YS × BS, YS × TR, and BS × TR were completely compatible, TR × BS was 80% and BS × YS and TR × YS were 70% compatible. The SC or SI nature of BS parents did not show marked relationship with regard to their cross-compatibility with YS or TR. This result is at variance with that of Sethi, Chowdhury and Sareen (1970) who found that SI BS × TR crosses were poor in siliqua and seed set as compared to SC BS × YS or TR crosses. Similarly, this study did not support the result of Sareen and Chowdhury (1968) that TR × BS cross combination was completely compatible. By and large, the observed degrees of cross compatibility in the three intervarietal combinations were high enough to advocate intervarietal hybridisation in *Brassica campestris* group. Our experimentation over years revealed that different dates of sowing used in different seasons could be a potent factor in altering the degree of seed and siliqua set in inter-varietal crosses. Taken with published reports, that the

TABLE 3

Mean values of some yield components in F_1, F_2 and BIP of 12 inter-varietal crosses

Cross	p			q			r			s			
	a	b	c	a	b	c	a	b	c	a	b	c	n
						I. BS-YS							
1 × 8	10·6	9·0	15·5	21·0	8·8	37·1	64·5	56·3	70·9	19·3	15·4	16·7	11
2 × 7	11·5	7·0	9·7	22·9	9·5	19·8	66·5	54·4	71·1	20·1	18·3	18·6	16
8 × 4	9·6	9·1	12·8	21·6	6·9	35·7	46·7	58·1	61·0	16·2	12·7	14·6	10
9 × 3	9·4	9·0	12·6	15·5	9·8	29·7	46·8	48·4	60·4	13·5	18·0	18·2	11
						II. BS-TR							
3 × 12	10·6	7·5	7·4	25·8	9·0	20·0	56·6	47·8	45·9	20·5	15·4	14·3	11
4 × 15	7·4	6·9	10·2	17·1	7·0	32·7	43·1	44·0	49·8	13·8	14·3	16·0	7
13 × 5	10·7	7·1	8·7	12·6	11·8	24·0	53·2	52·6	53·8	16·1	14·7	15·9	10
15 × 1	6·4	7·1	10·5	16·2	9·8	27·5	41·8	43·0	51·1	17·0	14·4	15·9	14
						III. YS-TR							
7 × 13	9·0	9·8	10·1	20·8	10·6	23·5	60·2	53·3	54·5	14·1	14·8	16·4	8
8 × 14	9·1	8·0	9·4	18·6	5·6	27·8	50·3	40·4	46·9	14·7	13·4	11·7	5
11 × 10	7·9	8·7	8·8	16·2	13·8	22·3	42·7	48·6	52·1	16·0	16·0	19·2	13
13 × 8	5·4	6·9	11·3	10·9	13·4	39·5	32·3	46·5	54·9	15·4	17·0	15·7	7

p=Number of primary branches; q=Number of secondary branches; r=Number of siliquae on main axis; s=Number of seeds per siliqua; a=F_1 mean; b=F_2 mean; c=BIP F_1 mean; n=number of BIP families.

expression of self-incompatibility was temperature sensitive, higher temperature increasing self-compatibility (Richard and Thurling, 1973), this point would be worth further examination under Indian conditions.

It was evident (Table 1) from an examination of 50 crosses in each of the BS-YS, YS-TR and TR-BS combinations, that selfing inter-varietal F_1 to obtain F_2 generation entailed a serious decrease in siliqua and seed set. The decrease was pronounced in all cases except YS × BS, in general. A scrutiny of 12 selected inter-varietal crosses (Table 2) would elaborate this point further. This decrease in siliqua and seed set was interestingly found to be repaired by BIP matings. Further, there was a remarkable compensatory action in the degree of siliqua set and the average number of seeds per siliqua as explained in 'Results' in BIP matings which would help to maintain a stable yield performance. This compensatory mechanism was marked when BIP progenies were selfed (Table 2). It would appear, therefore, that BIP matings in inter-varietal crosses would not only compensate the depression in yield components usually observed in inter-varietal F_2 but would augment the componental performance to stablise yield at a higher level. This concept would gain ground by a study of the average values for major yield components, PB, SB, SM and SS in all the inter-varietal combinations (Table 3). Based on 5 tc 16 BIP progeny families in each of the 12 inter-varietal crosses, it was observed that BIP families averaged quite high for all the yield components irrespective of the varietal forms that constituted the inter-varietal cross. The observation, that components of combining ability were not associated with the degree of siliqua or seed set both in the inter-varietal F_1 and

TABLE 4

Mean values of some yield components and single plant yield for some inter-varietal F_3 and F_2 of BIP+

Crosses	p	q	r	t
BIP F_2				
13 × 8	9·3	16·4	55·8	8·9
15 × 1	8·9	14·5	56·1	8·9
8 × 4	9·0	12·8	56·9	8·2
4 × 15	9·3	13·7	47·7	8·0
Inter-varietal F_3				
4 × 15	8·0	12·1	46·5	3·8
8 × 11	7·3	15·8	51·8	4·2
15 × 7	6·8	6·9	36·4	6·9
1 × 8	7·9	9·8	73·1	7·6

p, q, r=see table 3; t=single plant yield (gm).

+ =We thank Dr. A. Bandyopadhyay for supplying this unpublished data.

F_2, would further highlight the need for breeders to concentrate on inter-varietal hybridisation and on selection of suitable genotypes of BS, YS and TR for such hybridisation, for lifting up the stagnant yield levels. However, the effects of inbreeding (Tables 2 and 4) should be taken into careful consideration in raising advanced generations. Four of the BIP F_1's recorded depression in yield and its components in their F_2 generation; but a comparison of the depressions recorded by BIP F_2 with those of inter-varietal F_3 (Table 4) still showed the superiority of the former, in general. The yield components of the cross 4 × 15 (Table 4) in the F_3 and BIP F_2 generations would emphasise this point further. A safe strategy would, therefore, appear to be to first effect an inter-varietal cross with properly chosen varietal forms and then to raise further generations solely by inter-crossing single plants at random in their progeny. Such a process would ensure a profitable improvement in and stable maintanence of yield. Unlike inter-specific hybridisation in crops like jute or cotton, no evidence was available in this study and related ones (Amirthadevarathinam, Arunachalam and Murty, 1976; Arunachalam and Amirthadevarthinam, 1976) to support the theory of restricted or no recombination in F_2 and higher generations.

Summary

The degree of incompatibility was assessed at four different stages using 150 F_1 hybrids among the three varieties-brown sarson (BS), yellow sarson (YS) and toria (TR)—of the species *Brassica campestris* L., and 123 inter-varietal biparental progenies. By and large, all possible matings among BS, YS and TR were cross-compatible. Though the degree of siliqua and seed set was impaired on selfing inter-varietal F_1, it was found not only to be repaired but to be improved by biparental matings. A compensatory mechanism between the degree of siliqua set and the average number of seeds per siliqua observed in BIP progenies can be used with advantage to maintain stable and high yield levels. The remarkable improvement shown by BIP mating in inter-varietal crosses for major yield components and yield would suggest a new avenue for breeders to uplift the stagnant yield levels. The results of the study tend to support the view that long and intense human selection for maturity, height and branching habit had brought about the observed differences in BS, YS and TR.

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