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A Quantitative Evaluation of Inter-varietal Hybrids of *Brassica campestris* L.*

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Summary. A quantitative evaluation of yield components was carried out in 150 inter-varietal hybrids of *Brassica campestris* using five each of the three varieties, brown sarson (BS), yellow sarson (YS) and toria (TR). The results showed both additive and non-additive gene action for plant height, number of primary and secondary branches and number of siliquae on the main axis in all the six cross combinations - BS-YS, YS-BS, BS-TR, TR-BS, YS-TR and TR-YS. The general combining abilities of BS, YS and TR indicated that their nature and magnitude depended largely on the other parents which entered the hybrids. There were differences in combining ability between direct and reciprocal combinations. GBS II, Kanpur Lotni 17, Kanpur Lotni 27 and DS 17D in BS, IB 3, IB 5, IB 6 and EP 12 in YS, and T 165, T 244 and T 1842 in TR were identified as potential parents for inter-varietal hybridisation. Reciprocal effects were found when BS or YS was used as parent and they were least when TR was used as a parent. The amount and degree of heterosis was substantial in inter-varietal crosses. Based on the heterosis-combining ability relationship, the role of inter-varietal hybridisation in population improvement of *Brassica campestris* is discussed. A number of methods of utilising the inter-varietal hybrids in multiple crosses and synthetic complexes is suggested as potential supplements to population breeding in this crop.

Introduction

The oleiferous *Brassica campestris* L. includes three varieties, brown sarson(BS), yellow sarson(YS) and toria(TR), with distinct genetic and morphological differences but intermating with one another (Singh 1958). While YS and TR belong to strictly self-compatible and self-incompatible groups respectively, BS includes self-compatible, intermediate and self-incompatible forms. The presence of such variable degrees of incompatibility, temporal isolation due to changes in flowering time, and also chromosomal changes, have restricted and narrowed down the variation within each variety (Rajan 1958). During at least three decades no significant achievements have been made in improving the yield of these populations. Attempts were confined mainly to improving the yield of the three varieties separately by conventional and improved breeding procedures. Though the merits of these procedures can not be underrated, it would be desirable to plan a study to examine the basic potentialities of inter-varietal hybridisation among these varieties, to further boost population improvement with regard to seed and oil yield. Such a study would also provide a wealth of basic information on the yield components which could profitably be used in marking out powerful short term breeding methods. The results of such an investigation on inter-varietal crosses, conducted in this crop for the first time, are reported in this paper.

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Material and Methods

We would like to use the term, variety, when referring to BS, YS and TR and the term, populations, to refer to different sub-varieties of BS, YS and TR.

Fifteen populations, three sets of five each, in the three varieties as detailed below, were utilised as parents in this study. 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.

The parents 2 and 3 in BS were self-incompatible (SI), 4 and 5 were self-compatible (SC) and 1 intermediate-compatible (INT). In YS, the exotic parent 10 had bivalved, while the other four had multivalved siliquae. The TR parents differed in flowering duration, besides other characters. Each set of parents served both as lines and as testers for the other and this process resulted in 150 hybrids, including 75 crosses and 75 reciprocals as shown below:

	Tester		
Line	BS	YS	TR
BS	o	•	•
YS	•	o	•
TR	•	•	o

• Crosses made
o Crosses not made

Table 1. ANOVA for four yield components in inter-varietal crosses

Source	d.f.	Mean Sum of Squares X1	X2	X3	X4
Parents (P)	14	2480.7	16.7	128.7	203.0
BS	4	1360.4	9.5	52.5 *	459.2
YS	4	416.0	6.8 *	145.1	86.8 *
TR	4	231.7 *	3.0 *	9.4 *	66.3 *
BS vs YS	1	44.9 *	28.9	972.2	17.2 *
TR vs Rest	1	26653.1	129.0	1.3 *	373.8
Hybrids (H)	149	1340.2	16.0	16.8 *	402.3
BS × YS (a)	24	1033.5	23.1	182.1	562.6
YS × BS (b)	24	924.7	15.6	79.7	401.8
a vs b	1	266.3 *	2.1 *	19.3 *	2.5 *
BS × TR (c)	24	638.6	9.7	29.7 *	284.3
TR × BS (d)	24	273.0	6.0	38.1	78.5 *
c vs d	1	2353.0	12.6 *	183.9	1382.3
YS × TR (e)	24	473.8	10.1	82.2	150.8
TR × YS (f)	24	572.7	6.1	61.0	157.7
e vs f	1	12207.6	119.5	251.8	2329.7
(BS-YS) vs (BS-TR)	1	59682.2	341.6	13.8 *	8738.5
(YS-TR) vs BS crosses	1	29530.3	117.7	0.1 *	1232.2
P vs H	1	955.0	91.6	1722.0	6807.6
Error	492	99.0	3.2	21.3	86.1

* Not significant; all other m.s.s. significant at 5 % level

All the hybrids were raised in a complete randomised block design replicated four times. Each hybrid was grown in a single row three metres long. Spacing was 75 cm between and 10 cm within rows. Manuring was at 80 kg N, 40 kg P_2O_5 and 30 kg K_2O per hectare. Observations on four direct yield components - plant height (X1), number of primary branches (X2), number of secondary branches (X3) and number of siliquae on the main axis (X4) - were recorded on five plants at random in each row at the time of harvest. Combining ability analysis was carried out on the line × tester designs (Kempthorne 1957) and the magnitude of heterosis over the better parent was assessed for each yield component.

Results

Analysis of variance of plot means: The differences among the parents, those among the hybrids, except for X3, and the comparison Parents vs Hybrids were all significant (Table 1).

A further partitioning of the sum of squares (s.s.) due to parents showed that the variation among BS populations was the highest, followed by YS populations. The TR populations did not show significant variation for any character. BS vs YS mean sum of squares (m.s.) was significant for X2 and X3, while TR differed from BS and YS for all characters except X3.

The hybrids s.s. was further partitioned into those corresponding to various inter-varietal cross combinations and their reciprocals. Each one of the cross combinations s.s. was further subdivided into that due to lines, testers and line × tester interaction. A study of these components (Table 2) brings out the following:

BS-YS combinations: Significant differences were observed between the 50 hybrids (25 crosses and 25 reciprocals) for all the four yield components. In the crosses, BS × YS, where BS served as line, line, tester and line × tester differences were significant for all the characters, whereas in the reciprocals, YS×BS, line differences for X3 and line × tester interaction for X2 were not significant (Table 2). The reciprocal differences between BS × YS and YS × BS were not significant for any character.

BS-TR combinations: The differences among the 50 hybrids were significant for all the characters, but the differences for X3 in the crosses and for X4 in the reciprocals were not significant. BS as line showed non-significant differences for X2 and X3, while the tester (TR) differences were significant for all the characters (Table 2). When TR was the line, there were no significant line differences for any character, but the tester (BS) differences were significant for all characters except X3. Line × tester interaction was

Table 2. Analysis of combining ability in inter-varietal crosses

		BS × YS	YS × BS	BS × TR	TR × BS	YS × TR	TR × YS
X1	a	3223.1	629.2	2084.5	207.1 *	561.4	734.4
	b	295.6	3632.6	579.9	430.8	407.3	366.7
	c	670.5	321.6	291.8	262.4	468.5	583.8
	d	54.5	90.5	52.0	2.8	0.8	+
	e	142.8	55.6	48.2	41.1	92.4	121.2
X2	a	60.3	15.2	10.1 *	5.9 *	18.7	20.6
	b	41.6	58.6	21.5	11.5	6.9 *	2.2 *
	c	9.2	4.9 *	6.7	4.6 *	8.8	3.5 *
	d	2.1	1.6	0.7	0.2	0.2	0.4
	e	1.4	0.4	+	0.3	0.4	0.1
X3	a	475.2	79.7	45.0 *	21.1 *	148.0	39.6 *
	b	146.0	11.1	64.5	22.1 *	52.8	23.1 *
	c	117.9	65.8	16.0 *	46.3	73.1	75.9
	d	9.6	+	2.0	+	1.4	+
	e	24.1	19.7	+	6.2	12.8	13.7
X4	a	1971.9	401.8	708.1	67.0 *	189.5 *	197.0 *
	b	288.1	220.1	263.4	228.1	282.9	35.7 *
	c	278.9	1567.0	183.5	44.0 *	120.1 *	178.4
	d	42.6	36.9	15.1	5.2	5.8	+
	e	48.2	6.1	24.4	+	8.5	23.1

a = line m.s. (4 d.f.); b = tester m.s. (4 d.f.); c = line × tester m.s. (16 d.f.); d = Var(g.c.a.); e = Var(s.c.a.); * = not significant; + = not estimable; all m.s. are significant at 5 % level; d,e approximate estimates only (see Arunachalam, 1974 for details)

significant for X1 and X3. There were significant reciprocal differences for all characters except X2.

YS-TR combinations: There were significant differences for all the characters among the hybrids. When YS was used as line, the differences among lines and line × tester interaction were significant for all characters except X4 (Table 2). The tester (TR) differences for X2 were not significant. In the reciprocal, where TR was the line, there were significant line differences for X1 and X2 and tester differences for X1 only. The line × tester differences were also not significant for X2. Significant reciprocal differences were observed for all the four characters.

General Combining Ability: An overall assessment of the performance of the parents led to the identification of parents, GBS II, Kanpur Lotni 17, Kanpur Lotni 27 and DS 17D in BS, IB 5, IB 6 and EP 12 in YS and T 165, T 244 and T 1842 in TR, as potential parents for inter-varietal hybridisation (Table 3). Taking all four yield components into consideration, crosses 1×8 (GBS II × IB 6) and 2 × 6 (Kanpur Lotni 17 × IB 3) in BS×YS were found to be the best, having high general combining ability (g.c.a.) for the parents 2 and 8 and also high specific combining ability (s.c.a.). These two crosses consistently showed high s.c.a. for the yield components, but did not prove equally good in the reciprocal YS × BS combination. 2 × 8 (Kanpur Lotni 17 × IB 6) and 3 × 8 (Kanpur Lotni 27 × IB 6) were two other reliable crosses with superior g.c.a. for all the characters. The reciprocal cross 8 × 3 was as good as the cross 3 × 8, indicating practically no maternal effects.

In the BS × TR combination, the crosses 4 × 13, 5 × 12 and 5 × 13, which involved the two SC BS parents, 4 and 5, with 12 and 13 of TR, were found to be reliable, showing superior g.c.a. and s.c.a. for some yield attributes. BS parents 2 and 3, which exhibited superior g.c.a., were found to combine well with each of the TR parents to produce good hybrids.

In the YS × TR combination, 8 × 11 was an outstanding cross, showing superior s.c.a. for X1, X2 and X3, combined with high g.c.a. for the parent 11 only. This cross, with its reciprocal 11 × 8, was found to be a good specific cross combination.

Heterosis and its relation to combining ability: A study of the crosses showing heterosis over better parent for X2, X3 and X4 revealed that 13, 12 and 9 each from BS-YS, BS-TR and YS-TR combinations were heterotic (Table 4). Surprisingly only one cross, 1 × 8, showed s.c.a. effects for all the three characters, and only three crosses, 2×6, 7 × 12 and 10×14, did so for two characters. 18 out of the 34 heterotic

Table 3. Means and g.c.a. effects in inter-varietal hybrids

		BS						
		1	2	3	4	5	6	7
X1	m	120.1	122.1	122.0	83.1	129.7	107.5	123.4
	g1f	4.0	15.2*	0.8	-20.0*	0.0	3.3	1.4
	g1m	2.5	13.5*	1.5	-22.6*	5.2*	-1.7	3.0
	g2f	5.5*	5.0*	3.2	-16.6*	2.9	-6.5*	3.7
	g2m	0.8	5.2*	-0.9	-7.2*	2.2	-0.4	1.5
X2	m	8.9	10.2	6.4	7.3	7.2	9.5	10.7
	g1f	0.3	2.3*	0.5	-2.4*	-0.8*	0.6	-1.0*
	g1m	-1.4*	0.8*	1.4*	-2.2*	1.4*	0.1	-0.2
	g2f	-0.7	1.1*	0.2	-0.5	-0.1	-1.5*	0.6
	g2m	-0.6	0.2	-0.3	-0.6	1.2*	-0.3	0.0
X3	m	20.7	21.1	12.6	15.6	16.1	3.9	5.6
	g1f	0.8	4.8*	4.3*	-5.7*	-4.2*	2.6*	-3.2*
	g1m	-1.2	0.0	1.7	-2.3*	1.8	1.5	1.6
	g2f	-1.4	-1.9*	1.3	0.2	1.9*	-3.8*	3.5*
	g2m	1.9*	-0.6	-0.3	-0.4	-0.5	0.8	1.4
X4	m	44.7	53.1	38.7	24.8	46.8	38.8	47.2
	g1f	1.8	10.7*	0.8	-16.3*	3.1	2.2	-2.5
	g1m	2.0	5.9*	5.9*	-15.4*	1.6	1.1	0.8
	g2f	3.1	3.1	2.5	-10.6*	1.8	-4.3*	3.5
	g2m	-1.2	-1.1	0.4	-3.6	5.4*	-0.2	0.2

g = g.c.a. effect

1 = BS-YS; 2 = BS-TR

crosses did not show s.c.a. effects for any character, X2, X3 or X4. It was thus apparent that the s.c.a. effects were not pronounced in heterotic inter-varietal crosses in general (Table 4).

It was found that the inter-varietal crosses were intermediate in height when compared with the parents. No instance was noted in which the hybrids were better than the superior parent or worse than the inferior parent with regard to height. However, a range of heterosis over superior parent could be found for X2, X3 and X4 (Table 4). 13 crosses out of 34 showed 20 to 40 percent heterosis for X2 and 9 over 40 per cent, 3 showing between 60 to 70. Similarly, most of the crosses showed less than 50 per cent heterosis for X3 and 20 to 50 per cent for X4. The highest heterosis was observed for X3 (Table 4).

Of the 34 heterotic inter-varietal hybrids (over superior parent), 13 belonged to BS-YS, 12 to BS-TR and 9 to YS-TR combinations. The mean heterosis per cent for X2, X3 and X4 was found to be 28, 49 and 34, respectively. Using these values as norms, the frequency of crosses which showed an amount of heterosis equal to or above the norms for 2 or 3 characters (which will be named Rank Hybrids) was worked out individually for X2, X3 and X4. It was found that 14 out of 34 (= 41 %) were rank hybrids, of which 50 % were contributed by BS-YS combinations and the rest by BS-TR and YS-TR (Table 5). BS-YS also contributed four of the eight hybrids which were rank hybrids for all the characters X2, X3 and X4. The cross 8 × 11 and its reciprocal 11 × 8 were both rank hybrids in YS-TR. The rank hybrid 3 × 12 belonging to BS-TR did not have s.c.a. effect for any of the three characters.

Discussion

For the first time, a serious attempt has been made, in this study, to analyse the components of combining ability in a set of inter-varietal crosses whose parents were chosen to represent a good degree of genetic diversity for yield components important for population fitness and human selection. Since the intra-varietal divergence was lower than the inter-varietal one and the primary interest was to evaluate the performance of inter-varietal hybrids, a set of possible inter-varietal hybrids and their reciprocals distributed equally among BS-YS, BS-TR and YS-TR was made, as described earlier. The set of crosses did not exactly form a diallel system, due to the absence of diagonal entries, but the system adopted enabled us to evaluate the BS, YS and TR populations as male and female parents in a series of line × tester designs.

YS					TR		
8	9	10	11	12	13	14	15
107.1	118.9	130.6	75.9	73.1	60.3	69.1	80.3
3.5	- 9.9*	1.7	0.2	- 0.3	4.5*	0.1	- 4.6*
4.4*	- 5.2	- 0.6	2.6	3.3	4.5*	- 1.7	- 8.7*
2.6	- 4.8*	5.1*	0.2	1.8	- 9.5*	7.2*	0.3
- 2.8	- 4.7*	6.4*	6.7*	- 1.7	2.4	- 4.1*	- 3.3
7.5	10.1	10.6	4.7	6.9	5.3	6.3	5.4
0.3	- 0.9*	1.0*	0.3	- 0.7	0.4	0.5	- 0.5
2.4*	- 1.4	- 0.8*	0.5	1.4*	- 0.2	- 0.4	- 1.4*
0.3	- 0.5	1.2*	0.4	- 1.1*	- 0.9*	1.4*	0.1
0.0	- 0.3	0.6	0.9*	0.1	- 0.4	0.1	- 0.7
1.8	8.3	17.3	11.6	11.4	14.6	14.0	11.5
2.0*	- 0.8	- 0.7	0.9	- 1.0	- 0.6	- 0.6	1.3
2.4*	- 1.8	- 3.7*	- 1.1	3.0*	1.0	- 1.6	- 1.3
- 1.1	1.4	- 0.1	1.7	- 1.0	0.2	0.4	- 1.3
- 0.6	- 1.7	0.0	- 2.0*	1.0	0.0	2.1*	- 1.0
38.1	42.4	35.1	39.8	40.5	32.6	32.4	33.2
3.2	- 4.5*	1.7	0.5	1.8	0.8	- 0.1	- 3.0
5.1*	- 5.1*	- 1.9	0.5	2.9	4.0*	- 3.4	- 4.0*
2.4	- 0.8	- 0.7	1.0	2.1	- 5.2*	2.6	- 0.6
1.7	0.4	- 2.1	- 0.7	- 1.1	6.3*	- 0.7	- 3.7*

* = significant at 5 % level   f = as female   m = as male

1 = BS-YS; 2 = YS-TR   1 = BS-TR; 2 = YS-TR

The approximate estimates of g.c.a. and s.c.a. variances (Table 2) revealed both additive and non-additive gene action for all the yield components. While in BS × YS, additive components of genetic variance were high for X2 only, they were high for all the characters in YS × BS. In the other varietal combinations, non-additive was predominant over additive gene action. Usually both additive and non-additive gene action are present for almost all yield components in crop plants (see for example, Singh 1973, on YS; Joarder and Eunus 1970, on *Brassica campestris*; Zuberi and Ahmad 1973, on TR; Giriraj et al. 1973, on castor; Kambal and Webster 1965, on *Sorghum*). Hence a detailed understanding of the combining ability effects of the BS, YS and TR parents would be a prerequisite for formulating suitable breeding procedures to evolve varieties/hybrids.

The SC YS proved to be a success as a female parent and has produced a large number of promising hybrids. As a self pollinated crop, also comparatively late flowering, YS should show low within-line variability. The divergent genotypes chosen should have reflected their source divergence in the cross combination, especially when used as females. It was interesting to find that BS also recorded success when used as lines against YS or TR as testers. In fact, some of the BS × YS cross combinations showed very high combining ability for the yield components. Sprague (1964) observed during a study on open-pollinated varieties of maize and their hybrids that varieties differed in their potential as lines and that the estimates of genetic variance could vary markedly because of gene frequency variations and the relative importance of different types of gene action. This appeared to be true in the case of BS in that only parents 1, 2 and 3 could combine with YS as testers in BS-YS combination, while parents 4 and 5 were found to combine well with TR as testers and produce good hybrids. In fact, the SI parental populations of BS could produce heterotic hybrids with YS as the other parent. The success was limited when the other parent was highly cross-pollinated, TR, for example. The high intra-population variability usually associated with open-pollinated populations might be responsible for such a result. The need for a closer study of intra-population variability to account for the genetic effects and variances in the F_1 of inter-population crosses was stressed by Stuber and Cockerham (1966). In order to have greater success in inter-varietal crosses, where both the parents were cross-pollinated, it would be necessary to improve the parents (through selection, for example) before making the hybrids. This

Table 4. Means, heterosis and s.c.a. effects of heterotic inter-varietal crosses

Cross		X2			X3			X4		
		m	s	h	m	s	h	m	s	h
BS-YS	1 × 8	16.3	3.3 *	60	30.7	9.1 *	48	75.2	12.1 *	68
	2 × 6	14.0	1.3	37	33.6	8.8 *	59	83.8	15.9 *	58
	2 × 7	11.5	-0.9	8	22.9	-2.1	9	66.5	- 1.2	25
	2 × 8	15.3	0.3	50	24.0	-1.7	14	67.3	- 4.7	27
	3 × 8	12.2	-0.9	63	21.1	-4.1 *	68	60.7	- 1.4	57
	3 × 9	10.4	1.1	3	30.9	9.9 *	145	59.2	7.4	40
YS-BS	6 × 2	11.1	-0.7	9	25.3	4.7 *	20	65.6	1.1	24
	6 × 3	13.3	0.9	40	25.8	3.5	105	69.6	5.7	79
	6 × 5	11.9	-0.5	25	20.1	-2.2	25	49.9	- 9.7 *	7
	8 × 2	11.4	-0.1	12	21.5	1.5	2	70.2	5.2	32
	8 × 3	12.6	0.2	68	22.6	1.0	79	57.5	- 7.5 *	49
	8 × 4	9.6	1.1	28	21.6	4.0 *	39	46.7	3.0	23
	8 × 5	10.7	-1.4	43	19.1	-2.6	19	62.9	2.2	34
BS-TR	3 × 11	9.5	0.1	48	17.5	-1.4	39	51.1	- 1.3	28
	3 × 12	10.6	0.3	54	25.8	2.9	105	56.6	1.8	40
	3 × 13	7.5	-1.3	17	21.2	0.3	45	46.5	- 9.4 *	20
	3 × 14	8.9	0.3	4	17.5	-0.9	25	51.5	3.0	33
	3 × 15	8.2	0.6	28	17.9	-0.8	42	53.7	5.8	39
	4 × 12	9.2	-0.4	26	22.4	0.6	44	41.9	0.2	4
	4 × 13	9.0	1.0	23	20.7	0.9	33	40.4	- 2.3	24
	4 × 14	7.8	-0.1	7	16.1	-1.2	3	35.7	0.4	10
	4 × 15	7.4	0.5	1	17.1	-0.5	10	43.1	8.4 *	30
	5 × 12	11.3	1.3	57	23.0	-0.5	43	61.3	7.2	31
	5 × 13	8.9	0.5	24	18.5	-3.0	15	62.7	7.6 *	34
TR-BS	11 × 4	8.3	0.4	14	18.8	1.5	21	41.7	0.7	5
YS-TR	7 × 12	12.5	2.6 *	17	30.0	6.4 *	163	59.9	5.8	27
	8 × 11	12.3	1.9 *	64	19.9	3.9	72	58.3	4.8	47
	8 × 12	8.5	-1.1	23	15.7	-3.3	109	51.9	- 1.2	28
	8 × 14	9.1	-0.5	21	18.6	-1.5	27	50.3	- 3.2	32
	8 × 15	9.1	0.3	21	20.5	3.5	78	48.0	- 2.5	26
	10 × 14	13.0	2.4 *	23	26.2	5.1 *	51	59.9	0.6	71
TR-YS	11 × 8	9.5	1.4	27	20.4	2.5	76	56.6	8.9 *	42
	14 × 8	8.5	-0.6	13	16.2	-0.3	16	44.5	- 4.7	17
	14 × 10	11.4	1.7 *	8	20.2	3.0	17	51.7	6.3	47

m = mean; s = s.c.a. effect:, h = heterosis per cent over superior parent; * = significant at 5 % level (approximate t-test only)

should increase the expected performance of the hybrid to a greater extent than the repeated sampling of the base population in an orthodox inbreeding or hybridisation programme. The breeder should also modify his programme to achieve improvement for several attributes simultaneously rather than modifying single attributes separately.

Heterosis in inter-varietal crosses: In BS-YS combinations, it was possible to locate five crosses, 1×8, 2 × 6, 2 × 8, 3 × 8 and 3 × 9, each of which expressed high heterosis for all major yield components. Of those five crosses, 1 × 8 was outstanding in performance. This cross showed superior s.c.a. combined with high g.c.a. (of the parent 8, in particular). Similar was the case in the crosses 2 × 6 and 3 × 9. On the other hand, the crosses 2 × 8 and 3 × 8 had shown superior heterosis for three yield components even in the absence of high s.c.a. The high heterosis observed in those two crosses was, therefore, due to the reinforcement of the high g.c.a. of the parents (of 2 and 8, in particular).

The results with the reciprocal YS-BS combinations did not fall in line with those of BS-YS combinations. Two crosses, 6 × 3 and 8 × 3, showed substantial heterosis for X2, X3 and X4; this would perhaps point to the superiority of the parents in manifesting heterosis, as observed earlier. The crosses involving the parent 8 as female against each of the BS parents as male were found to show marked heterosis for one or other of the yield components, thus bringing out the superiority of parent 8 in the hybridisation programme.

The heterosis in BS-TR combinations was not consistently as high as in BS-YS combinations for the major yield components. Nevertheless, the crosses 3×11, 3 × 12, 3 × 13, 3 × 14, 4 × 12 and 4 × 15, which exhibited high heterosis, would deserve consideration. It

Table 5. Distribution of heterotic inter-varietal crosses for major yield components

Per Cent Heterosis	Number of Crosses X2	X3	X4
1- 20	12	10	6
21- 40	13	7	19
41- 60	6	7	6
61- 80	3	5	3
81-100	-	-	-
101-120	-	3	-
121-160	-	1	-
161 and above	-	1	-

Combination	a		b		Total	
	n	p	n	p	n	p
BS-YS	7	50	6	30	13	38
BS-TR	4	29	8	40	12	35
YS-TR	3	21	6	30	9	27
Total	14	41	20	59	34	

Crosses heterotic for X2, X3 and X4	
BS-YS	1 × 8**, 2 × 6*, 3 × 8, 3 × 9
YS-BS	8 × 3
BS-TR	3 × 12+
YS-TR	8 × 11, 11 × 8

a = crosses showing high heterosis for 2 or 3 characters out of X2, X3, X4
b = ---- do -------------- one or none ---- do ----
n = number; p = per cent; + = s.c.a. effects absent; * = s.c.a. effect for X3, X4; ** = s.c.a. effects for all characters; other crosses had s.c.a. effect for one character only.

was observed that only those parents which had shown superior combining ability produced high heterosis.

Similar results to those for BS-TR combinations were also found for YS-TR. The cross 8 × 11 and its reciprocal was an excellent combination. Another was 7 × 12 which produced the maximum heterosis of 163 % for X3.

Heterosis is a function of the square of the difference in the gene frequencies controlling a quantitative character and also the amount of dominance in the parents (Falconer 1964). It is, therefore, customary to associate high heterosis with high specific combining ability. This appeared not always to be true. The high s.c.a. in the crosses 9 × 12 and 10 × 3 for X1 did not result in high heterosis. A number of crosses was found to show heterosis even in the absence of high non-additive components of gene action. The implication of the expression of heterosis, as based by Falconer (1964) on a one-locus diallelic model, therefore needs modifying to be of general application.

Some practical difficulties could stand in the way of using highly inbred parents for inter-varietal hybridisation. A high level of heterozygosity was found in the BS and TR populations, because of the rigid system of self-incompatibility. Inbreeding would result in a marked decrease in vigour, as also observed in *Lolium perenne*, for example (Thomas 1967). The difficulty can partly be overcome if a representative male and female are identified and crosses effected between those plants only (instead of bulking the crossed seeds from several such plants). The heterosis of such hybrids should not be very greatly affected in general, as observed in *Brassica oleracea* (Watts 1970). Thus, the harmful effects of inbreeding could be offset with some sacrifice of homogeneity in the F1 hybrids.

A number of useful mating systems can be tried in a bid to boost the performance. One such system would be multiple hybridisation using the inter-varietal hybrid progenies as females and either superior hybrids (whatever the level of these hybrids may be - single, double or multiple crosses) or high yielding varieties as males (Welsh and Atkins 1973; Levings and Dudley 1963, and Moll and Robinson 1966). Programmes like (a) disruptive selection for flowering time would exploit the intra-level variation in the inter-varietal hybrids and achieve further yield improvement through correlated response in a set of yield components (Ram, Murty and Doloi 1969; Murty, Arunachalam, Doloi and Ram 1972). (b) Two way selection, where high and low lines could be selected and carried forward simultaneously on both the right and left tails of the phenotypic distribution, and at a later stage, inter-mated, would provide productive populations. (c) Bi-parental matings in F2 and advanced generations of the inter-varietal hybrids would obviate the harmful effects of linkage and linkage disequilibrium and shuffle the desirable genes in one recombinant (Comstock and Robinson 1952; Gates, Comstock and Robinson 1957, and Matzinger and Cockerham 1963).

Because of the high degree of open pollination in *Brassica campestris*, it should be possible to effect yield improvement through synthetic varieties composed of as many good combining parental genotypes as possible. This study indicates that such a synthetic complex can even be built using BS, YS and TR, especially in view of the complex level of cross compatibility found in them.

This study on inter-varietal crosses clearly indicates that the differences in the three varieties were mainly due to the imposed pollinating system and differences in flowering time of the varieties. No cryptic structural differences could be detected in the expression of characters. These ideas would gain ground if we considered that some inter-varietal hybrids could show good heterosis based on pure g.c.a. effects alone, while some others could not. In some cases, the opposing direction and magnitude of the s.c.a. of the inter-varietal cross cancelled out the desirable joint effects of the g.c.a. of the parents. Nevertheless, the desirable attributes of the varieties were found capable of recombination by inter-varietal crosses. This was clearly shown by the range and nature of variability in the F2 and biparental progenies. One can thus conclude that breeders of brown sarson can ill afford to relegate to the background the potentialities of population improvement by inter-varietal hybridisation.

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