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Are "Multiple Cross-multiple Pollen Hybrids" an Answer for Productive Populations in *Brassica campestris* var. 'brown sarson'?

Part 3. Potential of Component Characters in Population Breeding

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Summary. Results on 167 F_1 'mucromphs' reported earlier were re-examined with the view of determining the potential of component characters in correct identification of parental gca status and F_1 heterosis. It was found that a judicious combination of 'plant' and 'ratio' characters would be of direct usefulness in assessing population performance. The role of seedling characters in the process of making a desired level of multiple cross was illustrated. It was found that H×L mucromphs could provide a broad genetic base which has a higher probability of getting channelised into productive populations. It was concluded that 'multiple cross-multiple pollen hybrids' can provide a feasible solution for breeding productive composite populations in *Brassica campestris.*

Key words: *Brassica campestris* – Mucromphs – Yield components – Seedling characters – Multiple cross – multiple pollen – Hybrids

Introduction

In the earlier part of this series, Bandyopadhyay and Arunachalam (1980) assessed the potential of a set of mucromphs over a number of yield components, especially in relation to heterosis. In particular, the potential of the general combining ability (gca) of the parents was related to overall heterosis and High×Low heterotic crosses were identified as possible sources of direct population breeding. It is profitable in this context to identify a set of specific characters which adequately lead to relative conclusions with a good degree of repeatability in order to chalk out purposeful breeding strategies. As a next step, it would be necessary to outline at least a feasible short-term strategy of breeding for high yields in this crop. Relevant results on these aspects are discussed in the concluding part of this series.

Materials and Methods

The material and methods and the component characters were described in detail in the earlier papers (Arunachalam and Bandyopadhyay 1979; Bandyopadhyay and Arunachalam 1980). We will, for continuity, adopt the same abbreviations used in these preceding papers.

Results

The characters were broadly grouped into four major classes: A = seedling vigour, (SV); B = flowering time parameters, MF, VF; C = "plant characters" and D = "ratio characters" and E = the entire set of 16 characters (see part I, Arunachalam and Bandyopadhyay 1979).

An examination of the potential of A, B, C and D in the correct detection of the gca status given by E (Table 1) showed that ratio characters was the most potent followed by plant characters, seedling vigour and flowering time parameters. This order varied slightly when male and female parents were considered separately. However, plant and ratio characters were stable in having a high potential of correct identification of the gca status in male, female and over all parents.

It was then necessary to understand the usefulness and potential of these characters in the correct detection of heterotic mucromphs. This is better done by considering an example, as in Table 2. The categories HH, HL and LL can be denoted by a suffix "t" taking respective values 1, 2 or 3, for convenience.

In Table 2, we have, as an example, 25 crosses and have considered the flowering time parameters (MF; VF) as the current set of characters, U for an example. The crosses were made in a Line×Tester design with 5 female and 5 male parents, and were referred to by the code numbers given in Table 2. On the basis of the entire set of characters E, the parents were classified as H

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Table 1. Potential of different sets of characters in identifying the gca status of parents

	Set	m	n	m+n	p
Females	A	5/7	3/7	8/14	57
	B	5/7	5/7	10/14	71
	C	6/7	4/7	10/14	71
	D	7/7	7/7	14/14	100
Males	A	4/4	5/8	9/12	75
	B	2/4	3/8	5/12	42
	C	4/4	7/8	11/12	92
	D	4/4	6/8	10/12	83
Overall	A	9/11	8/15	17/26	65
	B	7/11	8/15	15/26	58
	C	10/11	11/15	21/26	81
	D	11/11	13/15	24/26	92

m = proportion of H parents classified correctly; n = proportion of L parents classified correctly; p = correct classification %; other symbols as in text

or L. This resulted in 2 H and 3 L females and 4 H and 1 L male parents, thus giving 8 HH, 14 HL and 3 LL crosses as in Table 2, Column E. The parental status was reclassified on the basis of U alone which resulted in 3 H and 2 L female parents. In the male parents also, 3 were found to be H and 2 L. This resulted in 9 HH, 12 HL and 4 LL crosses, as shown in Table 2, Column U. It may be emphasized however, that, usually only some of the parents classified as H or L on the basis of U will attain identical status when classified on the basis of E also. One of our aims was to detect that set of current characters U which gave results close to those given by

Table 2. Illustrative example on detecting heterosis through a current set of characters: MF and VF

E				U			
HH	HL		LL	HH	HL		LL
1	2	76	26	<u>3</u>[a,b]	<u>1</u>	74[a]	13
<u>3</u>	4	<u>78</u>	28	4	2[a]	<u>97</u>[b]	14
13	<u>6</u>	98	30	<u>6</u>[b]	15[b]	98[a]	25
15	14	<u>100</u>		75[a,b]	16[a]		28[a]
73	16	102		76	18[a]		
75	18			<u>78</u>[b]	26		
<u>97</u>	25			99[a,b]	27[a]		
99	<u>27</u>			<u>100</u>[b]	30		
	74			102[b]	73		
8	14		3	9	12		14

[a] Categorised correctly by current set of characters;
[b] Heterotic as determined by current set of characters;
= heterotic as defined by entire set of characters

E as far as High-Low status or frequency of heterotic crosses was concerned.

We would designate the crosses that were found to be heterotic on the entire set of characters E (based on the methods described in Part I) as 'truly heterotic' in the rest of the paper. Let us now consider the category HH of crosses, corresponding to $t=1$ in Table 2 for illustration.

The following 4 parameters can then be defined for each of the categories, t ($t=1, 2, 3$).

n_f = number of crosses in the groups HH, HL or LL, defined on the entire set of characters, E
= the set of 8 entries under HH in Table 2 column E

n_c = number of crosses defined on the current set of characters, U
= the set of 9 entries under HH in Table 2, column U

h_f = number of true heterotic crosses under HH
= the set of 2 entries (3, 97)

h_c = number of heterotic crosses defined on U under HH
= the set of 7 entries (3, 6, 75, 78, 99, 100, 102)

We note that $\Sigma\, n_f = \Sigma\, n_c$ = total number of crosses made, the Σ taken over t (=25 in our example). Similarly, $\Sigma\, h_f = HF$, total number of true heterotic crosses and $\Sigma\, h_c = HC$, total number of heterotic crosses based on U. In our example, HF is given by the set of 6 crosses (3, 6, 27, 78, 97, 100) and HC by the set of 9 crosses (3, 6, 15, 75, 78, 97, 99, 100, 102).

The following parameters can be derived from the above: n_a = the number of crosses identical between n_f and n_c; to be more precise, n_a is the intersection of the sets n_f and n_c, i.e., $n_a = n_f \cap n_c$ = the set of 3 crosses (3, 75, 99) in HH.

In a similar manner, we define $h_a = h_f \cap h_c$ = the single entry set (3); $h_{aa} = HF \cap HC$ = the set of 5 crosses (3, 6, 78, 97, 100). We define $F = n_a/n_f$; $I = h_a/h_f$; $DI = h_{aa}/HF$ and $DC = h_{aa}/HC$, the range for each of these parameters being (0,1).

If we take the classification of HH, HL and LL crosses based on E as the standard, F is the proportion of crosses in different categories classified correctly by U as compared to the standard. In a similar way, I is the proportion of heterotic crosses identified correctly by U as compared to the standard, in different categories. DI is the proportion of the total number of heterotic crosses which were identified as heterotic both on U and E compared to the total number of truly heterotic crosses; DC is again the proportion of the total number of heterotic crosses which were identified as heterotic both on U and E compared to the total number of heterotic crosses identified on U alone.

The values of F and I for the categories, t ($t=1,3$) along with their marginal values, in our example, are as follows:

t	HH 1	HL 2	LL 3	Marginal Value
F	3/8	6/14	1/3	10/25
I	1/2	0/4	–	1/6

DI = 5/6; DC = 5/9

We note that I cannot be defined for the category LL as no heterotic crosses based on E occurred in that category.

F is the parameter defining the degree of closeness between the categorization given by the entire character set, E and the character set in question, U. When F = 1, the categorisation given by U is identical to that given by E. The optimum value of F is obviously 1. By analogous arguments, I defines the degree to which the character set U identifies true heterotic crosses, the optimum value again being 1.

We note that F and I will have values for each category t (t = 1, 3). Their efficiency over the three categories can be judged by the marginal value (Table 3, for example).

However, there is another contingency to look at. In the example given in Table 2, we note that only 3 crosses from HH, 6 from HL and 1 from LL were identified correctly by U, the others being misclassified among the three categories. For example, crosses 4, 6, 76, 78, 100 and 102, which belonged to HL based on E, were misclassified into HH by U, of which 6, 78 and 100 were heterotic based on U and also on E. Due to this misclassification, the value of h_a was reduced with respect to HL thus affecting the value of I for that category. To be more specific, had there been no misclassification, I for HL would have been = 3/4 instead of 0/4. The marginal value of I does not take these contingencies into account. Hence it was found desirable to discover DI, the proportion of true heterotic crosses detected by U when all crosses are considered regardless of the categories. The other relevant parameter to take into account the misclassified true heterotic crosses is DC, the proportion of true heterotic crosses to the crosses defined to be heterotic by U. It is then easy to see that the optimum value for DI or DC = 1.

The power of the character sets in the correct categorization and correct detection of heterosis can be decided on the following logic:

(a) The character set can be considered to be really powerful in the above respects if I were ≈ 1, F ≈ 1 or T = (I + F) ≈ 2. While unit values of I and F (or near unit values) are preferred and hence can be allotted the first rank, T ≈ 2 allowing compensatory values for I and F in practical situations would rank next.

Table 3. Relative efficiencies of different sets of characters

Character set		HH	HL	LL	mt
A	n	63	80	24	167
	h	11	2	1	14
	p	79	14	7	100
	F	0.71	0.51	0.25	0.46
	I	0.22	0	0.13	0.09
	T	0.93	0.51	0.38	0.55
DI = 0.20					
DC = 0.50					
B	n	48	84	35	167
	h	22	25	10	57
	p	39	44	17	100
	F	0.36	0.46	0.27	0.38
	I	0.11	0.11	0.13	0.11
	T	0.47	0.57	0.40	0.49
DI = 0.66					
DC = 0.40					
C	n	45	88	34	167
	h	14	17	3	34
	p	41	50	9	100
	F	0.86	0.70	0.49	0.66
	I	0.78	0.61	0.13	0.54
	T	1.64	1.31	0.62	1.20
DI = 0.83					
DC = 0.85					
D	n	42	84	41	167
	h	20	38	13	71
	p	28	54	18	100
	F	1.00	0.83	0.75	0.83
	I	1.00	0.78	0.63	0.80
	T	2.00	1.61	1.38	1.63
DI = 0.97					
DC = 0.48					
E	n	28	84	55	167
	h	9	18	8	35
	p	26	51	23	100

mt = marginal total or ratio; for other symbols see text

(b) In situations where U entails a degree of miscategorization, as explained earlier, when compared to the categorization defined by E, it would be useful to strengthen the decision given by the criteria in (a) by applying the same logic to the values of DI, DC and DI + DC.

The relative efficiency of various sets of characters (Table 3) was examined from these points of view. The results showed that character sets C and D were first in importance, followed by B and A, based on the relative values of F, I and T. When these results were cross-checked with the values of DI and DC, it was found that character set C was the most efficient since DI and DC were almost equal to 0.85 and each was close to unity. D, on the other hand, did not show a desirable value for DC though DI was 0.97. In other words, the number of heterotic crosses identified by D was far more numerous than the number of true heterotic crosses. Hence its efficiency had gone down though it was able to trap 97% of the true heterotic crosses. On the other hand, character set C was the most efficient since it was able to correctly identify most of the heterotic crosses in addition to not misidentifying non-heterotic crosses as heterotic. Such an analysis would also place character set B above A.

A study of the potential to categorize the crosses correctly given by the marginal values of F (Table 3) would reveal that it was high in the case of D, followed by C, A and B. The potential for correct identity of a large number of true heterotic crosses given by I would substantiate the superiority of C and D.

Discussion

Breeding for productive populations offers a viable strategy not only in the context of sustaining reasonable degrees of resistance to pests and diseases and insurance against unforeseen risks but also in the context of maintaining (sometimes even surpassing) the existing high levels of yield of hybrids or variety derivatives. Much, however, needs to be done in providing viable programmes of breeding such populations in various crops, in particular, *Brassica campestris.* Diverse genetic bases being a prerequisite for populations breeding, it is necessary to identify ways of ensuring that base with a minimum of effort. Multiple crosses involving complex crosses as females and multiple-pollen would provide such a base. The results of evaluating 167 mucromphs discussed in this series of papers could provide clues on possible short term approaches for population breeding.

In such strategies, it is very important to identify potent characters that could easily and precisely be measured. Ideally that character set should have adequate stability in assessing the yield performance right from the F_1 level. Results on these aspects were encouraging. A critical examination of the potential of the characters using the parameters F, I, T, DI and DC (see Results) brought into focus the adequacy of the plant and ratio characters in that order, followed by mean and variance of flowering time and seedling vigour for identifying either the combining ability components or the F_1 heterotic potential or later yield performance.

However, the role of such early characters as seedling vigour come to focus when we consider the process of making desired multiple crosses. When a single or a multiple cross has to be a parent of a mucromph, it is necessary to identify its potential before it completes flowering in order to enable the breeder to make the mucromph in that season itself; otherwise the highly heterozygous genotype has to be genetically duplicated – an impossibility. Therefore, it is imperative to identify seedling attributes so that the categorization of the parents on them will not deviate seriously from the one based on E. Several studies have shown that seedling vigour, measured as the dry weight of a sample of seedlings collected at a fixed interval after sowing, would serve the purpose reasonably well (Reddy 1975; Parker et al. 1970). Early vigour has also been used as a preliminary test for mitochondrial complementation, which was observed to have a direct influence on heterosis (McDaniel and Sarkissian 1966; Sarkissian and Srivastava 1967, 1969; McDaniel 1970; Sage, 1973). Studies in sorghum (Rao and Venkateswarlu 1971; Maunder 1972) and groundnut (Wynne and Emery 1974) have also pointed out the importance of the pre-flowering stage of crop growth for achieving a production boost. In our studies also seedling vigour was found to be reasonably potent in categorizing the parents correctly (marginal $F=0.46$). The proportion of true heterotic crosses in these, identified by seedling vigour as heterotic, was fairly good ($DC=0.5$), considering the fact that it is based on a single character. When other early attributes such as seedling height, number of leaves and specific leaf weight are taken into account along with seedling vigour, the reliability can increase substantially. Thus, a properly defined set of seedling characters would help in devising an effective and repeatable method of making any level of multiple cross.

With increase in the level of multiple crosses, the complexity and heterogeneity of the populations to be studied would increase. Effective characterization of such populations would depend on the choice of a small set of stable characters that could be measured with relative ease. The results show that plant and ratio characters were almost equally efficient in measuring the potential of populations. The importance of ratio characters have also been brought forward in several other studies. For example, it was found that selection for yield per head in the progenies of complex crosses of wheat was a more promising approach than selection for plot yield (Alessandroni and Scalfati 1973). Worby et al. (1976), found that, in cotton, it would be more profitable to work with such ratio characters as bolls per unit area, lint yield per boll, seeds per locule, locules per boll and so on, instead of working with direct yield components. Moreover, unequal sample sizes and consequent differential magnitudes of variability influence decisions based on plant characters to a higher degree as compared to those based on ratio characters which are almost unbiased, resulting in a higher precision of measurement of the latter. Some of the ratio characters, such as number of secondary branches per primary branch (SBP) and number of primary branches per unit height (PBH), can be easily measured and are of direct use in breeding productive populations. However, other ratios, such as seed yield per siliqua (YDS) and number of siliquae per unit length of primary branch (SLP) are difficult to measure in a large population. In these cases, the component plant characters would provide feasible alternatives. A judicious combination of plant and ratio characters would hence be ideal in characterizing or measuring the potential of a population. One such combination that can be suggested by our studies would be flowering time, number of primary branches per unit height, number of secondary branches per primary branch and seed yield, though follow-up studies would be needed for confirmation.

To verify the productive potential of mucromphs assessed in their F_1 generation, 40 mucromphs representing the various categories, male and female groups were evaluated for yield and some ratio and plant characters during 1976 winter season (Y_1). 15 of them were tested again in the 1977 winter (Y_2) for relative repeatability of performance (Das 1979). A comparison of yields of the top six 'mucromphs' in their F_1 (Y_0), Y_1, and Y_2 (Table 4) brought out the following salient results:

a) Populations based on H×L mucromphs established their superior yield potential, regardless of their F_1 sca status. For instance, even out of a random and representative sample of 3 HH, 26 HL and 11 LL populations (from the 167 F_1 mucromphs) evaluated for their yield under open pollination, the top ranking performance came from HL category only (Table 4). Thus it would appear that the probability of HL category of mucromphs homogenizing into stable and productive populations would be high when they undergo large scale intermating in isolation.

b) The order of superiority of seed and pollen parents based on F_1 performance was not established by the mucromphs evaluated for yield. The performance would thus appear to depend on the particular genotypes making a mucromph. As such it may not be possible to rank either seed parent groups, SC, TC, BP, and VR or pollen parent groups, SP, DP and TP for a stable yield performance (see also part II) on the basis of F_1 mucromph evaluation.

A short-term strategy for breeding productive populations in *Brassica campestris* can be suggested from the results of the three parts of this series.

1) When a set of mucromphs made to a genetic design is available, it is useful to screen them on early plant and ratio characters for gca and sca status and heterosis. H×L crosses can then be selected for large scale inter-mating in isolation and evaluation of yield. This process needs to be repeated until phenotypic homogeneity and desired yield levels are achieved.

2) An alternative scheme is to evaluate a set of single crosses on seedling characters. These should involve parents diverse in their desirable attributes and made to a genetic design. Find out the gca status of parents and cross with desired parents to produce 3-way or with unrelated crosses to produce 4-way crosses. Earlier studies on triticale (Arunachalam and Srivastava 1980) and pearl millet (Arunachalam and Reddy 1979, 1981) showed that H×L crosses could serve as potential female parents of the multiple crosses. The genetic base can thus be widened as far as desired, after which the selected complex crosses can be intermated in isolation. Their yield levels can then be assessed on the chosen plant and ratio characters, in addition to yield.

It can then be said in conclusion, that "multiple cross-multiple pollen hybrids" can provide a feasible solution for breeding productive composite populations in *Brassica campestris* var. 'brown sarson'.

Table 4. Information on the top six mucromph populations

Source of population	Varietal identity	GS	SCS	Yield (gm/100 plants)		
				Y_0	Y_1	Y_2
TCTP	'26kl' × 'TIP3'	HL	L	191	263	253
VRTP	'PUKA' × 'TLP3'	HL	H	200	257	260
SCDP	'5995' × 'TP71'	HL	HN	170	259	241
VRDP	'PUKA' × 'TP71'	HL	HN	217	213	226
BPDP	'ID91' × 'BEDS'	HL	H	488	155	210
TCDP	'26K1' × 'TP71'	HL	H	324	193	–

GS = Gca status; SCS = Sca status; for other symbols see Part 2 of this series

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