FIELD PERFORMANCE OF *BRASSICA RAPA* L. DOUBLED HAPLOID LINES AND HYBRIDS IN SASKATCHEWAN

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FIELD PERFORMANCE OF *BRASSICA RAPA* L. DOUBLED HAPLOID LINES AND HYBRIDS IN SASKATCHEWAN

Brassica rapa cultivars occupy about 44% of Canada's five million hectares of canola. However, *B. rapa* cultivars yield 15 to 20% less seed than those of *B. napus*. In order to increase the competitiveness of *B. rapa*, significant increases in seed yield must be achieved. The development of hybrid cultivars of *B. rapa* could provide the basis for high yield.

The objective of this research was to evaluate the performance of *B. rapa* doubled haploid (DH) lines and their potential use as parents in hybrid cultivars. A total of 162 DH lines, derived from five *B. rapa* breeding populations were evaluated in field tests at Saskatoon. Bud pollination was used to obtain self seed for evaluation of the DH lines. Sixteen top cross and 27 polycross progenies, 45 single cross hybrids and eight hybrid mixtures were evaluated in the field to measure combining ability of DH lines.

Many *B. rapa* DH lines were chlorophyll deficient, a typical phenomenon of inbreeding, due to the expression of deleterious recessive genes. Average seed and biological yield and number of seeds/pod of DH lines were only 24, 48, 46% of their donor populations, indicating severe inbreeding depression. Inbreeding also, greatly extended days to flowering. The average effect of inbreeding was comparatively less for seed weight, pod length and days to mature. Several DH lines equalled their donor population in the number, weight or height of particular plant parts in early developmental stages indicating that slower growth, rather than the initial size, may be the reason for lower yields of DH lines compared to their respective donor populations. One (BC-3015) DH line equalled the seed and biomass yield of its donor population suggesting, dominance deviation not overdominance, is the genetic basis of high yield in *B. rapa*. It is suggested that chlorophyll deficient, late flowering DH plants could be discarded on the basis of greenhouse performance.

Top cross and polycross procedure were equally effective in ranking DH lines for general combining ability (GCA). The top cross method of predicting GCA is the preferred method since it will allow the use of a weak, recessive tester which will not mask dominant alleles present in DH lines. There was a high percent of hybridity in the seed of top cross progeny as measured by the amount of erucic acid present. The single cross procedure

identified heterotic combinations which were different from those identified in the top cross and polycross methods. It was concluded that this difference was caused by the differential effects of male parents used to calculate GCA. One single cross hybrid yielded significantly higher than the check cultivar Tobin (130%). The best hybrid mixture equalled the yield of Tobin. It is concluded that DH lines of *B. rapa* will be useful in developing inbred parents for hybrid development.

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ABSTRACT

Brassica rapa cultivars occupy about 44% of Canada's five million hectares of canola. However, *B. rapa* cultivars yield 15 to 20% less seed than those of *B. napus*. In order to increase the competitiveness of *B. rapa*, significant increases in seed yield must be achieved. The development of hybrid cultivars of *B. rapa* could provide the basis for high yield.

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Many *B. rapa* DH lines were chlorophyll deficient as a result of expression of recessive alleles, a classical inbreeding phenomenon. Average seed and biological yield and number of seeds/pod of DH lines were only 24, 48, 46% of their donor populations, indicating severe inbreeding depression. Inbreeding greatly extended days to flowering. However, seed weight, pod length and days to mature were less severely affected than other

traits measured. Several DH lines equalled their donor population in plant weight and height at specific stages of growth, however, on average the overall growth and development of the DH lines was slower than their respective donor populations. One DH line (BC-3015) equalled the seed and biomass yields of its donor population, suggesting that dominance deviation not overdominance was the genetic basis of high yield in *B. rapa*. It is suggested that chlorophyll deficient, late flowering DH plants could be discarded on the basis of greenhouse performance.

Top cross and polycross procedures were equally effective in ranking DH lines for general combining ability (GCA). The top cross method of predicting GCA is the preferred method since it will allow the use of a weak, recessive tester which will not mask dominant alleles present in DH lines. Hybridity of top cross seed was high as measured by the erucic acid marker. The single cross procedure identified heterotic combinations which were different from those identified in the top cross and polycross methods. It was concluded that this difference was caused by the differential effects of male parents used to determine GCA. One single cross hybrid yielded significantly more seed than the check cultivar Tobin (130%).

It is concluded that DH lines of *B. rapa* will be useful in developing inbred parents for hybrid development and procedures for combining ability testing and maintenance of SI DH lines for the production of hybrids is proposed.

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1.0 INTRODUCTION

Brassica napus L., *B. rapa* L. and the mustard species *B. juncea* (L.) Czern. and Coss. are the third most important source of edible oil in the world (Table 1.1). Total world production of rapeseed and mustard oil amounted to 7.6 million tonnes in 1988/89 and by 1994/95 production had increased to 9.9 million tonnes.

Table 1.1 World production of edible vegetable oils, 1988/89-1994/95

Crop	Oil production (millions of tonnes)						
	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95
Soybean	14.6	16.0	15.9	16.9	17.1	18.1	19.6
Palm	9.6	10.9	11.1	11.5	13.0	13.4	14.5
Rapeseed/mustard	7.6	7.8	8.7	9.3	8.4	9.1	9.9
Sunflower	7.2	7.8	7.9	7.7	7.3	7.0	8.1
Peanut	3.7	3.4	3.4	3.4	3.6	3.6	4.1
Cottonseed	3.7	3.4	3.8	4.2	3.7	3.4	3.7
Coconut	2.6	3.1	3.0	2.9	3.1	3.0	3.1
Olive	1.5	1.8	1.5	2.1	1.8	1.7	1.7

Source: Statistical Hand Book, 1995; Canadian Grains Council, Winnipeg, Manitoba.

The area sown to spring *B. napus* and *B. rapa* cultivars in Canada has increased from 2.9 million ha in 1989 to 5.2 million ha in 1995 (Anonymous 1995a). The Canadian *Brassica* crop is of canola quality, i.e., the seed oil contains less than 2% erucic acid, as percent of

total fatty acids, and the oil free meal contains less than 30 μmoles per g of aliphatic glucosinolates (Consumers and Corporate Affairs 1986).

In Canada, seed of *B. napus* and *B. rapa* are mixed in commerce and sold as a single commodity, referred to as canola. However, the two species differ from each other in agronomic performance. *Brassica rapa* cultivars yield, on average, 20% less seed than *B. napus* cultivars, but mature 10 to 14 days earlier (Anonymous 1995b). Due to their shorter life cycle, *B. rapa* cultivars are better adapted to the northern growing areas of the Canadian prairies. Under drought, late spring or early fall frost conditions, the yield of *B. rapa* cultivars can equal or exceed the yield of *B. napus* cultivars. Due to the early maturity of *B. rapa* cultivars, they are less likely to suffer grade losses than *B. napus* cultivars due to the presence of green seed. Most Canadian *B. rapa* canola cultivars are yellow-brown seeded, whereas all *B. napus* cultivars are black seeded. Yellow seeds of the *B. rapa* cultivars Candle and Tobin contain, on average, 2.5% more oil and 1.0% more protein than brown seeds of their respective cultivars (Daun and DeClercq 1988). It has also been shown that seed meal of yellow seeded *B. rapa* cultivar has a 5% lower fibre content than seed meal of brown seeded cultivars (Stringam *et al.* 1974). The development of yellow-brown seeded *B. rapa* cultivars has allowed seed quality improvements which have not been possible in black seeded *B. napus*. However, the yellow seed trait has recently been transferred into *B. napus* from *B. juncea* and *B. carinata* through interspecific crosses (Rashid *et al.* 1994).

The proportion of the total crop sown to *B. rapa* cultivars has been declining over the last 20 years. In 1973, *B. rapa* occupied 71% of the 1.09 million hectares sown to rapeseed in western Canada, but by 1992, the proportion sown to *B. rapa* was only 44% of the total

canola acreage of 3.16 million hectares (Anonymous 1973, 1992). The increase in the *B. napus* area, relative to *B. rapa,* resulted from the development of early maturing *B. napus* cultivars and the introduction of the herbicide trifluralin which controlled most annual weeds and permitted early planting of the crop. Producers, in the central prairies, switched to the potentially higher yielding *B. napus* cultivars but in the northern areas, where the growing season is short, *B. rapa* is still the preferred crop. If the yield of *B. rapa* cultivars could be improved, this species could recapture some of its market share. One approach to improve the yielding ability of *B. rapa* could be the development of synthetic or hybrid cultivars.

The development of superior hybrids involves the production, evaluation and selection of inbred lines and the evaluation of their combining ability. The conventional method of inbred line development is by selfing and selection, in successive generations, a procedure used in maize hybrid breeding programs (Russell and Hallauer 1980). However, the conventional method may not be efficient in self incompatible species where selfed seed production is inhibited by physiological mechanisms. Another approach is to produce haploid plants through androgenesis followed by chromosome doubling to produce doubled haploid (DH) lines. Using this technique, completely homozygous plants are produced in one generation, and these plants could be used as parents for hybrid production.

DH plants have been produced in the amphidiploid, self compatible species, *B. napus* (Thomas and Wenzel 1975), *B. juncea* (George and Rao 1982) and *B. carinata* (Choung and Beversdorf 1985), as well as, in diploid vegetable crops of the *B. oleracea* species (Kameya and Hinata 1970). Recently, Baillie *et al.* (1992) developed the first efficient method for *B. rapa* DH production through microspore culture.

The objective of this study was to evaluate the agronomic performance of *B. rapa* DH lines under field conditions, to assess their combining ability, and to produce and evaluate *B. rapa* hybrids.

2.0 LITERATURE REVIEW

The literature review sections on inbred line development and the breeding of hybrid cultivars focus primarily on research carried out in maize (*Zea mays* L.). Maize and *B. rapa* are both diploid, cross pollinated plant species and many of the observations made in maize could be relevant for the development of *B. rapa* inbreds and hybrids. In maize, outcrossing is conditioned by the monoecious nature of this species, although the plant is fully self fertile (Hallauer and Miranda 1988). In contrast, *B. rapa* contains self incompatibility alleles which ensure outcrossing and self pollination does not normally occur (Downey *et al.* 1980). The literature review will, therefore, deal with self incompatibility systems in species of the genus *Brassica*, followed by a review of inbreeding phenomena, the concepts of combining ability and heterosis. This will be followed by a review of research on the potential for seed yield heterosis in *B. rapa*, and the possible use of DHs in *Brassica* breeding programs.

2.1 Self incompatibility

Self incompatibility (SI) is a common phenomenon in 80 of 182 plant species in the Cruciferae family (Hinata and Nishio 1980) and is defined as "the inability of a fertile hermaphrodite seed plant to produce zygotes after self pollination" (deNettancourt 1977).

SI involves an exchange of "recognition" signals between the pollen tubes and cells of the stigmatic surface. Pollen tubes from compatible pollen can grow through the pectin cellulose layer of the style, dissolving the pectin. However, incompatible pollen tubes are blocked by callose deposition.

SI in *B. rapa* is of the sporohpytic type "in which the incompatibility phenotype in the pollen is determined by the genotype of the pollen producing plant" (deNettancourt 1977). Sporophytic SI in *Brassica* species is governed by one S allelic series with 50-60 alleles (Nasrallah and Nasrallah 1989). SI alleles express varying degrees of dominance and can also exhibit codominance relationships in the stigma as well as in the pollen. Codominance between pairs of SI alleles has been found to be more frequent in the stigma, whereas dominance relations were reported to be more frequent in the pollen (Richards and Thurling 1973). Other relationships, such as mutual weakening of S alleles in heterozygotes, were also reported (deNettancourt 1977).

SI reaches full strength at the mature bud stage one day before flower opening and the ability of stigmatic cells to distinguish between pollen genotypes becomes progressively weaker as the flower ages (Nasrallah and Nasrallah 1989).

Bud pollination is the most widely used method for producing selfed seed in diploid self incompatible *Brassica* species (Downey *et al.* 1980). This technique is effective because the recognition factor in immature papilla cells of the stigma is only partially expressed in the unopened flower. To affect self pollination in a self incompatible plant, immature flower buds, two days before opening, are pollinated with mature pollen of the same plant. Two to four seeds are usually produced per pollinated bud in self incompatible crucifer vegetables,

such as, *B. campestris* ssp *pekinensis*, *B. oleracea* ssp *capitata* and *Raphanus sativus* (Ito 1981). In contrast, self pollination of the open flower (in a selfing bag) produces no seed or an occasional single seed. However, bud pollination is very labour intensive and requires a skilled and experienced person.

Other methods used to overcome self incompatibility include stigma mutilation such as, stigma surface removal and steel brush pollination (Roggen and vanDijk 1972), high humidity treatment (Carter and McNeilly 1975), high temperature treatment (Roggen and vanDijk 1976), carbon dioxide treatment (Nakanishi and Hinata 1975), application of a differential electric potential between the pollen and stigma (Roggen *et al.* 1972), chemical treatment, such as; hexane (Ockendon 1978), paraffin oil (Roggen 1979), cycloheximide (Ferrari and Wallace 1976), acetone, chloroform (Roggen 1974) naringenin (Prabha *et al.* 1981) and salt (NaCl) water (Fu 1992). Among all these methods, only the salt water spray (Fu 1992) and the carbon dioxide treatment (Taylor 1982, Hinata *et al.* 1994) which have been used in selfed seed production on a large scale.

2.2 Inbreeding

Inbreeding is a system of mating between closely related individuals. Effects of inbreeding, particularly in animals and the human species, were known in medieval times (Zirkle 1952). Scientific studies on inbreeding in cross pollinated plants were initiated by Shull (1908) and East (1908) in maize. The effects of inbreeding in maize were documented by East and Hayes (1912). Their conclusions provide a comprehensive description of the inbreeding phenomena in maize. These observations were confirmed in later studies in maize and other cross pollinated crops. East and Hayes (1912) stated:

"(1) There is partial loss of power of development, causing a reduction in rapidity and amount of cell division. This phenomenon is universal and therefore cannot be related to inheritance. Further, it continues only to a certain point and is in no sense an actual degeneration.

(2) There is an isolation of subvarieties differing in morphological characters accompanying the loss of vigour.

(3) There is often regression away from instead of toward the mean of the general population.

(4) As these subvarieties become more constant in their characters the loss of vigour ceases to be noticeable.

(5) Normal strains with such hereditary characters that they may be called degenerate strains are sometimes, though rarely, isolated.

(6) It is possible that pure strains may be isolated that are so lacking in vigour that the mechanism of cell division does not properly perform its function, and abnormalities are thereby produced."

The loss of vigour following inbreeding has been described as inbreeding depression. Several authors (Davenport 1908, Bruce 1910, Keeble and Pellew 1910) explained inbreeding depression in terms of Mendelian genetics. They assumed that a naturally cross pollinated population was composed of a large number of heterozygous individuals and due to heterozygosity, many deleterious recessive genes were concealed within the population. After inbreeding, these genes were expressed in a homozygous state. These same recessive characters were also observed in small numbers in open pollinated populations. It was observed that upon inbreeding, dominant as well as recessive genes segregated and the original population became separated into different lines carrying homozygous recessive and homozygous dominant genes (Falconer 1989). Thus, it was concluded that inbreeding depression was a consequence of Mendelian segregation.

Allard (1960) stated: "The injurious effects of inbreeding are not produced by the

process of inbreeding itself, as believed by many early biologists (including Darwin), but are directly related to the number and kinds of Mendelian characters heterozygous in the original population."

2.2.1 Doubled haploids and conventional inbreds

DH plants are produced by doubling the chromosome number of a haploid plant, whereas, conventional inbred lines are developed by selfing in successive generations (Stoskopf *et al.* 1993).

With the DH method, homozygous plants are produced in one generation and homozygosity is 100% compared to the conventional method which results in an average level of homozygosity of 96.9% after five generations of selfing (Briggs and Knowles 1967). During DH production, only one recombination event takes place and selection is possible only after DHs are produced. In the production of inbreds by the conventional method, one recombination event can take place in every generation of selfing, and selection can be practiced in each generation. The greater number of recombinations, the greater the possibility of assembling a large number of favourable genes from two parents in one inbred plant (Hallauer and Miranda 1988).

DH lines produced through anther or microspore culture have been compared to inbreds developed by the single seed descent (SSD) method on the basis of theoretical considerations (Griffing 1975, Snape 1976, Jinks and Pooni 1981) and actual field comparisons (Powell *et al.* 1985, Jinks *et al.* 1985). Computer simulations, using data from DH and SSD populations of barley (Riggs and Snape 1977) were used to predict mean and variance distributions in these two types of inbred populations. Where the base population

was characterized as having excess coupling phase linkage, the means and variances were greater in the DH than the SSD population. However, when the base population contained excess repulsion phase linkage, the reverse was true. When no linkage was present in the base populations, means and variances of DH and SSD populations derived from that population were not different. These theoretical genetic predictions were confirmed with experimental data in barley (Powell *et al.* 1985) and tobacco (Jinks *et al.* 1985).

The time required to breed a new cultivar using the DH or the SSD method differs. Kasha (1987) estimated that the use of the "bulbosum method" for production of DHs of barley shortens the time of cultivar development by three years. Beversdorf *et al.* (1987) compared microspore culture and SSD methods for cultivar development in spring and winter *B. napus*. They reported that in spring rapeseed, the cultivar breeding time for the SSD and DH methods was 5.0 and 4.5 years, respectively, whereas, in winter rapeseed, the cycle length was 8.0 and 6.5 years, respectively. According to their calculations, the time required for the production of homozygous lines of spring *B. napus*, using the DH method, was 1.0 year and for the SSD method 1.5 years. The time calculation for the SSD method to produce five generations to reach near homozygosity appears conservative. On the other hand, DHs are theoretically 100% homozygous and with improvements in the DH method, haploid plants from embryogenic *B. napus* cultivars can be obtained in less than six months with another three and one half months needed for seed multiplication (Seguin-Swartz, G. personal communication).

2.3 Combining ability

2.3.1 General and specific combining ability

Combining ability is the ability of parents to produce a superior hybrid (Stoskopf *et al.* 1993). It is a measure of the value of inbred lines for their use in hybrid or synthetic cultivar development. Sprague and Tatum (1942) partitioned combining ability into general combining ability (GCA) and specific combining ability (SCA). When one line is used as a parent in crosses with other lines, the mean performance of all crosses involving that line is called GCA. The expected yield of a hybrid is the average of the GCA of the two parental lines. Any specific hybrid may deviate from the expected yield and this deviation is called SCA. The definition implies that GCA and SCA always refer to specific crosses.

In statistical terms, GCA represents the average male and female effect and SCA is an interaction term between the male and female. In terms of gene action, GCA is an indication of additive gene effects and SCA indicates dominance and epistatic effects (Falconer 1989). From their test cross data, Sprague and Tatum (1942) concluded that for yield increases in maize hybrids, GCA was more important than SCA when working with unselected inbred lines. They also suggested that top cross tests which involve the crossing of inbred lines with a specifically selected tester population, would be more effective in determining GCA than single cross tests. However, single cross tests are necessary to identify productive hybrids at the final stage.

2.3.2 Estimation of combining ability

Combining ability of inbred lines is estimated from progeny test performance. In the polycross method, lines to be tested for combining ability are grown together and allowed

to inter-pollinate freely (Falconer 1989). A natural mechanisms which ensures cross pollination between lines, such as SI, is required and plants of the same line must carry the same SI allele and must not cross with each other. Further, the plants are arranged within the polycross nursery in such a way that random pollination among plants can be expected. Seeds from plants of one line or clone are therefore a mixture of randomly crossed seed with all other lines or clones. When crossed seed from a single line or clone is grown, the performance of the plants grown from this crossed seed measures the GCA of that line. However, in nature, pollination is not always fully random as reported by Knowles (1969) in brome grass.

The top cross method is also used to determine GCA of an inbred line and is estimated by the test cross performance of plants derived from the cross between inbred lines and a specifically selected tester population (Falconer 1989).

2.3.3 Effects of the tester

It has been reported in maize that, one third of the genetic gain in seed yield observed in top cross progeny performance was contributed by the top cross parent (Horner *et al.* 1973). Other studies in maize indicated that the contribution of the top cross parent to the seed yield of top cross progenies was much greater which probably resulted from the specific genetic contributions of the top cross parents used (Russell *et al.* 1973, Russell and Eberhart 1975 and Hoegmeyer and Hallauer 1976). It has been suggested that the most informative tester would be the one that has homozygous recessive alleles at major loci since such a tester would allow the expression of all dominant alleles of the inbred line to be tested in their progenies (Hull 1945, 1946, 1952). This genetic hypothesis was supported by experimental

data on seed yield in maize (Rawlings and Thompson 1962, Allison and Curnow 1966, Hallauer and Lopez-Perez 1979).

2.3.4 Visual selection of inbred lines

The performance of crosses is related to their parental performance (Falconer 1989). Such a relationship should allow visual selection of parents that produce superior hybrids. Experimental evidence indicates that selection of maize inbreds for resistance to root and stalk lodging can be highly effective for producing lodging resistant hybrids (Brown 1967). However, several studies have shown that visual selection for high seed yield in maize inbred lines was not necessarily related to the seed yield of their derived hybrids. Jenkins (1935), compared the yield of maize hybrids derived from crosses between inbred lines that had been visually selected with hybrids derived from crosses between the rejected lines from the cultivars Iodent and Lancaster. Hybrids produced from selected inbred lines of the cultivar Iodent had significantly greater grain yield than that of hybrids produced from the rejected inbred lines. However, a visual preselection of the inbred lines for high yield from the cultivar Lancaster did not result in higher yielding hybrids.

Osler *et al.* (1958) reported that visual selection of inbred lines for production of high yielding hybrids was effective. Whereas, no effect of visual selection was found by either Brown (1967) or Russell and Teich (1967). Even with the conflicting reports on the effect of visual selection of inbred lines on the performance of their hybrids, it is commonly practiced in today's maize hybrid breeding programs (Hallauer and Miranda 1988).

2.3.5 Normal distribution of combining ability

Several maize researchers concluded that combining ability is a heritable trait and combining ability of inbred lines drawn from a base population is normally distributed (Jenkins 1935, Johnson and Hayes 1940, Cowan 1943, Sprauge 1946 and Green 1948).

Sprague (1946) selected 167 phenotypically desirable S_0 plants of Iowa Stiff Stalk Synthetic and outcrossed them to the double-cross-tester Ia13. Seed yields of 167 test-crosses were normally distributed with a range from 38.6 to 63.0 q/ha. At the 5% level of significance (6.0 q/ha) four of the crosses had significantly lower yields than Iowa Stiff Stalk Synthetic and two were significantly higher yielding than the double-cross-tester, Ia13.

2.3.6 Cultivar vs. inbred line derived hybrids

In maize, the level of heterosis expressed in hybrids derived from selected inbred lines has been about tenfold greater than the heterosis exhibited in hybrids derived from cultivar crosses (Hallauer and Miranda 1988). Heterosis in seed yield of individual plants in cultivar derived crosses differs and approximates a normal distribution if sampling is adequate. Based on this concept, Shull (1909) proposed the development of pure lines in maize for producing high yielding hybrids.

In *B. napus*, Brandle and McVetty (1989a) compared the yield of inbred line derived hybrids with yields of cultivar derived hybrids. Some of their inbred line derived hybrids were significantly higher yielding and others significantly lower yielding compared to their respective cultivar derived hybrids. Brandle and McVetty (1989a) suggested that," a hybrid oilseed rape breeding program should be based on inbred line crosses rather than cultivar crosses."

2.4 Heterosis

Heterosis is the difference in performance between the F_1 generation and average of the parents while combining ability of the parents determines the level of heterosis of their hybrids. Parents may be inbred lines, DHs, clones, hybrids, breeding populations, cultivars or different species.

Heterosis can be measured in several ways. Midparent or classical heterosis is defined as: [(value of F_1 - value of mid parent /value of mid parent) x 100], where the value of the mid parent is defined as [(value of parent 1 + value of parent 2)/2] (Falconer 1989). High parent heterosis is defined as [(value of F_1 - value of better parent /value of better parent) x 100] (Fonseca and Patterson 1968). In a commercial hybrid seed production program, a comparison of hybrids with a commercial open pollinated cultivar is usually used. Commercial heterosis may be defined as [(value of F_1 - value of a commercial cultivar/ value of a commercial cultivar) x 100] (Schuler *et al.* 1992).

2.4.1 Genetic basis of heterosis

Heterosis has been described as the opposite of inbreeding depression (East and Hayes 1912). These authors stated that, "The decrease in vigour due to inbreeding in naturally cross fertilized species and the increase in vigour due to crossing naturally self fertilized species are manifestations of one phenomenon. This phenomenon is heterozygosis. Crossing produces heterozygosis in all characters by which the parent plants differ. Inbreeding tends to produce homozygosis automatically."

The earliest hypothesis describing the genetic mechanism of heterosis assumed the existence of an unexplained physiological stimulation resulting from the union of unlike

gametes, i.e., 'heterozygosis', now termed heterosis (Shull 1908, East 1908). This hypothesis was not in accordance with Mendelian genetics. Other hypotheses, based on Mendelian genetics, were developed later.

2.4.1.1 Allelic or single locus heterosis

In a diploid organism the male and female each contribute an allele at the same locus in the zygote. Thus, an individual can carry two dominant, two recessive or one recessive and one dominant allele at a single locus. Controversy has occurred as to whether a plant having two dominant alleles at a single locus is superior to a plant having one dominant and one recessive allele at the same locus.

Dominance theory is based on the assumption that dominant alleles are beneficial to the organism possessing them, while recessive alleles have a weakening effect (Davenport 1908). Bruce (1910), in his letter to the editor of Science, gave a generalized formula for the effect of dominant alleles. If p and q are the respective frequencies of dominant and recessive alleles of one breed and P and Q are the frequencies of dominant and recessive alleles of another breed, then the array of individuals in the two groups would be $(p^2DD + 2pqDR + q^2RR)^n$ and $(P^2DD + 2PQDR + Q^2RR)^n$ where D and R are respectively the dominant and recessive alleles and n the number of factor pairs involved. If the mean number of recessive homozygotes in the parents were $n(q^2 + Q^2)/2$, i.e., $nqQ + n(q-Q)^2/2$ then when the two parents are crossed, the mean number of homozygous recessive loci would be nqQ. Thus, it is clear that the mean number of homozygous recessive loci in a hybrid is always less than that found in the parents. Bruce (1910) concluded,"that dominance is positively correlated with vigour, we have the final result that the crossing of two pure breeds

produces a mean vigour greater than the collective mean vigour of the parent breeds."

The overdominance theory was proposed independently by East (1908) and Shull (1908) to explain 'heterozygosis'. They assumed that each allele had a different function in reference to the physiological products of the gene, the sum of the products of the two alleles in the heterozygous condition being superior to that of the either homozygote. However, the theory was not compatible with Mendelian inheritance. Later, East (1936) explained the overdominance theory by assuming a multiple allelic system which fit the Mendelian concept.

When Shull and East were formulating this hypothesis, there was no evidence of single locus heterosis. Stadler (1939) pointed out that maize plants heterozygous for the R locus that codes for tissue pigmentation, contained more pigment than either of the homozygotes. Several Drosophila workers also demonstrated that some recessive mutants, such as, 'ebony' and 'sepia' had a higher selective value in the heterozygous condition than either homozygote. Many recessive mutations were identified in the natural Drosophila population and it was thought that these mutations were kept in the natural population because the heterozygotes were selected for their better fitness (Crow 1952). Flor (1947) reported in flax, that if each of the parents were resistant to two separate strains of rust, the hybrids were resistant to both. Another series of examples were found in blood antigen groups in humans and cattle. Heterozygotes had all the antigenic properties of both the homozygotes (Irwin 1947).

2.4.1.2 Non allelic interaction in heterosis

Non allelic heterosis is caused by the interaction of two or more non allelic genes. Jones (1917) first proposed that linked dominant genes coming from the two inbred parents complement each other to produce high vigour or high yield in hybrid corn. Two major objections are put forward concerning this hypothesis. If dominant genes coming from two parents are the reason for high yield of hybrids, it should be possible to select an inbred line having all dominant favourable genes which would yield more than the best hybrid. However, such an inbred has not been reported in corn (Hallauer and Miranda 1988). Jones (1917) pointed out that due to linkage, all favourable genes cannot be assembled in one inbred. Dominant and recessive alleles segregate according to the expansion equation, $(3/4 + 1/4)^n$, where n is the number of loci involved. The segregation pattern for a trait controlled by one dominant gene should be skewed in the F_2 generation of a cross. Collins (1921) pointed out that the segregation pattern for a trait controlled by many genes, e.g. seed yield, approaches normal distribution. The hypothesis of linked dominant genes as the cause of hybrid vigour was supported by the work of Richey and Sprague (1931) in maize. Examples of non allelic heterosis were obtained in tomato (Powers 1944, 1950) and also in barley (Powers 1936). It was shown that tomato fruit yield resulted from the interaction of fruit weight and fruit number with each being controlled by independent genes. In barley, seed yield of the hybrids was shown to be associated with several characters contributed by the two parents, e.g., spikes per plant, height of plant and length of awn (Powers 1936).

2.5 Combining ability and heterosis in summer oilseed *B. rapa*

A high level of genetic diversity has been observed in *B. rapa* (Singh 1958). Although, the Indian yellow sarson form of *B. rapa* is highly self compatible, the Indian brown sarson and toria types (Singh 1958) as well as North American and European *B. rapa* cultivars are highly self incompatible (Downey *et al.* 1980). Thus, this review focuses primarily on the self incompatible, summer oilseed forms of *B. rapa*.

Significant heterosis for oil content in brown sarson (*B. rapa*) was reported by Rao (1970). He crossed four self compatible, four self incompatible and a partially self compatible line, in all possible combinations following a diallel mating design. The 36 hybrids and their parents were evaluated for a single year in India. Ten of the 36 hybrids had oil contents significantly lower, 11 crosses had significantly higher and the remaining 15 crosses had oil contents similar to their mid-parent values. They commented, "genetic control of oil content in brown sarson depends upon the particular cross combinations involved and dominance is exhibited by the alleles both with positive as well as negative effects." Only two hybrids significantly out yielded the best parent in oil yield.

Heterosis in brown sarson cultivar crosses was reported by Patnaik and Murty (1978). They evaluated four breeding lines, two parental cultivars and the F_1, F_2, BC_1 and BC_2 generations. Data was reported for days to flower and mature and seed yield on a row basis, as well as, plant height, number of primary and secondary branches and pod density on the main shoot based on ten random plants per row. Mid parent heterosis for seed yield in crosses ranged from 8.8 to 42.5%. Their results indicated the presence of dominance and/ or epistasis for most of the characteristics observed. The authors commented, "the presence

of marked non additive gene action . . . points to the need for maintaining genetic diversity with a possible emphasis on heterozygosis in populations for higher productivity."

Combining ability of brown sarson inbred lines was assessed by crossing nine inbred lines as females with three cultivars as males following a line x tester mating design (Yadav *et al.* 1988). The 27 hybrids and their parents were grown and evaluated for plant height, number of branches/plant, number of seeds/pod, 1000 seed weight and seed yield/plant. Non additive gene effects in the inheritance of all the traits studied was indicated.

Heterosis in yellow sarson, a self compatible and a largely self pollinating group of *B. rapa,* was obtained by crossing cultivars with two-valved and four-valved pods (Singh and Murky 1980). Ten four-valved and five two-valved cultivars were crossed in all possible combinations, including reciprocals. Fifteen parents and 210 hybrids were grown at two locations in India in 1970-71. Observations were recorded on number of primary branches, secondary branches, siliqua on main axis and seeds /siliqua as well as length of main axis and siliqua, days to 50% flowering and maturity, seed yield/3m long row, seed size, weight of 25 ml of seeds and oil content. The mean and range for seed yield (g) and oil content (%) for the parents were 118 g (79-154g) and 42.6% (41-44%), respectively and for the hybrids 130g (62-221g) and 42.1% (39-44%), respectively. Significant maternal effects for seed yield and oil content in the hybrids were noted. Hybrids means were equal or only marginally superior to the parental means for all characteristics. The stability of the hybrids was equal to their parents for seed yield, yield components and oil content.

Heterosis in crosses between *B. chinensis* (a vegetable crop) and oilseed *B. rapa* lines was reported (Chaudhary *et al.* 1987). One *B. chinensis* and four *B. rapa* lines were crossed

following a diallel mating design. Ten hybrid lines (excluding reciprocals) were evaluated in a single year trial at Hissar, India. Plant height, branches/plant, siliqua/plant, siliqua length, seeds/siliqua, seed yield/plant and seed weight were studied. The dominance component was greater than the additive component for all traits except seed size and siliqua length. The best general combiners were two *B. rapa* genotypes, Pusa Kalyani and BSH1, but the hybrids with highest yield/plant and the best SCA were crosses between *B. chinensis* x Pusa Kalyani and *B. chinensis* x Span.

Performance of a naturally occurring top cross hybrid between the yellow sarson cv. R-500 and a breeding line of Agriculture and Agri-Food Canada (AAFC) was reported by Hutcheson *et al.* (1981). The top cross hybrid was grown in a replicated test in two row plots together with two *B. rapa* cultivars, Torch and Candle and three *B. napus* cultivars, Regent, Midas and Altex in 1979 at Saskatoon. The hybrid yielded significantly more seed than the *B. rapa* cultivars (146% of Candle and Torch) and yielded in the range of *B. napus* cultivars (113% of Regent). The oil and protein content was slightly lower in the hybrid seeds than that of the checks, but per hectare oil and protein yield was the highest among the entries tested. The hybrid seeds were brown in colour, but the percent crude fibre in the meal was equal to Candle and significantly lower than any other entries tested. In another study, using same yellow sarson cultivar R-500 crossed to a conventional Canadian cultivar, the hybrid exhibited high parent heterosis of 24-47% for seed yield (Hutcheson 1984).

Agronomic performance and quality of synthetic cultivars and cultivar derived hybrids was compared on a four row plot basis with commercial open pollinated cultivars at Saskatoon, Canada (Falk 1991). Hybrids were produced by crossing three Canadian

cultivars Echo, Torch and Tobin as well as one Swedish strain Sv 8236580 using a diallel mating design. The base seeds for the synthetic populations (Syn- 0) were produced by mixing an equal number of seeds of each of the component cultivars. Syn-1 and Syn-2 seed of six 2-component, four 3-component and one 4-component cultivar synthetics were produced under field isolation. Twelve hybrids and their parents were compared over three years (1984-86), while the hybrids, the Syn-1 and their parents were compared over 2 years (1985-86). In 1986, hybrids along with the Syn-1 and Syn-2 populations and the parents were compared. The hybrids yielded, on average, 13, 15 and 31% more seed than their parents in 1984, 1985 and 1986, respectively. The Syn-1 populations averaged 14 and 30% more seed than the parents in 1985 and 1986 respectively, whereas, the Syn-2 yielded 28% more seed in 1986. No significant difference in seed oil content among hybrids, synthetics or parents was observed.

Significant commercial heterosis in *B. rapa* was obtained by crossing cultivars and lines of European and Canadian origin (Schuler *et al.* 1992). Reciprocal paired crosses were made between the Canadian cultivar Tobin and 19 European genotypes. Hybrid lines along with their parents were planted in a six replicate test with 6m long single row plots in western Canada at Saskatoon and Beaverlodge in 1987 and at Saskatoon, Scott and Beaverlodge in 1988. Days to 50% flowering and maturity, plant height, seed yield and oil content data were compared with that of the commercial cultivar Tobin. Seed yield of the parents ranged from 1017 kg/ha (Noko) to 1441 kg/ha (Torpe), while seed yield of the hand crossed hybrids ranged from 1135 kg/ha (Tobin x Candle) to 1847 kg/ha (Tobin x Noko). Sixteen of the 19 hybrids were significantly lower yielding than Tobin. The hybrid Tobin

x Noko, had an oil content similar to Tobin, while all other hybrids had significantly lower oil contents. Six of the hybrids had significantly smaller seeds than Tobin and none had significantly larger. None of the hybrids and parent cultivars flowered or matured earlier than Tobin. All hybrids and all parents except the cultivar Candle were significantly taller than Tobin. The authors noted a small degree of dominance for late maturity over earliness and incomplete dominance of tall over short types.

2.6 Use of doubled haploids in *Brassica* breeding

The DH technique has been used in *B. napus* (Thompson 1979, Stringam *et al.* 1995b) and *B. juncea* (Abraham *et al.* 1988) breeding programs. However, it is only recently that protocols to efficiently produce DH plants of *B. rapa* have been developed (Baillie *et al.* 1992).

The spontaneous occurrence of DH plants of *B. napus* were reported by Japanese scientists (Morinaga and Fukoshima 1933). The frequency of spontaneously produced *B. napus* DH plants under field conditions was determined (Thompson 1969, Stringam and Downey 1973). A procedure to identify haploid lines of winter oilseed rape (*B. napus*) in the field and to make diploids from such haploid plants was described by Thompson (1974). A DH line, thus produced, showed a significant increase in oil yield when compared in field trials to the then commercial cultivar 'Victor'. Another spontaneous DH line derived from the Canadian low erucic acid summer oilseed rape (*B. napus*) cultivar 'Oro' yielded significantly more seed and oil in several trials and was later marketed as the cultivar 'Maris Haplona' (Thompson 1979). Certain spontaneous *B. napus* DH lines exhibited better resistance to diseases (light leaf spot, and stem canker) and lodging (Thompson 1984).

Production of DH plants in *Brassica* using androgenesis was initiated by Kameya and Hinata (1970) in a vegetable *Brassica* (*B. oleracea*) and later in *B. napus* (Thomas and Wenzel 1975).

In *B. napus,* a population of microspore derived DH plants was compared with a population of inbred lines developed using the single seed descent (SSD) method (Chen and Beversdorf 1990). They crossed lines containing contrasting amounts of erucic, oleic, linoleic and linolenic fatty acids. The means, ranges and distribution patterns of the fatty acid compositions of the seed were similar in both populations for each fatty acid.

Plant height, maturity, yield, and oil content of microspore derived and SSD derived inbred lines of *B. napus* was compared by Charne (1990) and Charne and Beversdorf (1991). It was found that inbred lines derived by both methods were very similar in population means, variances, skewness and kurtosis for all traits studied.

B. napus microspore derived DH plants were evaluated under field conditions at Guelph, Canada (Siebel and Pauls 1989). Microspores were obtained from F_1 plants of crosses between the spring *B. napus* cultivars Regent (canola) x Golden (rapeseed) and a highly embryogenic, canola breeding line G231 (canola) x Reston (high erucic, low glucosinolate). One line was equal in glucosinolate content to the high glucosinolate parent with no lines exceeding the glucosinolate levels of the high glucosinolate parent. This result contrasted with previous findings that androgenic DH lines can have higher glucosinolate contents than the high glucosinolate parent (Hoffmann *et al.* 1982). The range and distribution of glucosinolate levels in androgenic DH and F_2 populations from the same cross were identical (Lichter *et al.* 1988).

Selection for disease resistance through androgenesis was reported by Sacristan (1982). Pycnidiospores of the blackleg pathogen [*Leptosphaeria maculans* (Desm.) Ces. et de Not.] were added to the media during the regeneration of haploid plants. Using this technique, a *B. napus* plant with partial resistance to blackleg was isolated. However, whether the partial resistance to blackleg persisted in later generations was not investigated. The same technique for regeneration of *B. napus* DH plants resistant to leaf spot [*Alternaria brassicicola* (Scsw.)Wilts.] was reported by MacDonald and Ingram (1986). The regenerated plants were more resistant to the pathogen than seed grown plants, but there was no correlation between resistance of the embryoids to the selection medium and the field resistance reaction of the derived plants to the pathogen. MacDonald and Ingram (1986) considered that the resistance of the regenerated plants was due to mutagenesis which occurred during tissue culture. However, two recent reports have claimed that haploid embryo sensitivity to blackleg, when cultured on a selection medium, is a good indicator of the derived plant tolerance to the pathogen under field conditions (Jedryczka *et al.* 1991, Bansal *et al.* 1994).

Selection for herbicide tolerance using androgenesis proved to be effective in *B. napus* (Beversdorf and Kott 1987, Polsoni *et al.* 1988, Swanson *et al.* 1988). Microspores were treated with gamma radiation or chemical mutagens (sodium azide/ethyl methane sulfonate/ethyl nitrosourea) and grown in a culture media for induction of haploid embryogenesis. The embryos thus produced were exposed to selection agents such as, glyphosate and chlorsulfuron (Swanson *et al.* 1988, Beversdorf and Kott 1987, Polsoni *et al.* 1988). This process of mutagenesis and selection for tolerance to chlorsulfuron herbicide

during haploid embryogenesis was found to be effective in producing heritable levels of tolerance in regenerated *B. napus* lines. However, no glyphosate tolerant plants were regenerated through this mutagenesis method.

DH lines of *B. napus* with improved earliness, straw strength and high oil content were identified in field tests in western Canada (Scarth *et al.* 1991). Four DH lines were similar in seed yield to their parents. The results indicated strong genotype x environment interactions for the DH lines that completely homozygous inbreds might be expected to exhibit. Similar results of superior, similar and inferior DH lines, when compared with their *B. napus* parents, were reported by Cegielska and Krzymanski (1987).

DH lines derived from a *B. juncea* cultivar were evaluated for three successive years (Abraham *et al.* 1988). DH lines, yielding less than the parent cultivar TM4, were discarded each year resulting in the retention of 44, 17 and 8 lines over three years out of 79 lines tested in the first year. The oil percentage and seed yield of the eight selected DH lines in the 6th generation were similar to that of the parent cultivar. It was concluded that a large number of androgenetic DHs would be needed to recover genotypes that were more productive than their parents.

A spring *B. napus* cultivar, Cyclone, (registered with AAFC, April 16, 1991, Reg. No. 3421) was developed by Prodana Seeds A/S, Denmark using the DH technique. Anthers from an F_2 generation plant from the cross Topas x G85/83, were cultured and DH plants produced. Following evaluation, one of these lines was registered in both Eastern and Western Canada as Cyclone, a canola quality cultivar with improved blackleg tolerance and high seed yield.

Recently, another *B. napus* cultivar, Quantum, produced through haploidy by the Plant Science Department of the University of Alberta, was registered for use in Western Canada (Stringam *et al.* 1995a, Stringam *et al.* 1995b). The cultivar was derived from a cross of a canola quality Australian cultivar, Maluka and a University of Alberta F_8 sister line to the cultivar Alto. Following the culture of microspores from F_1 plants and colchicine treatment of the resulting haploid plants, 37 DH lines were obtained. In subsequent field trials, 1991 through 1994, one line, 91-21864NA yielded significantly more seed and was significantly more resistant to blackleg disease and lodging than the designated check cultivars in the Western Canada Cooperative trials. The line was registered by AAFC as Quantum, Registration No. 4062, in 1995 (Stringam *et al.* 1995b).

During the regeneration phase of DH plant production, mutations can occur. Several workers identified somaclonal variants in DH populations (Cegielska and Krzymansky 1987 and Hoffmann *et al.* 1982). All workers mentioned that such novel traits, induced during *in vitro* culture, were heritable.

To date studies in *B. napus* and *B. juncea* suggest that the range in variation among DH lines and that of conventional inbreds is similar. Griffing (1975) suggested that the DH method would be the preferred method in terms of accelerating the breeding process if sufficient numbers of DH plants for field testing could efficiently be produced.

2.7 Doubled haploid production in *Brassica*

DH plants have been produced from male gametophytes in several *Brassica* species including *B. oleracea* (Kameya and Hinata 1970), *B. napus* (Thomas and Wenzel 1975), *B. juncea* (George and Rao 1982), *B. carinata* (Choung and Beversdorf 1985) and *B. rapa*

(Baillie *et al.* 1992).

Several factors have been reported to influence the induction of embryogenesis of *Brassica* male gametophyte cells (Ferrie *et al.* 1995). The yield of microspore derived embryos has been shown to be affected by the age of microspore donor plants and by the photoperiod and light intensity under which the donor plants were grown. Microspores from older *B. napus* plants were found more embryogenic than microspores from young plants (Takahata *et al.* 1991). Increased embryogenesis from cultured anthers was found when donor plants were grown in high light intensity and at low temperatures (10/5^{0}C day/night cycle). The genotype of the donor plant is also a critical factor in determining whether haploid embryos can be efficiently produced. Microspores from plants of the *B. napus* cultivar, Topas, are highly embryogenic, while microspores from Westar plants are recalcitrant (Keller, W., personal communication). In general, microspores from winter *B. napus* types have been found to be more embryogenic than those of the spring type (Ferrie *et al.* 1995). Microspores from *B. rapa* were less embryogenic than those of *B. napus* with some genotypes yielding very few embryos while others, such as the BC86-18 population, used in the present study, produced a large number of embryos. Production of up to 8,000 haploid embryos per person per year is possible in highly embryogenic material, but the average yield of a *B. rapa* genotype is about 1000 haploid embryos/person/per year of which about 60% will become doubled haploids (Ferrie A., personal communication).

The late uninucleate stage has been found to be the most responsive developmental stage for embryogenesis in *Brassica* male gametophytic cells. In some *Brassica* species, haploid embryogenesis has been enhanced with the pretreatment of buds using techniques,

such as, gamma radiation, ethanol stress, heat treatment and reduced atmospheric pressure (Ferrie *et al.* 1995).

The composition of the medium in which the microspores are cultured has also been a critical factor in the successful production of embryos. Elevated media sucrose levels (8% or higher) have been essential for efficient haploid embryogenesis in *Brassica* spp and the use of liquid media has been found to be superior to solid media (Lichter 1981). In *B. rapa* an initial high level of sucrose (17-20%) in the media for the first two days followed by a reduction in sucrose concentration in the media was found to increase embryogenesis (Baillie *et al.* 1992). Exposing the cultured microspores to an initial elevated temperature (32-35^{0}C) treatment has also enhanced haploid embryogenesis (Baillie *et al.* 1992).

3.0 MATERIALS AND METHODS

3.1 Plant material

Brassica rapa doubled haploid plants were produced in the laboratories of the Plant Biotechnology Institute, National Research Council of Canada, 110 Gymnasium Place, Saskatoon, Saskatchewan, S7N 0W9, Canada, utilizing the protocol developed by Baillie *et al.* (1992). The chromosome complement of the haploid plants was doubled by colchicine treatment and these plants were defined as DH_0 generation plants in this thesis, following the notation used by Stringam *et al.* (1995b). DH_0 plants received from the Plant Biotechnology Institute were numbered consecutively within donor groups as they were received. In some instances there were two plants in one pot. In these cases both plants within a pot were given the same number and the second plant within such pots was given a suffix letter. Selfed seeds produced on some DH_0 plants were also supplied by the Plant Biotechnology Institute and designated as DH_1 seeds which developed into DH_1 generation plants.

DH lines were derived from several *B. rapa* breeding populations which served as microspore donor populations (DP or donors) as discussed below.

BC86-18 (BC): In 1982, single plants from all *B. rapa* canola quality lines grown at the

Saskatoon Research Centre were bulked and the bulked population was field grown under isolation (Rakow, G., personal communication). In the following four years approximately five plants with the lowest glucosinolate content were selected in each generation (Hutcheson, D., personal communication). In this way the 'BC' population with a very low alkenyl glucosinolate content (< 3 μmoles per g oil free meal) was developed.

Composite B (CB): Seeds of single plants from all the canola quality lines grown at the Saskatoon Research Centre were bulked in 1982 and subjected to recurrent selection for high oil content to produce the 'CB' population (Rakow, G., personal communication).

Echo/Polar/DLY (EPD) is a population derived from intercrossing the F_1 generation of the two crosses, Echo x DLY and Polar x DLY. This population was segregating for glucosinolate and erucic acid content as well as seed colour. Echo and Polar are two brown seeded turnip rape cultivars released by AAFC, Indian Head and the University of Manitoba, Winnipeg, respectively. The line DLY is a low erucic acid, low glucosinolate, yellow seeded breeding line derived from a cross between a canola quality *B. rapa* selection from the Saskatoon Research Centre and a selection from a *B. rapa* yellow sarson introduction from India.

Comp. B/Reward (CBR) is a population derived from the cross Comp. B x Reward. Reward is a canola quality *B. rapa* cultivar released by the University of Manitoba (Scarth *et al.* 1992). Reward has good tolerance to white rust race 7A as well as higher oil and protein content than Tobin but with a similar seed yield.

Comp. B/R-500/Swedish (CRS) is a population derived from a three way cross between plants of Composite B, R-500 and Swedish. R-500 is a high erucic acid selection of yellow

sarson developed by AAFC, Saskatoon. Swedish is a canola quality *B. rapa* line introduced from Sweden.

The following cultivars were used as checks or testers in crosses with the DH lines:

Tobin is a canola quality cultivar developed by AAFC, Saskatoon, selected from crosses among the cultivar Candle, a low erucic acid strain, Swedish, and the high erucic acid, high glucosinolate, white rust resistant *B. rapa* line Pachuca, introduced from Mexico. Tobin has moderate to good tolerance to white rust race 7A.

Echo is a brown seeded high erucic *B. rapa* cultivar selected for high seed yield from the *B. rapa* landrace Polish and released by AAFC, Indian Head. Echo has 11-31% erucic acid content in the seed oil.

AC Parkland is a canola quality yellow seeded *B. rapa* cultivar developed by AAFC, Saskatoon. It has a similar seed yield to Tobin but has a significantly higher oil content and better white rust resistance.

3.2 Seed production for field testing

3.2.1 Selfed seed production on DH lines

DH plants were grown in plastic pots (15cm diameter by 16cm high) in a growth cabinet with a day/night temperature of 18^0C/16^0C and an 18h photoperiod. Selfed seed was produced on DH plants by bud selfing (Downey *et al.* 1980). Buds were opened with a pair of tweezers two days prior to natural anthesis, the stigma exposed and fresh, mature pollen from the same plant immediately applied. The bud was then covered with a glassine bag to exclude foreign pollen. Approximately 24 hours later the bag was removed and fresh pollen of the same plant applied again. The pollinated buds were then recovered for two to three

days. Five to ten buds, depending on bud availability, were selfed on DH_0 plants in the first round. Later, if no pods were visible on DH_0 plants another 10-15 buds were selfed. The most productive growth stage for selfed seed production on DH plants was found to be after the mid-flowering stage. When the selfed pod growth was visible, all other branches, pods and flowers were removed. As the plants approached maturity the frequency of watering was reduced to hasten maturity and avoid germination of seeds in the pods.

Forty three DH lines (BC=15, CB=13, EPD=15), which produced more than ten seeds when up to 25 buds on DH_0 plants were selfed, were selected for further seed multiplication in the greenhouse in 1992. Sufficient bud-selfed seeds for up to three years of field trials were produced on 162 DH lines from five (BC, CB, EPD, CBR and CRS) donors (Appendix A).

DH plants were grown in a potting media developed by W. H. Leonard (Downey *et al.* 1980) consisting of the following ingredients: one 113 litre bale of sphagnum peat moss; 2 x 110 litre bags medium grade vermiculite; 3.5 kg finely ground calcium carbonate; 3.2 kg 'Osmocote' 17-6-10 controlled release fertilizer; 655g of 20% super phosphate fines (0-20-0 fertilizer); 20g 'fritted' trace element, plant product no. 555 and 13g cheated iron (13%). Four to six parts of the above mixture were mixed with one part of washed torpedo sand (maximum particle size 1cm). The potting mixture was adjusted to a pH of 5-6 through the addition of calcium. Trace amounts of liquid fertilizer (20:20:20 @ 40g/10 litres) were applied with the irrigation water to all pots two or three times a day.

3.2.2 Field production of top cross seed, Saskatoon, 1993

DH_2 - DH_5 generation seeds from 41 DH lines (BC=14, CB=13, EPD=14) were

grown in the field at Saskatoon in 1993, surrounded by a genetically different pollen parent, Echo for the BC and CB groups and AC Parkland for the EPD group (Table 3.1). The high erucic acid characteristic (11-31%) of the pollen parent Echo was used as a marker to determine the level of outcrossing between DH lines and their top cross parent. Two hundred

Table 3.1 Erucic acid content of three groups of female DH lines and two pollen parents used for top cross seed production, Saskatoon, 1993

Donor population	DH line		Pollen parent	
	Number	Erucic acid	Cultivar	Erucic acid
BC	14	low	Echo	high
CB	13	low	Echo	high
EPD	14	segregating	AC Parkland	low

and twenty five selfed seeds of each DH line were sown in a single row, 6m long with 12 rows of the pollen parent on both sides and 61 cm between rows. In addition, the ends of the DH plots were separated by a 3.6m footpath and the DH rows were staggered so that no DH plot was planted in the same row in two adjacent ranges. The top cross nursery occupied an area 65 x 126m. Seed from each DH line was harvested, weighed and retained for growing in multi-location, replicated field trials in 1994.

3.2.3 Field production of polycross seed, Saskatoon, 1993

Plants from 42 DH lines (BC=14, CB=13, EPD=15) were grown in hill-plots that were arranged in a 6 x 7 lattice design with 12 replications. Hills were 30cm apart, planted with 12 seeds each. After emergence, plant density was reduced to four plants per hill. The polycross nursery occupied an area of 6.3 x 7.3m which maximized the opportunity for

random pollination. The experiment was isolated by 400 metres from any other *Brassica* crops to avoid contamination by unwanted pollen as recommended by the Canadian Seed Growers' Association (1994). At maturity, seed from each plant was hand-harvested and weighed. Replications one and three were destroyed by rain. The polycross seed from the remaining 10 replicates of each DH line was bulked in equal quantity by volume and this seed was used to plant 1994 trials to assess the combining ability of the DH lines.

3.2.4 F_1 seed production from crosses between DH lines

DH lines producing sufficient polycross and top cross seed for multi-location trials were selected as parents for the production of F_1 seed in the greenhouse. F_1 seed was produced by emasculating unopened flower buds followed by the immediate pollination with pollen from the selected male parents. Each pollinated bud was covered with a glassine bag to exclude foreign pollen. Fifty cross combinations were produced following a line x tester mating design (Table 3.2) (Comstock and Robinson 1952, Arunachalam 1974). However, only 44 crosses produced sufficient seeds (>300) for field testing.

3.3 Evaluation of DH lines

3.3.1 Single row DH nurseries, 1993-95

All DH field evaluation tests were conducted at the AAFC Research Farm, Saskatoon using DH_2 - DH_5 generation bud selfed seeds. Thirty one lines were evaluated for three years, 96 for two years and 162 for one year.

Forty three DH lines were evaluated at Saskatoon (BC=15, CB=13, EPD=15) in 1993, 131 lines (BC=41, CB=20, EPD=17, CBR=48, CRS=5) in 1994 and 115 lines (BC=48, CB=15, EPD=17, CBR=35) in 1995. A randomised complete block design was used in 1994

Table 3.2 Mating scheme for F_1 seed production following a line x tester design

Female DH parent	Male DH parent				
	EPD-2932	EPD-2975	EPD-2987	EPD-2988	EPD-2989
BC-2573	*	*	*	-	-
BC-2668	-	*	*	*	*
BC-2791	*	*	-	*	*
CB-2625	*	*	*	*	*
CB-2736	-	*	-	*	*
CB-2740	*	*	*	*	*
CB-2741	*	*	*	*	*
CB-2857	*	*	*	*	*
CB-2940	*	*	*	*	*
CB-2941	*	*	*	*	*

* sufficient seeds produced for field test, - insufficient seed produced for field test

and 1995, whereas, in 1993 a nested design was used with donors as the main plots and the DH lines nested within the main plots. Four replications were used in 1993 and 1994 and three in 1995. Single row plots, 6m long with 200 seeds/row were used in 1993, whereas, 3m long, single row plots with 100 seeds/row were used in 1994 and 1995. Donors were repeated three times per replication as checks in all three years. Sowing dates were May, 18, June, 6 and May, 20 in 1993, 1994 and 1995, respectively. Among the lines tested in 1994 and 1995, 89 DH lines were common to both years. All the test plots were planted on summer fallow. Fifty kg/ha of 11-51-0 fertilizer was applied with the seed in all the test plots in all years. Furadan 10G was seed-placed at the rate of 1g/6m row for flea beetle control. The trials were maintained weed free by hand weeding.

3.3.1.1 Agronomic observations

In the 1994-95 field trial, DH plots were combine harvested, and the seed and the remaining plant top growth collected separately. Seed and top growth material was oven

dried at 40^{0}C for 3 days and the weight recorded. Plant height was recorded on the standing crop at three random sites per plot. Days to flower (DF) and mature (DM) were determined based on the date of sowing. Days to flower was recorded when two to three plants in a plot began flowering. Days to mature was determined visually when 90% of plants and pods in a plot turned brown. The pod filling period (PF) was calculated following the formula PF=DM-DF. End of flowering date was recorded when all petals had fallen from all the plants in a plot. Leaf color was scored at the late rosette stage. The following visual ratings were used, 1 = yellow (Y), 2 = yellow-green (YG), 3 = green (G) and 4 = deep-green (DG). Number of plants per plot were counted at the late rosette stage as well as before harvest. Number of plants/plot at maturity is presented in the results section. Lodging was scored on a plot basis at the podding and maturity stages using a 1-5 scale with 1 being all plants upright and 5 all plants lodged. In 1994, pod length was determined on 20 pods per plot plucked from the mid raceme of random plants within the plot, excluding border plants. A total of 80 pods per DH line from 4 replicates was measured. Number of seeds/pod were counted from the pods collected for measuring pod length. One hundred seeds were counted and weighed from the dried and cleaned seed lot from each plot. Pod length, number of seeds/pod and hundred seed weight were not recorded in 1995. In addition, in 1994 morphological differences among the DH lines and their DP were visually rated for the following traits: plant width (1=narrow, 2=medium bushy, 3=bushy and spreading), branching habit (N=normal, $\geq 45^0$ angle with the main axis, A=appressed, angle $< 45^0$ with the main axis), pod setting (D=dense, S=sparse) and podding habit (N=normal, $\geq 45^0$ angle with the raceme, A=appressed, angle $< 45^0$ with the raceme).

In 1993 DH field trial, 30 plants per single row were hand harvested at maturity when pods and plants had turned brown. Pods were separated from the plants by hand, oven dried at 40^{0}C for 3 days, weighed, hand threshed and the seeds weighed. Plants, after removal of the pods, were dried in the oven and weighed. Weight of threshed seeds and pods were later added to biological yield. Plant height was recorded on five representative plants from each plot. Two DH lines (BC-2618 and BC-2950) produced only five plants, thus, 30 plants could not be harvested per plot and these two lines were excluded from statistical analyses.

3.3.1.2 Observation at rosette, flowering and podding stages

Growth stages were identified as follows, R = rosette plants with 6-10 true leaves, F = opened flowers on three to five plants within the row and P = podded plants with petals fallen from all flowers. Average dry weight and plant height was recorded at the R, F and P stages from five and three plant samples, in 1994 and 1995, respectively. In 1993, the fresh weight, number and measurement of different plant parts were taken from five plants per plot (Table 3.3).

3.3.2 Multi-location DH plot trial, 1995

Yield trials of DH lines and their donors were planted at Melfort, Scott and Saskatoon. Seven DH lines (BC=2, CB=2, EPD=3) were included in the Melfort trial while the Scott and Saskatoon trials each contained 10 DH lines (BC=3, CB=3, EPD=4). The entries were arranged in a randomised block design with four replications. Plots consisted of 6 rows, 6 metre long, spaced 31cm apart with the four centre rows of each plot planted to the *B. rapa* entries at 200 seeds/row and the outside two rows sown to barley. Planting was done on May 20, 30 and 25 at Melfort, Scott and Saskatoon respectively. All the

management practices were the same as in section 3.3.1. Data recorded were plants/plot, seed yield, plant height and days to flower and mature.

Table 3.3 Plant parts of DH lines of *B. rapa* on which data were recorded at four developmental stages at Saskatoon in 1993

Plant parts and measurement	Developmental stage			
	Rosette	Flowering	Podding	Maturity
Weight (g)				
Total plant	+	+	+	+
Leaves	+	+	+	-
Stems	-	+	+	+
Pods	-	-	+	+
Seeds	-	-	-	+
Number of				
Leaves	+	+	+	-
Pods	-	-	+	+
Branches	-	+	+	+
Measurement (cm)				
Plant height	+	+	+	+

+ data taken, - data not taken

3.4 Evaluation of hybrids

3.4.1 Evaluation of top cross and polycross progenies, 1994

Sixteen top cross (BC=2, CB=6, EPD=8) and 27 polycross (BC=6, CB=10, EPD=11) progenies were tested at Melfort, Scott and Saskatoon (MLT). An additional 13 top cross (BC=5, CB=6, EPD=2) and eight polycross (BC=5, CB=2, EPD=1) progenies, which did not produce sufficient seed for a multi-location trial, were evaluated only at Saskatoon. A randomized complete block design with four replications was used for the multi-location top cross trial and the additional top cross and polycross trials, whereas, a 6x6 lattice design was used for the multi-location polycross trial. Plots consisted of 6 rows, 6m long, spaced 31cm

apart with the centre four rows sown to *B. rapa* with 200 seeds per row and the two outside rows sown to barley. The three donors, CB, BC and EPD together with the cultivar Tobin were used as checks in all trials. In both polycross trials two additional check cultivars, Echo and AC Parkland, were also included. All the check cultivars were repeated twice/replication in the polycross multi-location trial. Date of sowing for the top cross and polycross progeny trials was June 1 and May 26 at Melfort and Scott, respectively. At Saskatoon, the top cross trial was sown June 3, the polycross trial, June 6. All the management practices were the same as in section 3.3.1. All test plots at Scott in 1994 were adversely affected by residual triasulfuron herbicide activity in the soil. Data were recorded for seed yield/plot.

3.4.1.1 Degree of outcrossing

The erucic acid content of the seed oil of the top cross seed was used as a marker to determine the amount of cross pollination. This was possible because the erucic acid content of *Brassica* seed is controlled by the genotype of the embryo (Harvey and Downey 1964). The degree of cross pollination in top cross seed was estimated by analyzing the erucic acid content of individual seeds.

Thirty seeds harvested from each of 13 BC and CB DH lines (Table 4.4) in the top cross nursery were analyzed for their fatty acid composition according to the Saskatoon AAFC Research Centre laboratory method which is based on the method described by Thies (1971). In addition, 30 seeds from the reserve seed of Echo were also analyzed. If less than one percent of erucic acid was detected in a top cross seed it was classified as a selfed or sibbed seed. The fatty acid profile of field produced top cross seeds was used to determine the level of hybridity that occurred in these lines under field conditions. Ten seeds produced

by bud selfing in the greenhouse from 10 BC and 11 CB of the same DH lines were also analyzed as to their fatty acid profile to establish the erucic acid genotype of each DH line.

3.4.2 Evaluation of single cross hybrids, 1994

Forty four single cross hybrids, produced following a line x tester mating scheme (Comstock and Robinson 1952, Arunachalam 1974) and an additional hybrid (CB-2740 x CB-2736), were evaluated together with their three donors, the 15 parental DH lines and the cultivar Tobin, making a total of 64 entries. The entries were sown in single row plots, 100 seeds/plot, 3m long, 61 cm between rows, arranged in an 8 x 8 lattice design with three replicates. Seed from the cultivar AC Parkland was planted in alternate rows to provide equal competition of the test entries with adjacent rows. The experiment was sown on June 6, 1994. All the management practices were the same as in section 3.3.1. In addition, the herbicide Muster (ethametsulfuron) was spray applied at the recommended rate of 10-15gms dissolved in 100 litres/ha of water, when the crop was at the 6-leaf stage, to control stinkweed and wild mustard. Data was recorded as in the 1994 DH trial (section 3.3.1.1). However, data at the R stage could not be recorded due to adverse weather conditions and plant morphological data were not recorded.

3.5 Statistical analyses

Data were statistically analyzed in SAS, for all DH field trials, all multi-location and hybrid trials, appropriate for the various designs. Correlation coefficients were calculated from DH line data only (excluding DP data) following 'Proc CORR procedure in SAS'. Rank correlations were determined using the statistical program Minitab. Frequency distribution graphs were produced using the graphics program "Cricket graph" and edited in "Canvas".

4.0 RESULTS

4.1 Production of seed for field testing

Selfed seed was produced on DH plants derived from five donor populations (Table 4.1. Appendix A Table 1-8). On average, 61% of DH_0 plants and 84% of DH_1 plants produced seed upon bud selfing. Average seed set on DH_0 and DH_1 plants ranged from 2.5 to 4.4 seeds per pod with the exception of DH_0 plants derived from Tobin which produced only 0.2 seeds per pod. The very low number of seeds/pod observed in the Tobin DH population may not be representative of Tobin DH plants since due to a misscommunication the Tobin DH plants were subjected to a high level of stress in the growth chamber. Crosses involving DH lines of BC and CB as females with EPD as males produced 18.2 and 19.4 seeds/pod, respectively, in the two crossing groups (Table 4.2, Appendix A Table 9).

Upon selfing up to 25 buds the DH_0 generation plants varied greatly in amount of seed set (Appendix A Tables 1, 3, 5). Of the 252 DH_0 plants from the three donors (BC=185, CB=30, EPD=37) 37% failed to produce any selfed seed while 44% produced >10 seeds (Appendix A Tables 1, 3, 5). A total of 111 plants produced >10 seed per pod, 17 plants produced 6-10 seeds per pod, 32 plants produced 1-5 seeds per pod and 92 plants produced

no seed (Appendix A Tables 1, 3, 5). Sixty two DH lines from the group that produced more than 10 seeds/pod and four DH lines that produced 6-10 seeds/pod were field tested (Appendix A Tables 1, 3, 5).

Table 4.1 Selfed seed production on DH_0 and DH_1 generation plants of *B. rapa* doubled haploid lines in the greenhouse, 1992 through 1994

Donor population	Gener-ation	Number of lines selfed	Number of lines setting seed	% lines setting seed	Av. no. of seeds/pod
BC[1]	DH_0	185	120	65	3.0
	DH_1	82	74	90	4.0
CB[1]	DH_0	30	17	57	4.4
	DH_1	51	31	61	3.4
EPD[1]	DH_0	37	23	62	2.5
	DH_1	28	27	96	3.9
CBR[2]	DH_0	-	-	-	-
	DH_1	85	74	87	3.9
Tobin[3]	DH_0	40	24	60	0.2
	DH_1	-	-	-	-

[1] Additional DH_1 seeds supplied by Plant Biotechnology Institute, Saskatoon
[2] All DH_1 seeds supplied by Plant Biotechnology Institute, Saskatoon
[3] DH_1 plants not grown

Table 4.2 Seed set in crosses between 10 female DH lines (three of BC and seven of CB) and five male DH lines of the EPD group in the greenhouse, 1992 through 1994

Donor population	Number of Crosses made	Number of Pods set	Number of Seeds harvested	Number of Seeds per pod
BC	15	1,938	35,234	18.2
CB	35	5,781	112,192	19.4

Forty one DH lines grown in the top cross nursery produced varying amounts of seed (Table 4.3). The 16 DH lines producing >16g of seed were evaluated at Melfort, Scott and Saskatoon while 13 DH lines producing >6g and <16g of seed were evaluated at Saskatoon only. Lines producing less than 6g of seed were not tested.

Table 4.3 Amount of top cross seed produced on 41 *B. rapa* DH lines from the BC, CB and EPD populations using Echo or ACParkland as top cross testers, Saskatoon, 1993

DH ♀ BC line	Seeds/row (g)	DH ♀ CB line	Seeds/row (g)	DH ♀ EPD line	Seeds/row (g)
---------♂ Echo----------		---------♂ Echo----------		------♂ AC Parkland--------	
BC-2573 [1]	43	CB-2624 [2]	8	EPD-2684 [2]	12
BC-2576	2	CB-2625 [2]	8	EPD-2712	3
BC-2588 [2]	9	CB-2627 [2]	10	EPD-2713 [1]	49
BC-2648 [2]	9	CB-2628 [1]	16	EPD-2716 [1]	20
BC-2660 [2]	7	CB-2630 [2]	7	EPD-2842	4
BC-2668 [2]	10	CB-2690 [2]	11	EPD-2932 [1]	42
BC-2678 [2]	8	CB-2736 [2]	12	EPD-2933	6
BC-2774 [1]	25	CB-2740 [1]	33	EPD-2935 [2]	8
BC-2791	6	CB-2741 [1]	28	EPD-2975 [1]	91
BC-2889	2	CB-2857 [1]	29	EPD-2978 [1]	28
BC-2916	5	CB-2940 [1]	23	EPD-2985	3
BC-3016	6	CB-2941 [1]	30	EPD-2987 [1]	35
BC-2618	2	CB-2689	5	EPD-2988 [1]	51
BC-2725	3			EPD-2989 [1]	41

[1] Produced sufficient seed for testing at Melfort, Scott and Saskatoon,
[2] Produced sufficient seed for testing at Saskatoon only

A high level of outcrossing in the top cross nursery was indicated by the high proportion of seed that contained erucic acid (Table 4.4). Hybridity ranged from 67-97% among the BC DH lines and from 47-100% for the CB lines. The hybridity level in 17 out of 26 lines was 80% or more. Since the DH lines from the EPD population were segregating for erucic acid content and the top cross pollen parent was a low erucic acid cultivar, AC Parkland, hybridity could not be determined using erucic acid as a marker.

Table 4.4 Range of erucic acid (%) in the seed oil of 30 individual field produced top cross seeds from of 13 DH lines from both the BC and CB groups, % hybridity (% of seeds containing >1% erucic acid) and the number of greenhouse produced selfed seed containing <0.4% erucic acid in 10 individual seeds/line

Top cross line	% erucic acid		DH selfed line	No. seeds in a 10 seed sample with <0.4% erucic acid
	Range in 30 seeds	%hybridity[1]		
BC-2573	<1-27	77	BC-2573	9
BC-2576	<1-27	97	BC-2576	10
BC-2588	<1-25	84	BC-2588	-
BC-2648	<1-25	94	BC-2648	9
BC-2660	<1-29	74	BC-2660	9
BC-2668	<1-27	67	BC-2668	10
BC-2678	<1-31	97	BC-2678	10
BC-2725	<1-26	90	BC-2725	9
BC-2774	<1-27	94	BC-2774	10
BC-2791	8-28	100	BC-2791	-
BC-2889	<1-31	84	BC-2889	10
BC-2916	<1-27	99	BC-2916	10
BC-3016	<1-27	87	BC-3016	-
CB-2624	<1-27	77	CB-2624	10
CB-2625	<1-27	80	CB-2625	10
CB-2627	<1-27	60	CB-2627	-
CB-2628	<1-26	87	CB-2628	10
CB-2630	<1-26	80	CB-2630	10
CB-2689	<1-27	84	CB-2689	9
CB-2690	<1-28	94	CB-2690	10
CB-2736	35-49	?	CB-2736	-
CB-2740	<1-26	67	CB-2740	10
CB-2741	<1-24	90	CB-2741	10
CB-2857	<1-25	94	CB-2857	10
CB-2941	<1-27	47	CB-2941	10
CB-2940	34-59	?	CB-2940[2]	0
Echo [3]	11-31	-	-	-

[1] Seed containing >1% erucic acid classed as outcrossed seed

[2] (41-48% erucic acid in selfed seed) [3] Pollinator cultivar

Polycross seed produced on 42 DH lines ranged from 1 to 69g (Table 4.5). Several lines, such as, BC-2576, BC-2588, BC-2889, EPD-2639, EPD-2716, EPD-2935 and EPD-2985 exhibited leaf chlorosis, were short, comparatively late to flower and produced little seed. Because of the limited seed available, only 27 polycross lines were evaluated at Melfort, Scott and Saskatoon and eight lines were evaluated only at Saskatoon.

Table 4.5 Amount of polycross seed produced on 42 *B. rapa* DH lines from the BC, CB and EPD donor populations, Saskatoon, 1993

BC DH line	Seed produced (g)	CB DH line	Seed produced (g)	EPD DH line	Seed produced (g)
BC-2573[1]	19	CB-2624[1]	28	EPD-2639	1
BC-2576	5	CB-2625[2]	12	EPD-2684[1]	21
BC-2588[2]	8	CB-2627[1]	26	EPD-2712[1]	19
BC-2648[2]	6	CB-2628[1]	30	EPD-2713[1]	22
BC-2660[2]	17	CB-2630[1]	21	EPD-2716	3
BC-2668[1]	39	CB-2689	5	EPD-2842[1]	16
BC-2678[2]	10	CB-2690[2]	12	EPD-2932[1]	26
BC-2725[1]	28	CB-2736[1]	36	EPD-2933[1]	21
BC-2774[1]	24	CB-2740[1]	39	EPD-2935[2]	7
BC-2791[1]	36	CB-2741[1]	40	EPD-2975[1]	34
BC-2889	3	CB-2857[1]	47	EPD-2978[1]	17
BC-2916[2]	6	CB-2940[1]	69	EPD-2985	4
BC-3016[1]	24	CB-2941[1]	31	EPD-2987[1]	27
BC-2618	6			EPD-2988[1]	20
				EPD-2989[1]	28

[1] Produced sufficient seed for testing at Melfort, Scott and Saskatoon,
[2] Produced sufficient seed for testing at Saskatoon only

4.2 Performance of DH lines

Thirty one lines were evaluated for three years, 96 for two years and 162 for one year. Evaluation was done on selfed progeny produced on DH_1 - DH_4 plants. Data were collected on plants/plot at maturity, seed yield, biological yield, plant height, days to flower and mature, pod filling period, pod length, number of seeds/pod and 100 seed weight. Preliminary observation on *B. rapa* DH lines were done in 1993 to asses general effect of inbreeding in this species. Data on individual DH lines are presented in Appendix B.

4.2.1 Agronomic observations on DH lines, Saskatoon, 1993-95

On average, DH lines differed significantly from their donor populations for seed and biological yield, plant height, days to flower, pod filling period, pod length and number of seeds/pod in all years tested (Table 4.6). For plants/plot, days to mature and hundred seed weight, DH lines were not significantly different from their donors over all years.

In comparison to their respective donors the DH lines were generally shorter in height, later to flower, earlier in maturity, had a shorter pod filling period, produced fewer seeds/pod and had a lower seed and biological yield. Plants in all donor populations flowered very early and matured comparatively later than their derived DH lines. The average number of seeds/pod for all donor populations was approximately double, seed yield three to seven times higher and biological yield two to four times greater than the average of their respective DH lines (Table 4.6).

Table 4.6 Average of 10 traits and contrasts comparing *B. rapa* doubled haploid (DH) lines and their donor populations (DP), Saskatoon, 1993-95

Trait measured	1993			1994			1995		
	DP(3)[1]	DH(41)	Contrast	DP(3)	DH(131)	Contrast	DP(3)	DH(115)	Contrast
Plants/plot (number)[2]	134	86	**	31	29	ns	21	11	**
Seed yield (g)[3]	9.3	2.9	**	191	47	**	238	35	**
Biological yield (g)[3]	26	14	**	560	336	**	766	222	**
Plant height (cm)	110	87	**	99	84	**	86	64	**
Flowering (days)	35	45	**	33	38	**	30	39	**
Maturity (days)	99	99	ns	87	82	**	104	102	ns
Pod filling period (days)	64	54	**	57	45	**	75	64	**
Pod length (cm)	6	5	**	6	5	**			
Seeds/pod (number)	22	10	**	23	11	**			
100 seed weight (mg)	254	224	**	208	212	ns			

*,** Significant at 5 and 1% level, respectively

[1] Numbers of entries tested in parentheses

[2] 200 seeds planted in 1993, 100 seeds planted in 1994 and 1995

[3] Yield: 1993 on per plant basis, 1994 and 1995 on per plot basis

A preponderance of low yielding DH lines was evident in all three years (Fig. 4.1a). The same trend was observed for biological yield and for number of seeds/pod (Figs. 4.1a, 4.1c). However, the opposite trend was observed for plant height in all three years, i.e., there was a preponderance of tall lines among the DHs. The existence of a distinct low biomass and seed yielding group was identified in all three years (Figs. 4.1a). This low yielding group was made up of the same lines in both 1994 and 1995 when yield was recorded on a per plot basis. A distinctly late flowering group was also present in all three years (Fig. 4.1b)

4.2.2 Association between traits of DH lines.

Correlation coefficients between traits of 41 DH lines in 1993, 131 DH lines in 1994 and 115 DH lines in 1995 were calculated (Table 4.7). Significant positive associations were found between seed yield and the following traits for each year the trait was measured; biological yield, plant height, pod length, number of seeds/pod, leaf color index and the pod filling period. A negative association between seed yield and days to flower was also found in every year. In 1994 or 1995 when seed yield was recorded on a plot basis, seed yield was positively correlated with plants/plot and hundred seed weight. In 1993, seed and biological yield/plant was measured from 30 plants/plot. The number of plants/plot was variable which influenced plant size.

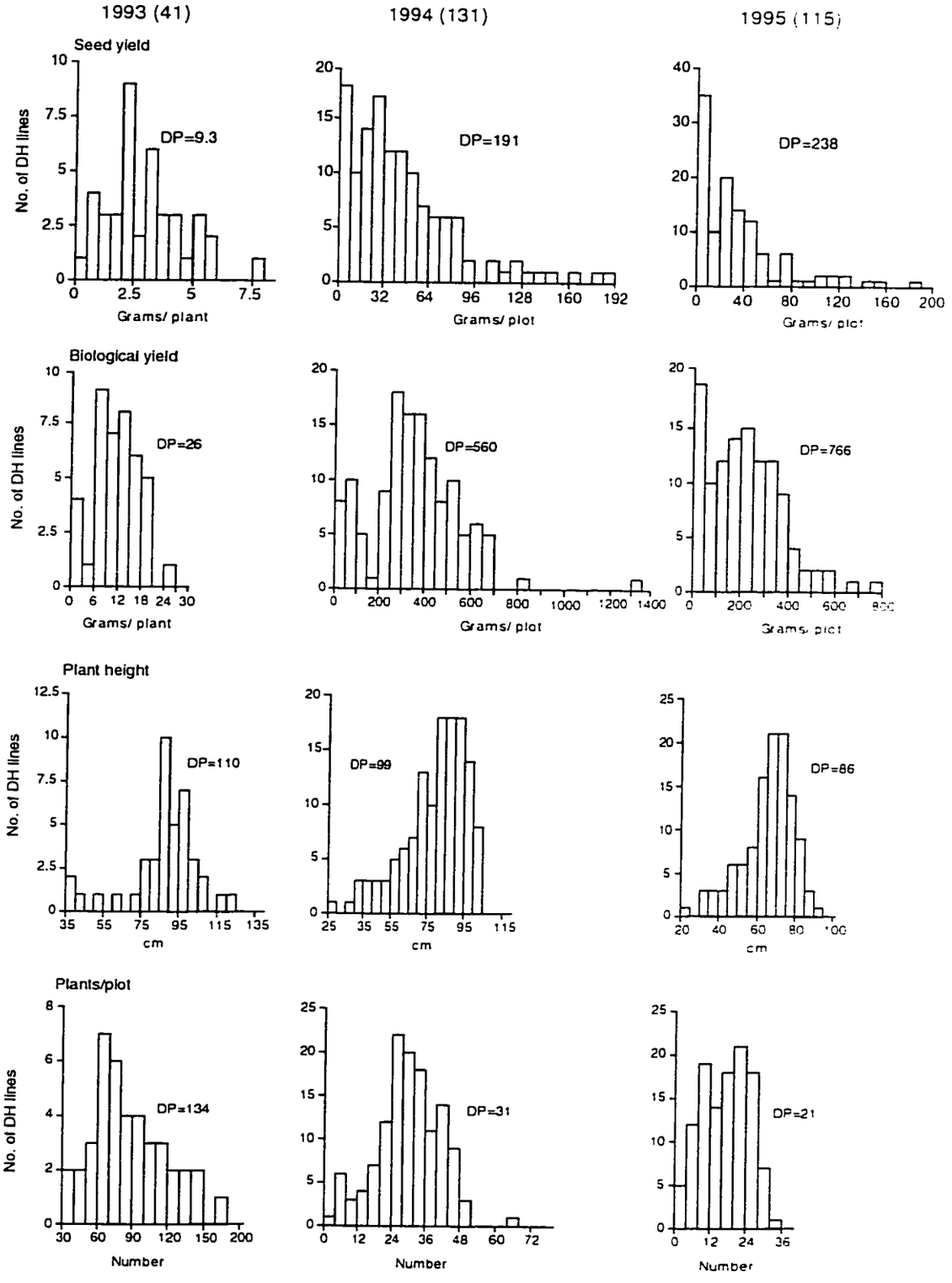

Fig. 4.1a Variation in seed yield (g), biological yield (g), plant height (cm) and plants/plot of *Brassica rapa* DH lines grown in the field and the average of their donor populations (DP), Saskatoon, 1993-1995

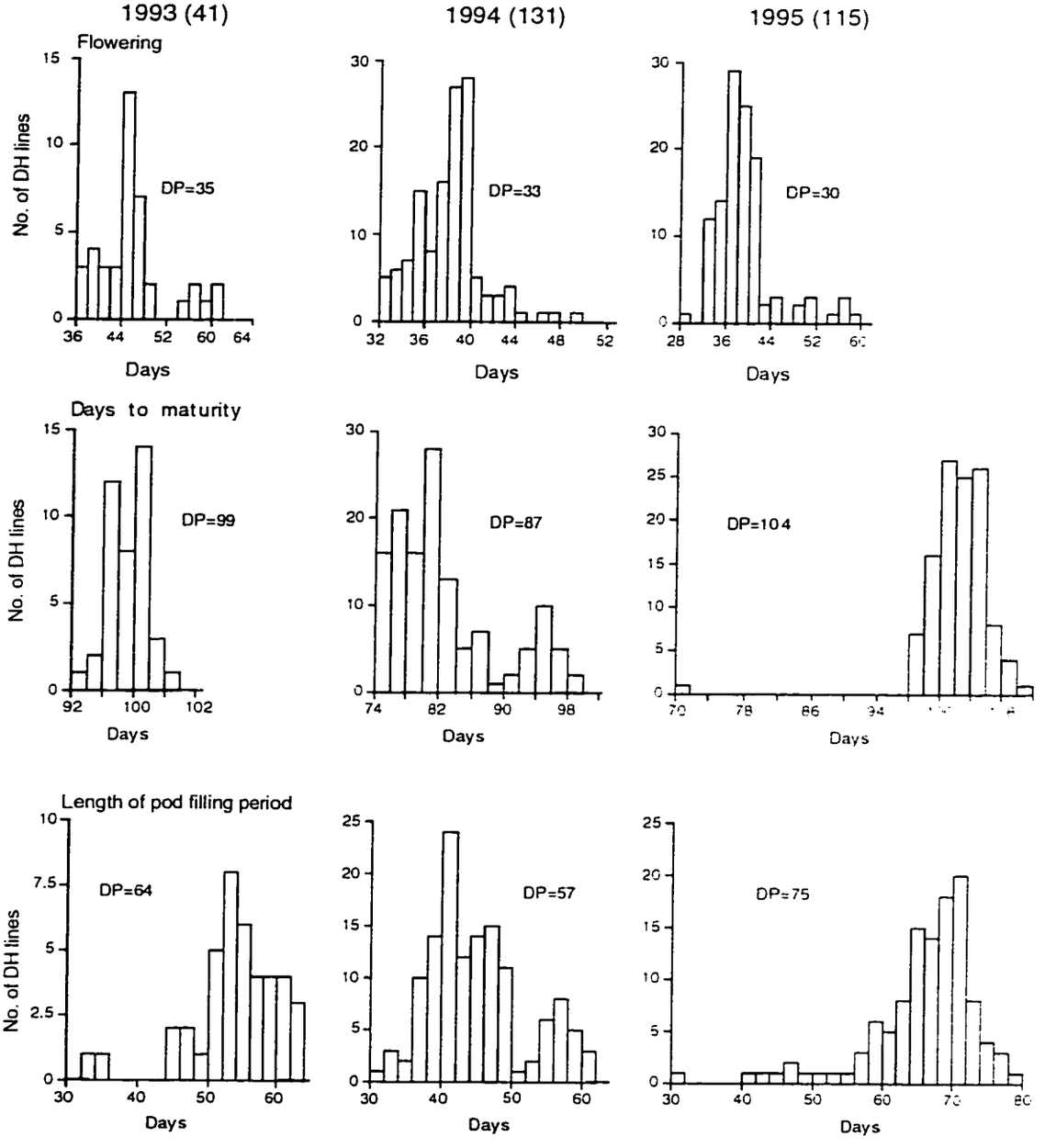

Fig. 4.1b Variation in days to flower and mature and pod filling period (days) of *Brassica rapa* DH lines grown in the field and the average of their donor populations (DP), Saskatoon, 1993-1995

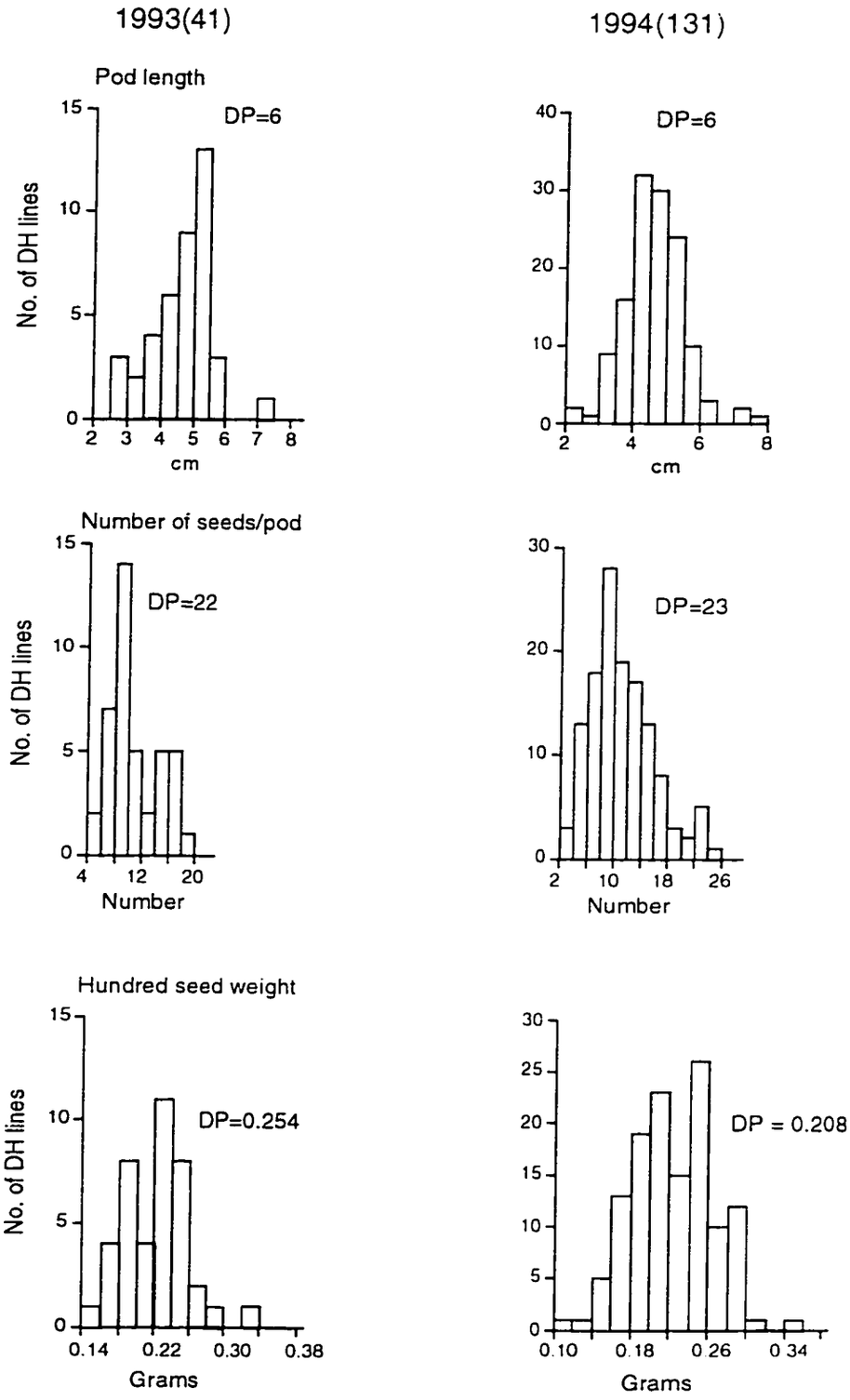

Fig. 4.1c Variation in pod length (cm), number of seeds/pod and hundred seed weight (g) of *Brassica rapa* DH lines grown in the field and the average of their donor populations (DP), Saskatoon, 1993-1995

Table 4.7 Correlation coefficients between traits of *B. rapa* doubled haploid lines, Saskatoon, 1993-95

Trait	Biological yield	Plants /plot	Plant height	Days to flower	Days to mature	Leaf color	Pod filling period	Pod length	Seeds /pod	100 seed weight
1993 (41 lines)										
Seed yield/plant	0.64**	-0.12	0.46**	-0.34*	0.09	0.48**	0.35*	0.53**	0.45**	-0.01
1994 (131 lines)										
Seed yield/plot	0.78**	0.55**	0.44**	-0.61**	0.14	0.61**	0.40**	0.50**	0.74**	0.18*
1995 (115 lines)										
Seed yield/plot	0.84**	0.54**	0.45**	-0.51**	0.37**	0.64**	0.54**			

4.2.3 Performance of 89 DH lines, Saskatoon, 1994-95

Eighty nine DH lines tested over the two years in 1994 and 1995 at Saskatoon were analyzed seperately. Mean square values for entries were significant for number of plants/plot, seed yield, biological yield, plant height and days to flower and mature (Table 4.8). A high positive association was obtained between the ranked performance of DH lines in 1994 and their ranked performance in 1995 (Table 4.9).

Contrast mean square values for donors vs. derived DH lines were highly significant for seed yield, biological yield, plant height and days to flower for all groups in both years (Table 4.10). Contrast mean square values comparing the average of all DH lines with the average of all donors (All DP vs. all DH) were significant for seed yield, biological yield, plant height and days to flower and mature over the two years (Table 4.10).

Table 4.8 Mean square values for plants/plot, seed and biological yield, plant height and days to flower and mature for 89 doubled haploid lines derived from *B. rapa* donor populations, BC, CB, EPD, CBR grown at Saskatoon, 1994-95

Source of variation	df	Plants /plot	Seed yield	Biological yield	Plant height	Days to flower	Days to mature
1994							
Entries	100	483**	15174**	142129**	1130**	40**	148**
Replication	3	27	79	1353	119	2	3*
Error	300	25	161	2823	73	3	1
1995							
Entries	100	177**	17908**	162603**	617**	104**	25**
Replication	2	17	200*	1740	745**	186**	35**
Error	200	8	68	1030	65	19	6

*,** Significant at 5 and 1% level, respectively

Table 4.9 Correlation coefficients of the ranked average plants/plot, seed and biological yield, plant height, days to flower and mature in 1994 and 1995 for 89 *B. rapa* doubled haploid lines grown at Saskatoon

Trait	Correlation coefficient
Plants/plot	0.61**
Seed yield	0.78**
Biological yield	0.78**
Plant height	0.80**
Days to flower	0.57**
Days to mature	0.52**

** Significant at the 1% level.

Table 4.10 Contrast mean square values for plants/plot, seed and biological yield, plant height and days to flower and mature comparing 89 *B. rapa* doubled haploid (DH) lines and their donor populations, BC, CB, EPD and CBR, Saskatoon, 1994-95

Source of variation	Year	Plants /plot	Seed yield	Biological yield	Plant height	Days to flower	Days to mature
		----------Donor vs. derived DH----------					
BC	94	302**	246538**	270793**	1179**	107**	230**
	95	628**	149074**	994666**	1529**	124**	17ns
CB	94	19ns	150770**	1634389**	5241**	276**	726**
	95	118**	237522**	2625420**	6121**	293**	69**
EPD	94	5ns	110212**	380619**	1659**	283**	229**
	95	316**	414045**	2147823**	2616**	1180**	103**
CBR	94	328**	412117**	1245561**	1918**	269**	135**
	95	1061**	528907**	3259631**	3193**	842**	64**
All DP vs All DH	94	1ns	4019**	3026718**	10020**	851**	1625**
	95	380**	1274000**	8791214**	12517**	2303**	188**

** Significant at the 1% level.

Only one of the 89 DH lines (BC-3015Y) was equal in yield to its respective donor (Table 4.11). Seven lines common to both years had a high seed yield per plot (90-200g) (Table 4.11 in bold face), while 26 lines were low yielders (0 -25g) in both years (Table 4.11, italicized). The lines which performed well (>50g) in both years were BC-111, BC-2913, BC-2953, BC-3015Y, BC-3015G, BC-3015B, CB-42, CB-2741, CB-2940, EPD-2975, EPD-2987, EPD-2988, CBR-210, CBR-452, CBR-466, CBR-591, CBR-592, CBR-597 and CBR-643. Several lines (BC-2459, BC-2665, BC-2774, BC-2791, BC-2965, CB-2524, EPD-9, EPD-2932, EPD-2978, EPD-2989, CBR-13, CBR-60, CBR-99, CBR-462, CBR-519, CBR-581) were good seed yielders under the good growing conditions of 1994 however, in 1995 when drought stress occured at the seedling stage, their performance was comperatively low (7-47g).

Table 4.11. Plants/plot, seed and biological yield, harvest index, plant height, days to flower and mature and leaf color index of 89 *B. rapa* doubled haploid (DH) lines and their donor populations, BC, CB, EPD and CBR, Saskatoon, 1994-95

Entry	Plants /plot		Seed yield		Biological yield		Harvest index	
	1994	1995	1994	1995	1994	1995	1994	1995
BC-111	35	18	78.6	50.4	342	420	0.23	0.11
BC-276	32	25	45.9	59.6	290	309	0.16	0.19
BC-2459	39	10	73.2	36.3	544	195	0.13	0.20
BC-2507	44	30	39.8	43.2	570	321	0.07	0.15
BC-2576	*37*	*11*	*14.7*	*4.8*	*214*	*56*	*0.07*	*0.12*
BC-2588	*26*	*20*	*10.4*	*8.4*	*82*	*43*	*0.13*	*0.18*
BC-2595	*23*	*18*	*3.0*	*2.1*	*55*	*43*	*0.06*	*0.05*
BC-2660	20	18	27.7	20.3	290	152	0.10	0.14
BC-2665	38	27	80.6	31.0	492	205	0.16	0.15
BC-2668	8	13	20.3	35.7	218	178	0.10	0.22
BC-2678	*28*	*23*	*8.9*	*9.7*	*132*	*173*	*0.07*	*0.06*
BC-2679	*34*	*22*	*5.6*	*8.8*	*101*	*147*	*0.06*	*0.06*
BC-2705	*21*	*11*	*14.9*	*6.6*	*375*	*145*	*0.04*	*0.05*
BC-2723	4	19	14.1	28.6	139	239	0.10	0.13
BC-2725	27	18	35.6	29.5	293	217	0.12	0.14
BC-2774	40	16	52.1	25.2	332	194	0.16	0.13
BC-2791	25	19	72.5	26.5	424	229	0.17	0.12
BC-2886	13	6	41.0	10.0	230	105	0.18	0.10
BC-2889	*17*	*5*	*5.7*	*0.0*	*87*	*16*	*0.07*	*0.02*
BC-2913	40	30	63.6	73.4	458	499	0.14	0.15
BC-2916	*23*	*10*	*17.6*	*6.1*	*299*	*76*	*0.06*	*0.09*
BC-2927	*47*	*24*	*25.2*	*22.2*	*350*	*283*	*0.07*	*0.08*
BC-2953	33	28	54.3	77.7	458	326	0.12	0.31
BC-2960	*18*	*11*	*5.0*	*1.5*	*72*	*38*	*0.07*	*0.03*
BC-2965	32	27	54.9	38.7	549	388	0.10	0.10
BC-3011	28	24	29.7	15.5	373	139	0.08	0.11
BC-3015Y	**28**	**22**	**185.9**	**188.3**	**1309**	**696**	**0.14**	**0.28**
BC-3015G	**47**	**29**	**181.9**	**151.4**	**834**	**769**	**0.22**	**0.20**
BC-3015B	**36**	**27**	**120.5**	**111.0**	**599**	**515**	**0.20**	**0.22**
BC-3016	27	11	38.3	12.2	359	114	0.11	0.11
BC-3034	40	22	25.2	44.6	261	228	0.10	0.19
BC donor [1]	24	11	199.1	172.0	652	589	0.31	0.29

Table 4.11 contd.

Entry	Plants /plot		Seed yield		Biological yield		Harvest index	
	1994	1995	1994	1995	1994	1995	1994	1995
CB-13	*42*	*18*	*10.5*	*7.9*	*83*	*45*	*0.13*	*0.16*
CB-15	*30*	*15*	*11.0*	*2.5*	*84*	*34*	*0.13*	*0.07*
CB-42	40	23	61.5	74.6	658	536	0.10	0.14
CB-56	*30*	*5*	*1.8*	*2.1*	*23*	*30*	*0.08*	*0.07*
CB-2524	43	29	70.4	45.6	523	277	0.14	0.16
CB-2625	*17*	*20*	*23.0*	*24.9*	*267*	*200*	*0.08*	*0.12*
CB-2627	22	22	16.2	33.9	233	283	0.07	0.13
CB-2630	*19*	*14*	*23.1*	*20.8*	*256*	*204*	*0.09*	*0.10*
CB-2690	17	14	38.7	22.0	405	293	0.09	0.08
CB-2740	18	19	28.2	28.5	254	175	0.11	0.16
CB-2741	29	22	56.9	76.6	318	344	0.19	0.22
CB-2857	32	22	44.4	45.0	283	353	0.16	0.13
CB-2940	24	11	89.9	53.4	451	194	0.20	0.27
CB-2941	28	19	34.9	49.8	281	190	0.13	0.26
CB donor [1]	30	22	160.1	213.8	824	821	0.20	0.26
EPD-1	33	9	42.0	46.1	344	376	0.12	0.12
EPD-7	27	27	30.6	42.3	377	356	0.07	0.10
EPD-9	35	15	54.5	25.5	642	363	0.09	0.07
EPD-2684	*26*	*14*	*18.3*	*22.6*	*211*	*240*	*0.09*	*0.10*
EPD-2842	*27*	*20*	*21.0*	*19.6*	*318*	*233*	*0.07*	*0.09*
EPD-2932	41	26	54.8	26.9	335	200	0.16	0.14
EPD-2933	23	13	45.9	14.5	322	131	0.14	0.11
EPD-2935	*24*	*9*	*12.1*	*6.1*	*129*	*31*	*0.09*	*0.20*
EPD-2975	**47**	**30**	**108.0**	**94.2**	**512**	**367**	**0.21**	**0.26**
EPD-2978	32	19	67.2	24.1	319	142	0.21	0.19
EPD-2985	*21*	*9*	*0.2*	*0.0*	*28*	*12*	*0.01*	-
EPD-2987	34	25	79.8	52.1	329	288	0.24	0.18
EPD-2988	36	33	107.2	77.2	449	348	0.24	0.23
EPD-2989	39	16	55.0	26.9	340	126	0.16	0.21
EPD donor [1]	31	25	155.3	270.5	634	779	0.25	0.35

Table 4.11 contd.

Entry	Plants/plot		Seed yield		Biological yield		Harvest index	
	1994	1995	1994	1995	1994	1995	1994	1995
CBR-2	31	22	26.7	22.6	385	351	0.07	0.06
CBR-11	25	26	27.0	35.0	346	337	0.08	0.10
CBR-13	25	9	68.1	7.3	388	86	0.18	0.08
CBR-14	*24*	*4*	*25.8*	*4.6*	*255*	*69*	*0.11*	*0.06*
CBR-26	*35*	*25*	*16.7*	*20.6*	*312*	*288*	*0.05*	*0.07*
CBR-33	*29*	*15*	*15.2*	*17.1*	*259*	*193*	*0.06*	*0.09*
CBR-60	48	23	90.1	46.5	504	332	0.18	0.14
CBR-61	*9*	*2*	*0.0*	*0.0*	*3*	*0*	-	-
CBR-83	14	1	40.0	0.0	112	0	0.36	-
CBR-85	42	14	51.1	6.0	336	37	0.15	0.18
CBR-85A	*5*	*3*	*6.1*	*0.0*	*56*	*16*	*0.09*	-
CBR-99	37	17	66.8	29.9	677	420	0.10	0.07
CBR-106	29	21	36.1	30.4	251	193	0.14	0.14
CBR-210	**37**	**18**	**117.1**	**107.1**	**406**	**348**	**0.27**	**0.30**
CBR-452	35	21	70.3	81.9	412	426	0.17	0.19
CBR-455	*7*	*1*	*22.1*	*3.3*	*188*	*21*	*0.12*	*0.05*
CBR-462	44	15	63.6	30.3	550	281	0.12	0.10
CBR-464	46	20	30.1	41.4	421	297	0.07	0.14
CBR-465	41	27	72.9	38.6	647	374	0.11	0.01
CBR-466	42	21	70.6	145.5	516	588	0.14	0.24
CBR-490	23	9	40.4	15.2	209	102	0.19	0.11
CBR-494	26	9	26.2	3.7	183	19	0.14	0.22
CBR-507	50	24	47.3	5.5	372	261	0.13	0.02
CBR-519	43	26	62.7	35.6	331	146	0.19	0.23
CBR-581	19	6	82.0	18.3	400	184	0.21	0.10
CBR-591	65	27	86.1	129.7	672	583	0.13	0.22
CBR-592	42	21	146.7	61.1	541	327	0.27	0.19
CBR-597	**41**	**22**	**141.8**	**125.1**	**530**	**306**	**0.27**	**0.40**
CBR-643	**47**	**18**	**163.9**	**114.3**	**620**	**323**	**0.26**	**0.35**
CBR-705	*4*	*4*	*2.5*	*8.7*	*47*	*73*	*0.04*	*0.11*
CBR donor [1]	41	27	250.0	293.8	891	875	0.28	0.34
LSD(0.05)[2]	7	5	18	13	38	51	0.05	0.04
LSD(0.05)[3]	6	4	15	11	31	42	0.04	0.04

Table 4.11 contd.

Entry	Plant height		Days to flower		Days to mature		Leaf color index	
	1994	1995	1994	1995	1994	1995	1994	1995
BC-111	85	67	33	36	77	104	3	3
BC-276	74	67	34	36	78	101	3	3
BC-2459	108	79	38	37	86	106	3	3
BC-2507	100	66	39	38	76	105	3	3
BC-2576	86	60	43	48	80	101	2	1
BC-2588	55	58	39	48	80	102	1	1
BC-2595	49	39	39	42	77	98	1	2
BC-2660	78	61	35	42	81	102	3	3
BC-2665	86	69	35	38	83	104	3	3
BC-2668	94	66	36	44	76	101	3	3
BC-2678	61	44	39	39	76	98	2	2
BC-2679	56	47	40	40	80	103	1	2
BC-2705	86	67	39	38	77	105	2	2
BC-2723	87	72	39	38	77	101	3	3
BC-2725	89	62	35	35	75	103	3	3
BC-2774	84	59	34	37	81	101	3	3
BC-2791	96	74	37	34	75	100	3	3
BC-2886	86	88	38	39	74	102	3	3
BC-2889	62	42	40	56	81	109	1	1
BC-2913	105	82	39	32	83	104	3	3
BC-2916	90	64	39	40	90	103	3	3
BC-2927	88	70	35	39	76	101	3	3
BC-2953	89	69	34	35	81	104	3	3
BC-2960	59	53	41	59	81	98	1	1
BC-2965	100	74	38	32	93	103	3	3
BC-3011	95	78	38	37	84	104	3	3
BC-3015Y	107	89	32	32	86	109	4	4
BC-3015G	103	87	32	39	86	109	4	4
BC-3015B	93	82	32	32	86	105	4	4
BC-3016	94	73	38	41	81	103	3	3
BC-3034	68	54	39	40	77	99	3	3
BC donor [1]	95	80	34	36	85	104	3	3

Table 4.11 contd.

Entry	Plant height		Days to flower		Days to mature		Leaf color index	
	1994	1995	1994	1995	1994	1995	1994	1995
CB-13	64	46	42	43	76	100	1	2
CB-15	47	39	44	40	75	99	1	2
CB-42	98	69	38	35	96	106	3	3
CB-56	47	31	42	40	79	99	1	2
CB-2524	100	69	39	35	96	104	3	3
CB-2625	97	73	38	36	79	102	3	3
CB-2627	95	81	37	34	79	102	3	3
CB-2630	101	73	37	38	81	102	3	3
CB-2690	108	74	38	35	80	102	3	3
CB-2740	104	77	38	37	79	101	3	3
CB-2741	96	69	35	32	76	101	3	3
CB-2857	95	65	38	36	77	101	3	3
CB-2940	102	70	39	36	78	98	3	3
CB-2941	80	63	38	32	76	99	3	3
CB donor [1]	111	93	34	30	94	104	3	3
EPD-1	72	53	39	38	81	106	3	3
EPD-7	91	82	39	39	81	102	3	3
EPD-9	94	72	36	36	81	103	3	3
EPD-2684	95	74	34	35	82	103	3	3
EPD-2842	92	68	35	33	75	101	3	3
EPD-2932	92	72	35	32	80	102	3	3
EPD-2933	92	75	37	40	83	104	3	3
EPD-2935	76	62	41	39	78	101	2	2
EPD-2975	88	75	35	37	78	100	3	3
EPD-2978	79	52	39	40	79	99	3	3
EPD-2985	35	23	46	56	75	96	1	1
EPD-2987	84	58	35	38	82	100	3	3
EPD-2988	80	76	36	35	78	97	3	3
EPD-2989	91	71	38	38	77	99	3	3
EPD donor [1]	96	84	32	25	84	105	3	3

Table 4.11 contd.

Entry	Plant height		Days to flower		Days to mature		Leaf color index	
	1994	1995	1994	1995	1994	1995	1994	1995
CBR-2	86	78	34	37	86	105	3	3
CBR-11	97	93	39	37	86	102	3	3
CBR-13	79	71	35	37	83	105	3	3
CBR-14	63	45	38	51	94	101	3	3
CBR-26	94	83	38	37	86	101	3	3
CBR-33	86	73	39	36	83	103	3	3
CBR-60	78	69	33	33	83	108	3	3
CBR-61	40	45	42	50	75	96	1	1
CBR-83	44	45	49	50	94	98	1	2
CBR-85	75	59	36	39	78	71	2	2
CBR-85A	73	51	38	45	80	99	2	1
CBR-99	102	81	37	38	97	105	3	3
CBR-106	71	66	37	40	85	101	3	3
CBR 210	77	68	35	34	81	105	3	3
CBR-452	108	79	37	33	81	107	3	3
CBR-455	90	61	43	40	75	100	2	1
CBR-462	86	56	34	36	75	104	3	3
CBR-464	99	84	39	39	75	106	3	3
CBR-465	97	67	38	36	75	99	3	3
CBR-466	98	78	37	29	78	103	3	3
CBR-490	80	61	37	41	76	101	3	3
CBR-494	70	42	35	37	75	99	3	3
CBR-507	86	72	38	42	96	105	3	3
CBR-519	75	60	33	36	75	100	3	3
CBR-581	79	68	35	39	91	102	3	3
CBR-591	101	84	36	39	94	105	3	3
CBR-592	90	68	36	34	95	106	3	3
CBR-597	78	58	35	33	77	103	3	3
CBR-643	89	63	33	34	80	103	3	3
CBR-705	51	63	38	40	81	103	1	2
CBR donor [1]	95	87	32	28	87	105	3	3
LSD(0.05)[2]	12	13	2	7	2	4	-	-
LSD(0.05)[3]	10	11	2	6	2	3	-	-

Bold face=lines performed well and italicized=lines performed poorly in both 1994-1995

[1] Average of three plots/replicarion [2] LSD for comparing DH vs. DH [3] LSD for comparing DP vs. DH

4.2.4 Performance of DH lines, Melfort, Scott and Saskatoon, 1995

Seven DH lines (BC=2, CB=2, EPD=3) at Melfort and 10 DH lines, (BC=3, CB=3, EPD=4) at Scott and Saskatoon were evaluated in 1995 together with their donor populations as checks. Mean square values for entries were significant for plants/plot, seed yield, plant height and days to flower and mature at all three locations (Table 4.12).

A consistent pattern was observed for all traits except seed yield over the three locations. (Tables 4.13-4.17). For most DH lines, Scott had the highest number of plants/plot followed by Melfort and Saskatoon (Table 4.13). All DH lines were tallest at Melfort followed by Scott and Saskatoon (Table 4.15). For days to flower many of the DH lines were the earliest at Saskatoon and latest at Melfort (Table 4.16), while for days to mature all the DH lines matured the earliest at Scott followed by Saskatoon and Melfort (Table 4.17).

BC3015G was highest yielding line at both Scott and Saskatoon followed by EPD-2975 (Table 4.14). In the absence of BC-3015G at Melfort, EPD-2975 ranked first followed by EPD-2989. One line EPD-2978 was ranked third at all three locations. The yield of DH lines ranged 6-89% of their respective donors.

Table 4.12 Mean square values for plants/plot, seed yield, plant height, days to flower and mature of *B. rapa* doubled haploid (DH) lines and their donor populations grown at Melfort, Scott and Saskatoon, 1995

Source of variation	df	Plants /plot	Seed yield /plot	Plant height	Days to flower	Days to mature
Melfort						
Entries	9	1226**	335438**	1153**	2.41**	14.6**
Replication	3	47	4305	16	0.22	1.0
Error	27	21	1833	34	0.17	1.0
Scott						
Entries	12	4073**	179482**	607**	16.5**	16.5**
Replication	3	130	665	140*	1.0	1.0
Error	36	54	1071	47	1.0	1.3
Saskatoon						
Entries	12	506**	90071**	642**	112**	32**
Replication	3	12	1132	11	67*	10*
Error	36	11	2278	23	19	3

*,** Significant at 5 and 1% level, respectively

Table 4.13 Average number of plants/plot of *B. rapa* doubled haploid (DH) lines and their donor populations (DP), BC, CB and EPD grown at Melfort, Scott and Saskatoon, 1995

Entry	Melfort			Scott			Saskatoon		
	No.	%DP	Rank	No.	%DP	Rank	No.	%DP	Rank
BC-2588	54	225	5	67	248	7	41	195	5
BC-2791	31	129	7	23	85	9	39	186	6
BC donor[1]	**24**	**100**		**27**	**100**		**21**	**100**	
CB-2857	61	103	3	77	106	4	44	98	4
CB-2941	57	97	4	76	104	5	39	87	6
CB donor[1]	**59**	**100**		**73**	**100**		**45**	**100**	
EPD-2975	88	147	1	116	168	2	60	118	1
EPD-2978	63	105	2	89	129	3	37	73	8
EPD-2989	52	87	6	72	104	6	31	61	9
EPD donor[1]	**60**	**100**		**69**	**100**		**51**	**100**	
BC-3015G	-	-		119	441	1	58	276	2
CB-2627	-	-		40	55	8	45	100	3
EPD-2933	-	-		20	29	10	27	53	10
LSD(0.05)	7	-		11	-		5	-	

[1] Donor populations are bold faced

Table 4.14 Average seed yield/plot of *B. rapa* doubled haploid (DH) lines and their donor populations (DP), BC, CB and EPD grown at Melfort, Scott and Saskatoon, 1995

Entry	Melfort			Scott			Saskatoon		
	g/plot	%DP	Rank	g/plot	%DP	Rank	g/plot	%DP	Rank
BC-2588	53.8	8	7	71.3	15	9	53.5	13	7
BC-2791	151.5	24	4	73.8	16	8	97.8	23	5
BC donor[1]	**639.5**	**100**		**473.8**	**100**		**425.8**	**100**	
CB-2857	136.3	20	5	116.3	19	6	29.5	7	9
CB-2941	96.5	14	6	134.5	22	5	47.8	11	8
CB donor[1]	**685.5**	**100**		**618.5**	**100**		**434.3**	**100**	
EPD-2975	378.8	44	1	354.3	54	2	160.3	47	2
EPD-2978	157.8	18	3	312.8	48	3	156.3	46	3
EPD-2989	211.3	24	2	215.8	33	4	125.8	37	4
EPD donor[1]	**865.5**	**100**		**653.3**	**100**		**341.8**	**100**	
BC-3015G	-	-	-	423.5	89	1	287.8	68	1
CB-2627	-	-	-	85.0	14	7	20.3	6	10
EPD-2933	-	-	-	71.0	11	10	53.8	16	6
LSD(0.05)	62	-	-	47	-	-	69	-	-

[1] Donor populations are bold faced

Table 4.15 Average plant height of *B. rapa* doubled haploid (DH) lines and their donor populations (DP), BC, CB and EPD grown at Melfort, Scott and Saskatoon, 1995

Entry	Melfort			Scott			Saskatoon		
	(cm)	%DP	Rank	(cm)	%DP	Rank	(cm)	%DP	Rank
BC-2588	65	65	7	58	64	10	43	57	10
BC-2791	106	106	1	98	108	2	69	92	6
BC donor[1]	**100**	**100**		**91**	**100**		**75**	**100**	
CB-2857	106	86	1	86	86	6	74	84	3
CB-2941	82	66	6	74	74	9	58	66	8
CB donor[1]	**124**	**100**		**100**	**100**		**88**	**100**	
EPD-2975	91	81	4	89	91	5	72	91	4
EPD-2978	85	75	5	80	82	8	50	63	9
EPD-2989	93	82	3	86	88	6	66	84	7
EPD donor[1]	**113**	**100**		**98**	**100**		**79**	**100**	
BC-3015G	-	-	-	104	114	1	82	109	1
CB-2627	-	-	-	94	94	3	76	86	2
EPD-2933	-	-	-	90	92	4	70	89	5
LSD(0.05)	9	-	-	10	-	-	7	-	-

[1] Donor populations are bold faced

Table 4.16 Days to flower for *B. rapa* doubled haploid (DH) lines and their donor populations (DP), BC, CB and EPD grown at Melfort, Scott and Saskatoon, 1995

Entry	Melfort			Scott			Saskatoon		
	Days	%DP	Rank	Days	%DP	Rank	Days	%DP	Rank
BC-2588	48	104	1	39	111	1	48	141	1
BC-2791	48	104	1	38	109	4	34	100	8
BC donor[1]	**46**	**100**		**35**	**100**		**34**	**100**	
CB-2857	48	104	1	38	106	4	36	120	6
CB-2941	48	104	1	38	106	4	32	107	10
CB donor[1]	**46**	**100**		**36**	**100**		**30**	**100**	
EPD-2975	47	102	6	36	109	8	37	142	5
EPD-2978	48	104	1	39	118	1	40	154	2
EPD-2989	47	102	6	38	115	4	38	146	4
EPD donor[1]	**46**	**100**		**33**	**100**		**26**	**100**	
BC-3015G	-	-	-	33	94	10	36	106	6
CB-2627	-	-	-	39	108	1	34	113	8
EPD-2933	-	-	-	36	109	8	40	154	2
LSD(0.05)	1	-	-	1	-	-	6	-	-

[1] Donor populations are bold faced

Table 4.17 Days to mature for *B. rapa* doubled haploid (DH) lines and their donor populations (DP), BC, CB and EPD grown at Melfort, Scott and Saskatoon, 1995

Entry	Melfort			Scott			Saskatoon		
	Days	%DP	Rank	Days	%DP	Rank	Days	%DP	Rank
BC-2588	135	102	1	91	105	1	102	99	3
BC-2791	133	101	2	88	101	2	100	97	6
BC donor[1]	**132**	**100**		**87**	**100**		**103**	**100**	
CB-2857	130	97	6	85	98	6	101	97	5
CB-2941	128	96	7	84	97	9	99	95	8
CB donor[1]	**134**	**100**		**87**	**100**		**104**	**100**	
EPD-2975	131	100	4	84	100	9	100	96	6
EPD-2978	132	101	3	87	104	4	99	95	8
EPD-2989	131	100	4	85	101	6	99	95	8
EPD donor[1]	**131**	**100**		**84**	**100**		**104**	**100**	
BC-3015G	-	-	-	85	98	6	109	106	1
CB-2627	-	-	-	88	101	2	102	98	4
EPD-2933	-	-	-	87	104	4	104	100	2
LSD(0.05)	2	-	-	2	-	-	3	-	-

[1] Donor populations are bold faced

4.2.5 Growth characteristics of DH lines at the rosette (R), flowering (F) and podding (P) stages, Saskatoon, 1994-95

The mean square values for entries for plant height and weight at the R, F and P stages in 1994 and 1995 were highly significant (Table 4.18). Contrast mean square values comparing donor populations and derived DH lines were significant for plant height and weight at the R and P stages in 1994 and 1995. Many DH lines were equal to their respective donors in height and weight at the R stage, and significantly exceeded their donor at F stage (Table 4.19). However, at the P stage very few DH lines were equal to their donors in plant height or weight. DH lines flowered up to 9 and 23 days later than their donors in 1994 and 1995, respectively (Table 4.11). In 1995, donors flowered earlier than in 1994 and almost all entries had fewer plants/plot due to drought and heat stress (Table 4.11, 4.6).

Table 4.18 Mean square values for plant height and weight recorded at the rosette, flowering and podding stages and contrast mean square values comparing *B. rapa* doubled haploid (DH) lines and their donor populations (DP), Saskatoon, 1994-95

Source of variation	df	Rosette		Flowering		Podding	
		Plant height	Plant weight	Plant height	Plant weight	Plant height	Plant weight
1994							
Entries	96	2.19**	24**	1082**	777**	3065**	1220**
DP vs. DH	1	63.00**	379**	383ns	62ns	111975**	14057**
Replication	3	0.03	1.5	166	153	4	51
Error	288	0.23	3.6	139	114	52	61
1995							
Entries	97	35.0**	3.5**	493**	566**	646**	2210**
DP vs. DH	1	287.0**	5.0**	91ns	16ns	15113**	131012**
Replication	2	2.0	0.2	29	0.2	7	31
Error	194	3.0	0.2	71	5	33	25

Table 4.19 Plant height and weight (5 and 3 plant samples in 1994 and 1995, respectively) of *B. rapa* doubled haploid lines and donor populations at the rosette, flowering and podding stages, Saskatoon, 1994-95

Line and donor	Rosette				Flowering				Podding			
	Plant height		Plant weight		Plant height		Plant weight		Plant height		Plant weight	
	94	95	94	95	94	95	94	95	94	95	94	95
BC-111	11	10	4	3	44	54	17	40	70	66	40	50
BC-276	10	8	4	2	50	44	28	30	60	63	37	37
BC2459	12	9	5	2	79	56	43	30	80	65	67	40
BC2507	11	8	5	2	68	54	30	20	78	65	57	30
BC2576	11	7	4	1	60	50	15	13	68	56	19	18
BC2588	7	5	4	1	41	33	9	2	38	40	10	4
BC2595	7	4	4	1	33	30	6	4	32	38	6	7
BC2660	10	9	5	1	54	49	51	9	60	53	55	17
BC2665	11	10	5	1	68	62	39	14	69	67	43	20
BC2668	12	9	4	3	74	56	40	32	78	65	50	40
BC2678	8	5	4	1	44	35	13	17	46	41	20	20
BC2679	7	6	4	1	42	37	7	7	39	45	9	2
BC2705	10	10	6	1	59	60	51	15	60	64	76	25
BC2723	-	8	-	2	-	60	-	22	-	62	-	37
BC2725	11	8	5	1	57	48	27	18	73	55	43	22
BC2774	10	7	4	2	51	55	24	21	67	59	39	30
BC2791	12	8	6	1	74	55	53	18	79	68	72	26
BC2886	11	11	6	2	64	70	64	20	68	80	76	30
BC2889	8	5	4	1	43	30	14	4	46	35	14	10
BC2913	13	8	5	1	74	70	36	30	89	80	47	40
BC2916	11	7	5	2	67	53	39	15	76	55	51	19
BC2927	10	10	4	1	40	60	25	10	69	65	31	20
BC2953	11	7	5	2	63	60	42	20	70	63	50	30
BC2960	7	6	4	1	22	47	10	5	41	50	13	12
BC2965	12	13	6	2	78	61	56	20	80	69	72	30
BC3011	11	7	5	1	70	62	35	4	79	66	51	10
BC3015Y	13	20	7	5	65	76	96	64	90	84	130	90
BC3015G	12	21	6	4	56	75	67	53	85	83	77	80
BC3015B	12	15	6	3	58	74	65	38	78	80	81	50
BC3016	12	10	5	1	51	64	44	10	78	70	59	20
BC3034	8	8	4	1	45	44	18	10	50	52	23	20
BC donor [1]	10	10	5	2	51	41	32	17	89	80	103	100

Table 4.19 contd.

Line and donor	Rosette				Flowering				Podding			
	Plant height		Plant weight		Plant height		Plant weight		Plant height		Plant weight	
	94	95	94	95	94	95	94	95	94	95	94	95
CB-13	7	5	4	1	44	36	7	3	58	40	8	5
CB-15	8	6	3	1	34	32	8	5	40	35	8	7
CB-42	8	6	5	4	78	60	70	36	91	68	72	50
CB-56	6	5	4	1	31	25	2	16	40	30	4	18
CB2524	14	13	5	1	76	62	37	11	96	65	52	21
CB2625	13	11	6	1	73	65	27	10	90	70	63	20
CB2627	13	15	5	3	75	75	38	30	89	78	53	40
CB2630	13	14	5	3	80	66	42	25	95	70	58	31
CB2690	13	6	6	3	76	65	61	30	100	70	95	40
CB2740	13	15	5	1	75	68	47	10	98	73	51	25
CB2741	12	10	5	3	77	60	30	34	90	67	46	40
CB2857	12	8	5	3	75	57	37	30	90	60	36	38
CB2940	13	14	6	2	71	60	46	20	96	65	83	31
CB2941	10	13	6	2	72	55	40	20	74	60	41	30
CB donor [1]	17	15	6	3	67	70	42	26	104	88	107	103
EPD-1	10	10	5	4	54	45	41	70	65	50	43	90
EPD-7	12	10	5	2	63	75	48	30	87	80	61	40
EPD-9	12	14	6	2	51	68	49	31	87	70	81	42
EPD2684	12	9	5	2	50	65	31	30	88	70	31	40
EPD2842	11	10	5	2	72	63	45	29	85	66	53	37
EPD2932	11	10	4	2	69	65	22	19	86	70	32	20
EPD2933	11	10	5	1	67	66	40	10	85	72	47	20
EPD2935	10	9	4	1	52	54	15	9	70	60	19	12
EPD2975	11	6	5	2	61	60	26	28	80	65	42	39
EPD2978	10	8	4	1	62	45	30	13	70	50	42	20
EPD2985	4	6	4	2	21	45	3	22	30	50	6	35
EPD2987	10	10	5	2	64	65	29	20	78	70	37	30
EPD2988	10	8	5	1	67	60	34	17	77	68	53	25
EPD2989	11	5	5	1	66	18	26	4	85	22	34	5
EPD donor[1]	13	11	5	2	57	56	24	21	89	78	91	86

Table 4.19 contd.

Line and donor	Rosette				Flowering				Podding			
	Plant height		Plant weight		Plant height		Plant weight		Plant height		Plant weight	
	94	95	94	95	94	95	94	95	94	95	94	95
CBR-2	11	14	5	3	49	70	23	30	79	77	48	40
CBR-11	12	10	5	2	74	65	37	20	90	70	56	30
CBR-13	10	6	6	2	50	40	48	18	70	42	57	21
CBR-14	8	11	5	2	52	75	35	20	58	80	41	40
CBR-26	12	10	4	2	79	65	30	21	88	70	33	30
CBR-33	9	8	4	2	63	60	33	20	80	65	35	30
CBR-60	10	6	5	3	41	57	37	26	72	61	44	35
CBR-61	6	-	4	-	29	-	3	-	36	-	2	-
CBR-83	6	-	4	-	30	-	31	-	39	-	33	-
CBR-85	-	6	-	1	-	42	-	4	-	45	-	8
CBR-85A	9	-	5	-	52	-	38	-	66	-	46	-
CBR-99	13	9	6	5	78	57	50	45	96	60	80	60
CBR-106	9	8	4	1	57	53	28	12	66	60	30	25
CBR-210	9	10	5	4	58	66	33	40	69	70	44	50
CBR-452	13	9	5	4	74	52	36	40	100	59	52	50
CBR-455	-	7	-	3	-	47	-	30	-	55	-	40
CBR-462	10	8	5	3	60	45	50	31	79	50	48	40
CBR-464	12	13	4	3	71	75	31	31	90	80	37	40
CBR-465	12	8	6	3	75	60	46	30	90	65	67	40
CBR-466	12	8	5	6	75	70	48	70	90	75	49	80
CBR-490	10	8	4	2	55	51	32	20	72	58	34	30
CBR-494	9	6	4	1	57	36	22	2	66	40	28	5
CBR-507	11	5	4	1	65	60	21	10	80	64	30	20
CBR-519	9	11	4	1	45	54	15	4	69	57	31	10
CBR-581	9	8	6	3	54	55	74	50	70	60	89	56
CBR-591	13	10	5	2	83	64	38	20	95	70	43	30
CBR-592	11	15	5	3	64	60	37	30	84	60	52	40
CBR-597	10	10	5	3	40	48	21	26	70	53	49	35
CBR-643	11	8	5	1	57	50	38	6	80	55	58	10
CBR-705	-	7	-	2	-	46	-	36	-	50	-	40
CBR donor[1]	12	12	6	2	57	61	27	23	88	84	90	93
LSD (0.05)[2]	1	3	3	1	16	13	8	4	10	9	11	8
LSD (0.05)[3]	1	3	3	1	13	11	7	3	8	7	9	7

[1] Average of three plots/replicarion [2] for comparing DH vs. DH [3] for comparing DP vs. DH

In 1993, the recorded fresh weight for biological yield/plant at the R, F and P growth stages was divided into several components: **a)** Rosette (leaf weight), **b)** Flowering (stem + leaf weight) and **c)** Podding (stem + leaf + pod weight). The data recorded in 1993 is presented in the Appendix B.

Early leaf senescence during flowering was observed in DH lines (Fig 4.2a, Appendix B Table 2, 3). Three lines from each of the donor populations BC and EPD and one line from CB retained a few leaves at the podding stage whereas, the donors retained many leaves at this stage. Early leaf senescence in DH lines specially in CB group was observed in the greenhouse (observation only). Pod abortion was also higher in DH lines compared to their respective donors (Fig 4.2b, Appendix B Table 3, 5).

4.2.6 Variability in DH lines

Emergence (Fig. 4.3, 4.4, 4.5), timing and duration of developmental stages (Fig. 4.6), leaf color (Fig. 4.7), shape and size of leaf (Fig. 4.8), branching habit (Fig. 4.9, 4.10), pod density, angle and size (Fig. 4.11, 4.12), seed color (Fig. 4.13) and plant width (Fig. 4.9, 4.10) varied greatly for DH lines over the three years of testing. DH line BC-2618 produced, on average five plants per plot in 1993 when 200 seeds were sown/row and only three plants in 1994 when 100 seeds/row were planted. These plants grew 75cm tall and had green leaves (LCI-3). On the other hand, DH lines BC-2588, BC-2889, EPD-2639 and EPD-2985 produced many seedlings/plot which developed into weak, short plants with yellow leaves (LCI 1 or LCI 2). Plants with yellow leaves remained in the rosette stage for a long time and yielded little seed. Plants of one DH line EPD-2716 germinated with yellow green leaves (LCI-2) and developed chlorophyll before flowering. This line flowered in 47 days, was 79

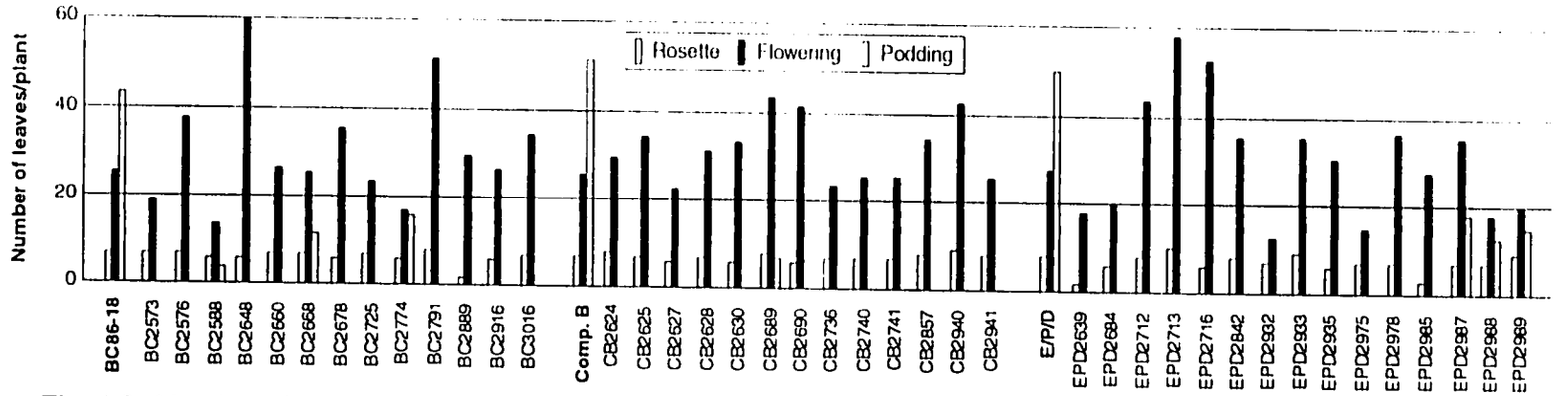

Fig. 4.2a Number of leaves/plant at the rosette, flowering and podding stages on *Brassica rapa* DH lines and their respective donor populations, BC86-18 (BC), Comp. B (CB) and E/P/D, Saskatoon, 1993

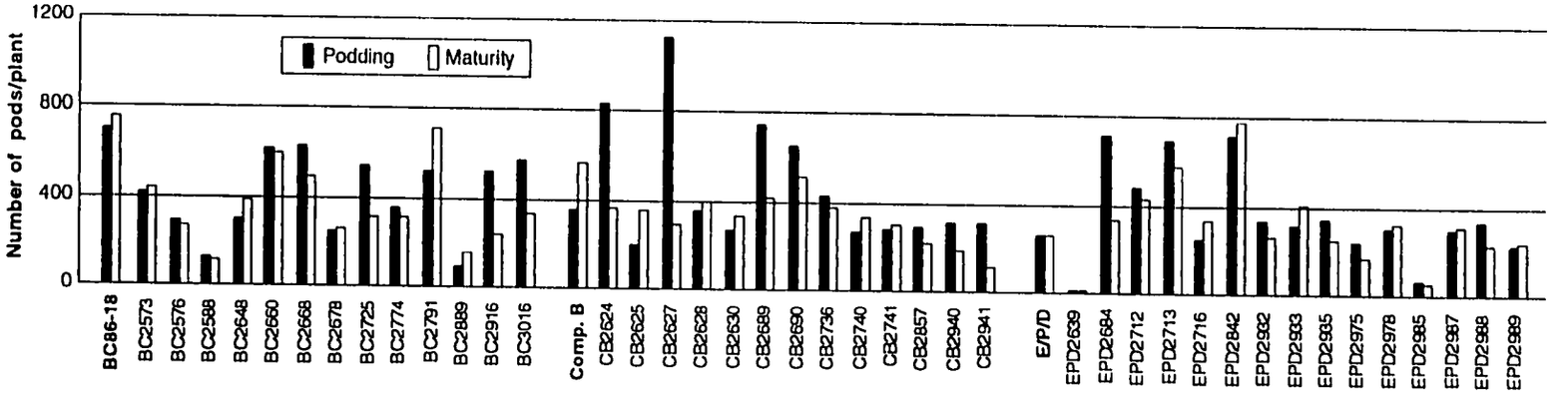

Fig. 4.2b Number of pods/plant at the podding and maturity stages on *Brassica rapa* DH lines and their respective donor populations, BC86-18 (BC), Comp. B (CB) and E/P/D, Saskatoon, 1993

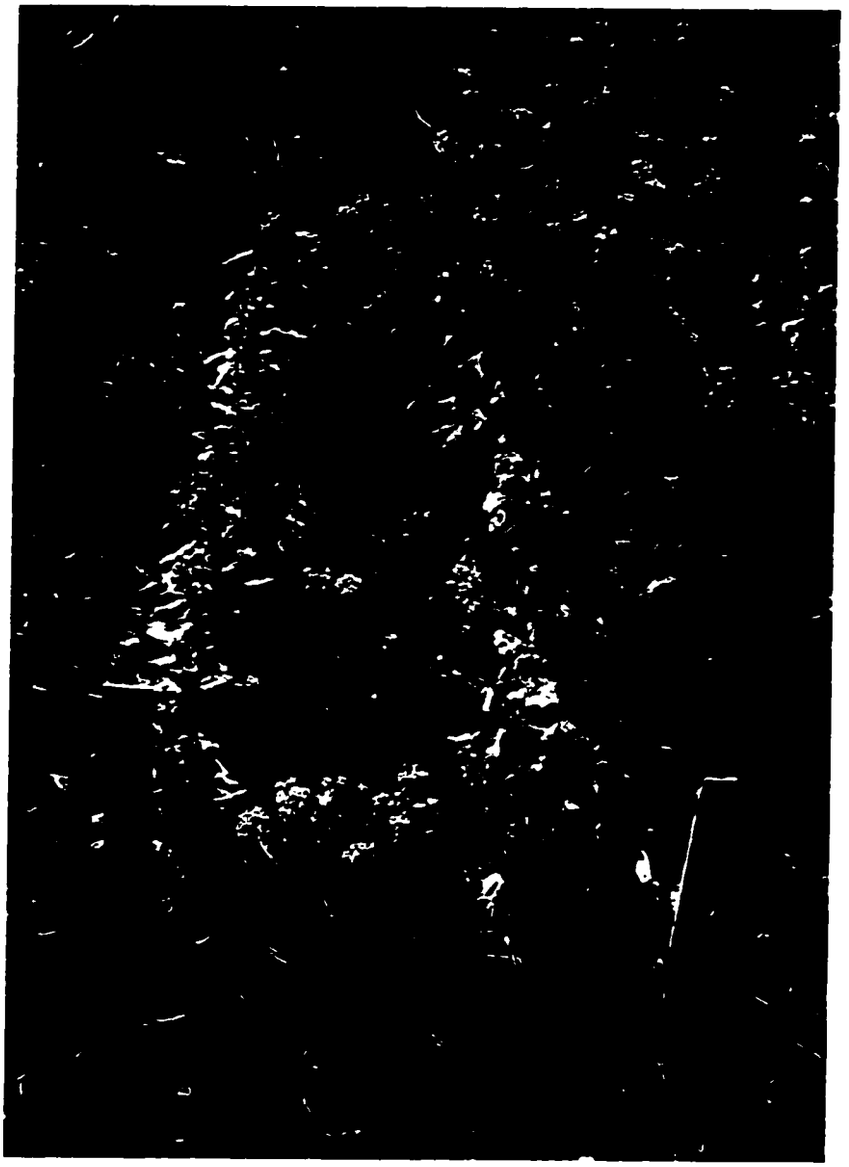

Fig. 4.3 Low yielding, dwarf, chlorophyll deficient (LCI-1), *Brassica rapa* DH line, EPD-2985 (left), with a high rate of germination and stand establishment compared to the average yielding, medium tall, green DH line, CB-2941, (right), Saskatoon,1994

Fig. 4.4 Low yielding, semi dwarf, chlorophyll deficient (LCI-2) *Brassica rapa* DH line, BC-2588, with a high rate of germination and stand establishment (centre), Saskatoon, 1994.

Fig. 4.5 Tall, green (LCI-3) *Brassica rapa* DH line, BC 2618, (centre) producing only five plants from 100 seeds planted, Saskatoon,1994

Fig. 4.6 Green, tall, early flowering *Brassica rapa* DH line BC-2507 (left), semi dwarf, medium early DH line 3-490 (centre) and late, green DH line 6746-1 (right), Saskatoon, 1994.

Fig. 4.7 Leaf color and leaf color index (LCI) scores measured on upper (a) and lower (b) leaves from the main shoot of doubled haploid (DH) lines and donor populations (DP) at the beginning of flowering, grown in the greenhouse

DH or DP	Color of upper (a) and lower (b) leaf		Leaf color index (LCI)
DH EPD-2985	a		
	b		1
DH EPD-2639	a		
	b		
DH BC-2588	a		
	b		2
DH BC-2576	a		
	b		
DH EPD-2987	a		
	b		
DH EPD-2975	a		
	b		
DH BC-2668	a		
	b		
DH CB-2857	a		3
	b		
DP BC donor	a		
	b		
DP CB donor	a		
	b		
DP EPD donor	a		
	b		
DH BC-3015	a		4
	b		

Fig. 4.8 Variation in leaf shape of basal leaves from 15 *Brassica rapa* DH lines grown in the greenhouse, 1992

Fig. 4.9 Normal branching habit in *Brassica rapa* DH line, BC-3015Y, grown in the field, Saskatoon, 1994

Fig. 4.10 Appressed branching habit in *Brassica rapa* DH line, CRS-2 grown in the field, Saskatoon, 1994

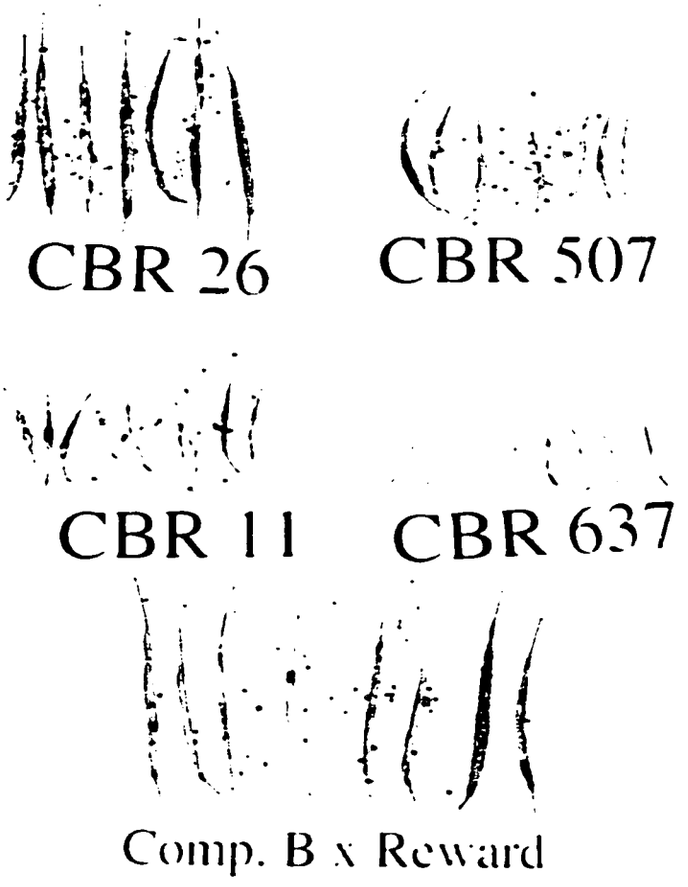

Fig. 4.11 Pod sizes of one plant each of *Brassica rapa* DH lines, CBR-26, CBR-507, CBR-11, CBR-637 (upper two rows) and donor population, Comp. B x Reward (CBR) (lower row) from which the above four DH lines were derived, Saskatoon, 1994

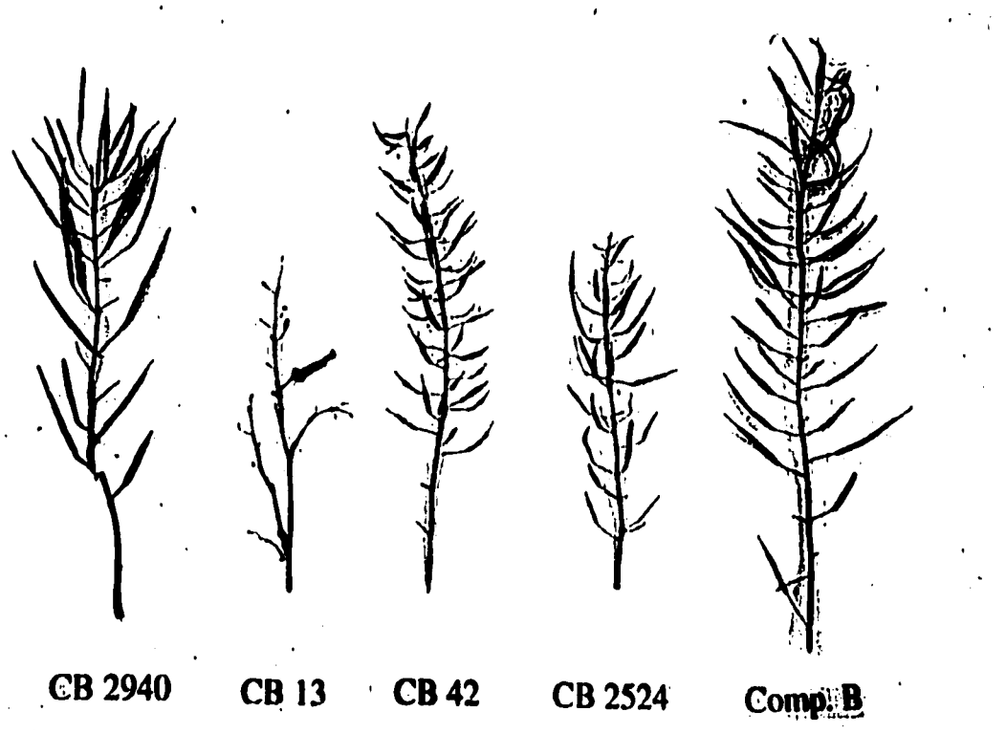

Fig. 4.12 Main racemes types from one plant each of four *Brassica rapa* DH lines, CB-2940, CB-13, CB-42, CB-2524 and their donor population, Comp. B (CB), grown in the field, Saskatoon, 1994

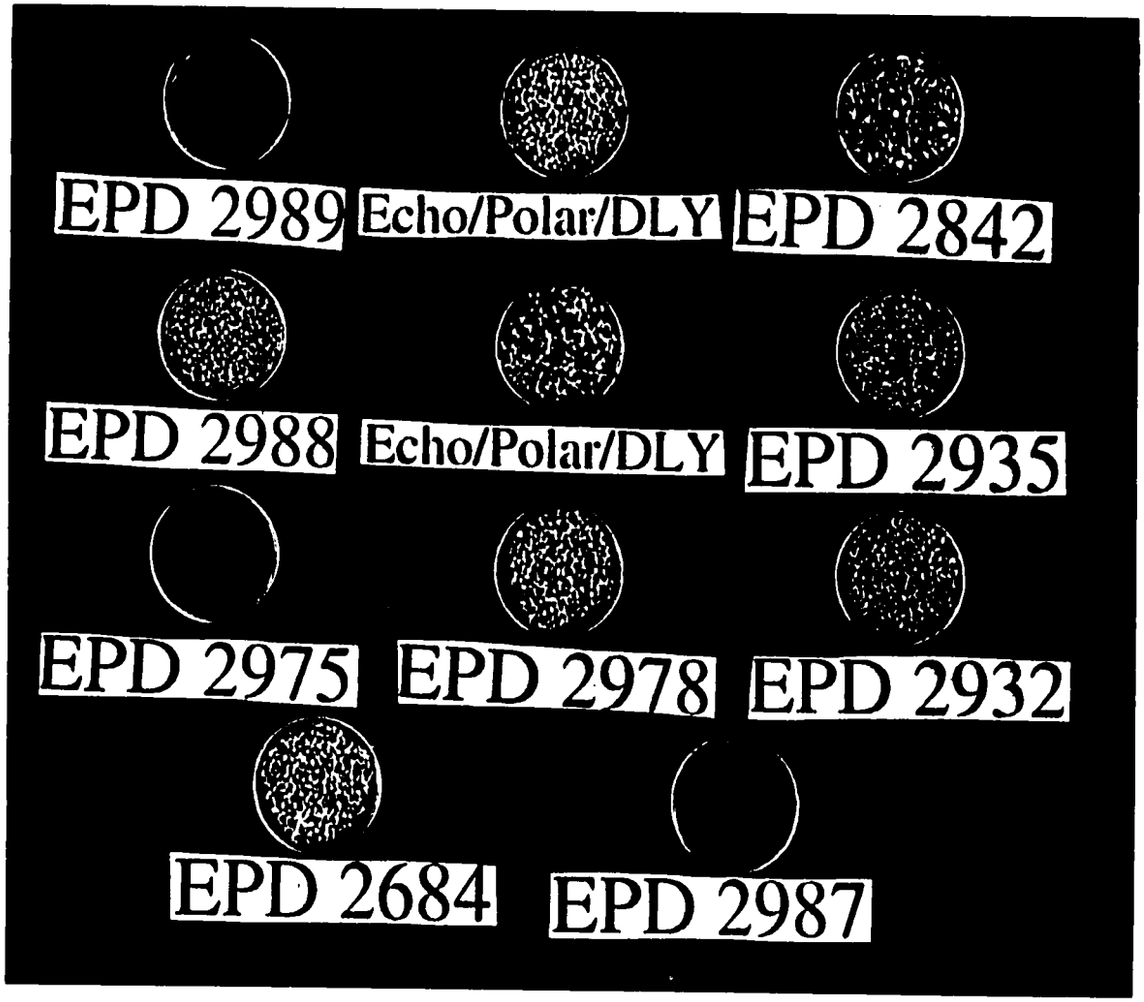

Fig. 4.13 Seed color of greenhouse(1st row, centre) and field (2nd row, centre) produced seed of the Echo/Polar/DLY(EPD) donor population of *Brassica rapa* and seed color of selfed seed of nine greenhouse produced *Brassica rapa* DH lines derived from a single donor plant (6294-4 op) of the EPD donor population

cm tall, but had low yield (Appendix C Table 2). All plants within the donor population plots had green leaves (LCI-3), whereas DH lines exhibited a range in leaf color varying from yellow to dark green (LCI-1 to LCI-4). A variety of leaf shapes and sizes, such as, dentate and entire margins, curly and flat lamina, normal and arrow shaped leaves and wide and narrow venation were observed among the DH lines. The branching habit of DH lines was classified as either normal, exhibiting a wide angle of the branch relative to the main axis, or appressed with a narrow angle between the main axis and the branches (Appendix C Table 3). Normal branching was recorded in 90 lines, whereas, 41 lines exhibited the appressed branching habit. Pod setting on a raceme was rated visually as dense or sparse on 131 lines. A dense pod setting was observed on 90 lines, while the remaining 41 lines had sparsely podded racemes. Pod angle in relation to the raceme axis was rated as appressed or normal. Sixteen lines exhibited an appressed podding habit while the remaining 115 lines carried their pods at the normal wide angle. Various seed colors including, bright yellow, mottled yellow and brown as well as black were observed. Within the mottled seed color group, considerable variation was observed such as, yellow with a slight brown tinge, yellow with one large brown spot, yellowish mottled, brownish mottled and yellow greenish mottled. Plants within the donor population plots were all wide and bushy and rated 3 for plant width. Only four DH lines (BC-2850 and BC-3015GM, BC-3015Y, BC-3015B) were rated equal to donors for plant width. Other characteristics, such as very slow petal opening during flowering, male sterility, hair like thin sterile style and stigma, whitish petal color, small petal, stigma exposure at a very small bud stage, fused racemes and pods, with very small roots plants (observed in the greenhouse) and spindly, thin stems were observed.

4.3 Hybrid performance

4.3.1 Performance of top cross progenies, 1994

Sixteen top cross progenies (BC=2, CB=6, EPD=8), three donors and the cultivar Tobin were evaluated at Scott, Melfort and Saskatoon. Mean square values for entries were highly significant at all three locations (Table 4.20).

One entry EPD-2987 yielded significantly higher than the check cultivar Tobin at three locations. Other high performing lines were EPD-2975, EPD-2988, EPD-2989 and EPD-2932 and yielded similar to Tobin (Table 4.21). The best entry EPD-2987 averaged over the three locations yielded 114% of Tobin (Table 4.21).

The average top cross seed yields of progeny of the BC group at Melfort, Scott and Saskatoon were 143, 107 and 153% of their donors, respectively (Table 4.21). The average top cross progeny yields from the CB group were 67, 53 and 72% of their donors and top cross progenies from EPD group yielded 135, 123 and 140% of their donors at Melfort, Scott and Saskatoon, respectively (Table 4.21).

Table 4.20 Mean squares values for seed yield/plot of 16 *B. rapa* doubled haploid derived top cross progenies, their three donor populations and the cultivar Tobin at Melfort, Scott and Saskatoon, 1994

Source of variation	df	Mean square at		
		Melfort	Scott	Saskatoon
Entries	19	170191**	218502**	103460**
Replications	3	10784	44401	68685**
Error	57	10479	23280	6195

** Significant at 1% level

Table 4.21 Seed yield/plot of 16 *B. rapa* doubled haploid derived top cross progenies, their three donor populations, BC, CB and EPD and the cultivar Tobin grown at Melfort, Scott and Saskatoon, 1994

Entry	Melfort			Scott			Saskatoon		
	g/plot	%DP	%Tobin	g/plot	%DP	%Tobin	g/plot	%DP	%Tobin
BC donor	**509**	**-**	**55**	**473**	**-**	**60**	**337**	**-**	**50**
BC-2753	737	145	80	567	120	72	406	120	60
BC-2774	715	141	77	447	95	57	628	186	93
BC average	***726***	***143***	***78***	***507***	***107***	***64***	***517***	***153***	***77***
CB donor	**711**	**-**	**77**	**659**	**-**	**83**	**458**	**-**	**68**
CB-2628	571	80	62	409	62	52	338	74	50
CB-2740	417	59	45	516	78	65	355	78	53
CB-2741	560	79	61	474	72	60	429	94	64
CB-2857	534	75	58	277	42	35	418	91	62
CB-2940	413	58	45	227	35	29	207	45	31
CB-2941	371	52	40	210	32	27	237	52	35
CB average	***478***	***67***	***52***	***352***	***53***	***45***	***331***	***72***	***49***
EPD donor	**668**	**-**	**72**	**638**	**-**	**81**	**437**	**-**	**65**
EPD-2713	746	112	81	509	80	64	509	117	76
EPD-2716	820	123	89	610	96	77	589	135	88
EPD-2932	967	145	104	751	118	95	630	144	94
EPD-2975	1034	155	112	1014	159	128	608	139	91
EPD-2978	868	130	94	646	101	82	442	101	66
EPD-2987	999	150	108	925	145	117	797	182	119
EPD-2988	932	140	101	969	152	123	564	129	84
EPD-2989	835	125	90	834	131	106	742	170	110
EPD average	***900***	***135***	***97***	***782***	***123***	***99***	***610***	***140***	***91***
Tobin	**926**	**-**	**-**	**790**	**-**	**-**	**672**	**-**	**-**
LSD(0.05)	145	-	-	216	-	-	110	-	-

Top cross progenies, derived from 13 lines (BC=5, CB=6, EPD=2) which did not produce sufficient seed for multi-location trial were evaluated at Saskatoon together with their donor populations and the cultivar Tobin as a check. The mean square values for entries were highly significant for seed yield/plot (Table 4.22).

Seed yield of two top cross progenies were equal to Tobin (Table 4.23). The highest yielding top cross progeny produced from BC-2648, yielded 109% of Tobin (Table 4.23). Other good performing top cross progenies identified were CB-2736, BC-2678, BC-2588 and EPD-2684. The average seed yield for the additional top cross progenies tested from BC, CB and EPD groups were 154, 120 and 96% of their respective donors (Table 4.23), while the average seed yield for top cross progenies which were tested in multi-location trials, were respectively 134, 64 and 133% of their donors from the BC, CB and EPD groups, over the three locations (Table 4.21). The level of heterosis was also high in top cross progenies derived from low vigour DH females which produced insufficient seed for multi-location trials.

Table 4.22 Mean square values for seed yield/plot of 13 *B. rapa* doubled haploid derived top cross progenies, their three donor populations and the cultivar Tobin, Saskatoon, 1994

Source of variation	df	Mean square
Entries	16	44670**
Replications	3	9512
Error	48	4884

** Significant at 1% level of probablity

Table 4.23 Seed yield of 13 *B. rapa* doubled haploid derived top cross progenies, their three donor populations, BC, CB and EPD and the cultivar Tobin grown at Saskatoon, 1994

Entry	Seed yield		
	g/plot	%DP	%Tobin
BC donor	**385**	-	**56**
BC-2588	576	150	84
BC-2648	746	194	109
BC-2660	549	143	80
BC-2668	495	129	72
BC-2678	595	155	87
BC average	***592***	***154***	***86***
CB donor	**394**	-	**57**
CB-2624	474	120	69
CB-2625	389	99	57
CB-2627	436	111	64
CB-2630	456	116	66
CB-2690	484	123	71
CB-2736	601	153	88
CB average	***473***	***120***	***69***
EPD donor	**499**	-	**73**
EPD-2684	556	111	81
EPD-2935	403	81	59
EPD average	***480***	***96***	***70***
Tobin	**687**	-	-
LSD(0.05)	99	-	-

4.3.2 Performance of polycross progenies, 1994

Twenty seven polycross progenies (BC=6, CB=10, EPD=11) were tested at Melfort, Scott and Saskatoon together with the three donor populations and the cultivars Tobin, AC Parkland and Echo repeated twice in a replication. In general, performance of all polycross progenies and checks at Scott was poor due to a residual herbicide effect and only a few plants were harvested from most plots. At Saskatoon, the trial was sown late into a clay soil

such that the germination was poor. Data from each location were analyzed separately. Mean square values for entries were highly significant at each location (Table 4.24). However, the coefficient of variability for yield at Scott was very high and the Scott data are not reported.

On average the polycross progenies from EPD were high yielding followed by the progeny of the BC and CB donors groups (Table 4.25). The same relative ranking among these three groups was indicated in the top cross trials (Table 4.21), but the polycross trials provided a larger sampling of each group. None of the entries were higher yielding than the check cultivar Tobin at Melfort, however, one entry EPD-2989 was equal to Tobin at Saskatoon. The best progenies identified in these trials EPD-2989, EPD-2987, EPD-2975, EPD-2988 and EPD-2932 (Table 4.25) are the same progenies identified as top yielders in the top cross trial but with a slightly different relative rank (Table 4.21).

Table 4.24 Mean squares values for seed yield/plot of 27 *B. rapa* doubled haploid derived polycross progenies, their three donor populations and three cultivars grown at Melfort, Scott and Saskatoon, 1994

Source of variation	df	Mean squares at		
		Melfort	Scott	Saskatoon
Entries	35	233111**	221516**	53891**
Replications	3	20426*	64351**	81248**
Error	105	9079	10259	3179

*,** Significant at 5 and 1% level, respectively

Table 4.25 Seed yield/plot of 27 *B. rapa* doubled haploid derived polycross progenies, donor populations, BC, CB and EPD and three cultivars grown at Melfort and Saskatoon, 1994

Entry	Melfort			Saskatoon		
	g/plot	%DP	%Tobin	g/plot	%DP	%Tobin
BC donor	**479**	-	**62**	**177**	-	**47**
BC-2573	313	65	40	88	50	23
BC-2668	245	51	32	89	50	24
BC-2725	244	51	31	129	73	34
BC-2774	251	52	32	116	66	31
BC-2791	264	55	34	147	83	39
BC-3016	308	64	40	124	70	33
BC average	***271***	***57***	***35***	***116***	***66***	***31***
CB donor	**646**	-	**83**	**236**	-	**62**
CB-2624	218	34	28	85	36	23
CB-2627	262	41	34	85	36	23
CB-2628	156	24	20	93	39	25
CB-2630	134	21	17	86	36	23
CB-2736	357	55	46	231	98	61
CB-2740	96	15	12	60	25	16
CB-2741	187	29	24	157	67	42
CB-2857	130	20	17	89	38	24
CB-2940	267	41	34	120	51	32
CB-2941	120	19	15	101	43	27
CB average	***193***	***30***	***25***	***105***	***45***	***28***
EPD donor	**634**	-	**81**	**282**	-	**75**
EPD-2684	320	51	41	171	61	45
EPD-2712	173	27	22	113	40	30
EPD-2713	328	52	42	105	37	28
EPD-2842	339	54	44	145	51	38
EPD-2932	463	73	60	253	90	67
EPD-2933	183	29	24	67	24	18
EPD-2975	519	82	67	269	95	71
EPD-2978	383	60	49	194	69	51
EPD-2987	621	98	80	268	95	71
EPD-2988	490	77	63	229	81	61
EPD-2989	644	101	83	378	134	100
EPD average	***406***	***64***	***52***	***199***	***71***	***53***
Echo	**839**	-	**108**	**439**	-	**116**
Parkland	**849**	-	**109**	**365**	-	**97**
Tobin	**777**	-	-	**378**	-	-
LSD(0.05)[1]	134	-	-	79	-	-
LSD(0.05)[2]	115	-	-	68	-	-

[1] comparing progenies [2] comparing cultivars with progenies

Eight polycross progenies (BC=5, CB=2, EPD=1) for which sufficient seed for multi-location trial was not available were evaluated only at Saskatoon. The three donors and the cultivars Tobin, Echo and AC Parkland (repeated twice in a replication) were used as checks. The mean square for entries was highly significant for seed yield/plot (Table 4.26). The highest yielding entry (BC-2678) yielded 93% of Tobin (Table 4.27). Two other entries BC-2648 and BC-2588 also performed well. These three entries from the BC group were also identified as general good combiners in the additional top cross progeny trial at Saskatoon (Table 4.23). The average seed yield of polycross progenies from the BC, CB and EPD group were 71, 44 and 22% of their donors respectively (Table 4.27) while in the multi-location polycross trials seed yield of polycross progenies averaged over two locations from the BC, CB and EPD group were 62, 38 and 68% of their respective donors (Table 4.25). Only one DH line from EPD group was tested in the additional top cross progeny trial which was 22% of the donor.

Table 4.26 Mean square values for seed yield/plot of eight *B. rapa* doubled haploid derived polycross progenies, their three donor populations and three cultivars, Saskatoon, 1994

Source of variation	df	Mean square
Entries	16	43821**
Replication	3	16332
Error	48	6260

** Significant at 1% level of probablity

Table 4.27 Seed yield/plot of eight *B. rapa* doubled haploid derived polycross progenies, their three donor populations, BC, CB and EPD and three cultivars grown at Saskatoon, 1994

Entry	Seed yield	%DP	%Tobin
BC donor	**222**	-	**79**
BC-2588	152	68	54
BC-2648	153	69	54
BC-2660	91	41	32
BC-2678	260	117	93
BC-2916	129	58	46
BC average	***157***	***71***	***56***
CB donor	**217**	-	**77**
CB-2625	124	57	44
CB-2690	68	31	24
CB average	***96***	***44***	***34***
EPD donor	**284**	-	**101**
EPD-2935	62	22	22
Echo	**365**	-	**130**
Parkland	**336**	-	**120**
Tobin	**281**	-	-
[1]LSD(0.05)	113	-	-
[2]LSD(0.05)	97	-	-

[1] comparing progenies [2] comparing cultivars with progenies

4.3.3 Performance of single cross hybrids, Saskatoon, 1994

Ten DH lines (BC=3, CB=7) were crossed with five DH lines from EPD as male parents to produce 44 single cross hybrids using a line x tester mating design and evaluated at Saskatoon in 1994 along with an additional hybrid obtained from the cross CB-2740 x CB-2736. The cultivar Tobin, three donors and the 15 DH parent lines were used as checks.

All BC and CB DH parent lines died due to herbicide spray damage. However, the

five parent DH lines derived from EPD survived together with the three donor populations, the cultivar Tobin and 45 single cross hybrids (Appendix E).

Data for 45 hybrids, three donors and the check cultivar Tobin were analysed statistically. The mean square values for entries were significant for plants/plot, seed and biological yield, days to flower and mature, pod filling period, pod length, number of seeds/pod and hundred seed weight (Table 4.28).

The performance of individual crosses were compared with the average performance of the two donor populations (mid-DP) from which the two DH parent lines were derived and to the performance of the check cultivar Tobin (Table 4.29). One hybrid showed significant commercial heterosis when compared to Tobin and seven hybrids produced less seed than Tobin while the remainder of the hybrids were equal to Tobin in yield (Table 4.29). Eight hybrids were higher yielding, two hybrids were lower yielding compared to their mid-DP values, and the remainder of the hybrids were equal to the performance of their mid-DP values. The best hybrid, BC-2668 x EPD-2975, yielded 130% of Tobin and 189% of its mid-DP value (Table 4.29). Four hybrids produced significantly more plants/plot, seven produced less and the remainder of the hybrids produced an equal number of plants/plot compared to Tobin. Thirty four hybrids were equal to Tobin and none produced higher biological yield. There were no significant differences among the entries in plant height. The donor BC was significantly late flowering compared to Tobin. However, the flowering time of 14 hybrids was not different than that of Tobin. All hybrids matured at the same time as Tobin.

Seed yields of the 11 hybrids arising from the crosses between DH lines of BC (♀) with DH lines from EPD (♂) were normally distributed.

Table 4.28 Mean square values for plants/plot, seed and biological yield, plant height, days to flower and mature, pod filling period, pod length, number of seeds/pod and 100 seed weight for 45 crosses produced by crossing DH lines from BC and CB as females and EPD as males, three donor populations and the cultivar Tobin, Saskatoon, 1994

Source of variation	df	Plants /plot	Seed yield	Biological yield	Plant height	Days to flower
Entries	48	507*	4027**	14127**	68ns	12.7**
Replications	2	274*	11313**	15663ns	92ns	0.4ns
Error	96	78	925	5006	69	1.0

Source of variation	df	Days to mature	Pod filling period	Pod length	Seeds /pod	100 seed weight
Entries	48	6.0**	11**	0.65**	51**	0.00183**
Replications	2	16.0**	17**	0.31*	42*	0.00007ns
Error	96	3.0	4	0.09	9	0.00007

*,** Significant at 5 and 1% level, respectively

Table 4.29 Plants/plot, seed and biological yield/plot, plant height, days to flower and mature of single cross hybrids produced by crossing *B. rapa* doubled haploids (DH), donor populations and the cultivar Tobin, Saskatoon, 1994

Cross and donor population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Plant height (cm)	Days to flower	Days to mature
BC2573 x EPD2932	40	90.8	347	88	35	92
BC2573 x EPD2975	28	119.8	387	85	30	90
BC2573 x EPD2987	57	171.5	554	98	31	89
BC2666 x EPD2975	65	218.8	668	99	30	89
BC2668 x EPD2987	38	94.0	441	98	32	90
BC2668 x EPD2988	78	202.8	607	99	29	89
BC2668 x EPD2989	62	132.8	508	101	30	89
BC2791 x EPD2932	39	116.3	454	95	36	91
BC2791 x EPD2975	46	183.4	658	102	33	91
BC2791 x EPD2988	44	150.9	553	100	34	90
BC2791 x EPD2989	35	154.0	600	106	35	91
CB2625 x EPD2932	48	77.9	393	99	35	91
CB2625 x EPD2975	47	153.7	667	104	34	89
CB2625 x EPD2987	37	98.2	532	105	33	92
CB2625 x EPD2988	60	196.0	659	106	33	92
CB2625 x EPD2989	48	165.2	617	111	34	91
CB2736 x EPD2975	57	173.6	610	97	33	91
CB2736 x EPD2988	32	152.2	635	103	34	92
CB2736 x EPD2989	56	146.3	575	92	34	91
CB2740 x EPD2932	55	105.5	519	102	34	91
CB2740 x EPD2975	67	156.4	562	100	31	89
CB2740 x EPD2987	67	173.0	646	104	32	89
CB2740 x EPD2988	54	160.8	640	103	34	90
CB2740 x EPD2989	55	168.2	625	102	32	88
CB2741 x EPD2932	45	139.2	577	99	32	91
CB2741 x EPD2975	55	172.1	614	102	29	89
CB2741 x EPD2987	58	155.4	582	102	29	89
CB2741 x EPD2988	55	131.2	477	99	30	89
CB2741 x EPD2989	59	180.7	707	97	29	89
CB2857 x EPD2932	42	129.8	530	100	33	91
CB2857 x EPD2975	70	200.3	601	104	33	89
CB2857 x EPD2987	63	172.0	677	105	34	88
CB2857 x EPD2988	60	185.3	610	103	33	90
CB2857 x EPD2989	54	166.9	585	94	33	88

Table 4.29 Contd.

Cross and donor population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Plant height (cm)	Days to flower	Days to mature
CB2940 x EPD2932	60	178.9	723	104	33	92
CB2940 x EPD2975	57	194.4	643	105	30	90
CB2940 x EPD2987	52	196.4	707	100	32	90
CB2940 x EPD2988	36	162.8	551	98	31	90
CB2940 x EPD2989	55	170.4	637	99	32	89
CB2941 x EPD2932	74	165.3	589	98	34	91
CB2941 x EPD2975	62	187.7	713	105	34	90
CB2941 x EPD2987	58	200.6	610	105	29	88
CB2941 x EPD2988	57	139.9	538	102	34	89
CB2941 x EPD2989	60	177.4	636	105	31	88
CB2740 x CB2736	16	49.3	315	103	37	91
BC	18	77.6	363	93	33	93
CB	25	137.2	622	107	31	94
EPD	53	153.8	561	104	30	91
Tobin	51	168.1	663	98	29	91
LSD(0.05)	12	49	114	-	2	3

The mean square values for males and females and their interaction were calculated by analyzing crosses between six DH lines from the CB donor population as females and five DH lines from EPD donor as males. The mean square values for females were significant for plants/plot, seed yield, days to flower and mature, pod filling period, pod length, number of seeds/pod and 100 seed weight (Tables 4.30). The mean square values for males were significant for seed yield, days to flower and mature, pod length, number of seeds/pod, and 100 seed weight. The mean square values for the females x males interaction were significant for plants/plot, seed yield, days to flower and 100 seed weight.

Table 4.30 Mean square values for plants/plot, seed and biological yield/plot, plant height, days to flower and mature, pod filling period, pod length, number of seeds/pod and 100 seed weight of 30 hybrids produced by crossing *B. rapa* DH lines following a line x tester mating design grown at Saskatoon, 1994

Source of variation	df	Plants /plot	Seed yield	Biological yield	Plant height	Days to flower	Days to mature
Females	5	401**	3842**	3141ns	50ns	29.25**	8*
Males	4	106ns	5465**	7709ns	30ns	13.83**	14**
Females x Males	20	213**	1946*	9814ns	32ns	3.93**	2ns
Replications	2	28ns	2835ns	1925ns	94ns	0.14ns	7ns
Error	58	66	1066	5866	62	0.79	3

Source of variation	df	Pod filling period	Pod length	No. of seeds/pod	100 seed weight
Females	5	27**	1.99**	118**	0.0017**
Males	4	4ns	0.61**	128**	0.0064**
Females x Males	20	5ns	0.10ns	9ns	0.0003**
Replications	2	7ns	0.08ns	32*	0.00004ns
Error	58	4	0.09	10	0.00005

*,** Significant at 5 and 1% level, respectively

The good general combiners identified were CB-2940, CB-2941 and CB-2857 among the females and EPD-2975, EPD-2989, EPD-2987 and EPD-2988 among males (Table 4.31). The good general combiners identified by rank in the multi-location top cross trial were EPD-2987, EPD-2975, EPD-2988 and EPD-2989 (Table 4.21) and in the multi-location polycross trial were EPD-2989, EPD-2987, EPD-2975 and EPD-2988 (Table 4.25). Thus, the ranking of the single cross hybrids differed with those of the top cross and polycross for combining ability.

High yielding cross combinations were CB-2857 x EPD-2975, CB-2941 x EPD-2987, CB-2940 x EPD-2987, CB-2625 x EPD2988, CB-2940 x EPD-2975 (Table 4.31). The cross

between the best female general combiner in the single cross test, CB-2940, and the best male general combiner, EPD-2975, ranked fifth for seed yield, but was not significantly different from the highest yielding hybrid. Seed yield of twenty hybrids were statistically similar to the best hybrid CB-2941 x EPD-2987.

Table 4.31 Seed yield/plot of 30 single crosses among *B. rapa* doubled haploid lines following a line x tester mating design, Saskatoon, 1994

Female parent	Male parent					
	EPD-2932	EPD-2975	EPD-2987	EPD-2988	EPD-2989	Average[1]
	----------Seed yield (g)----------					
CB-2625	77.9	153.7	98.2	196.0	165.2	138.2c
CB-2740	105.5	156.4	173.0	160.8	168.2	152.8c
CB-2741	139.2	172.1	155.4	131.2	180.7	155.7abc
CB-2857	129.8	200.3	172.0	185.3	166.9	170.8ab
CB-2940	178.9	194.4	196.4	162.8	170.4	180.6a
CB-2941	165.3	187.7	200.6	139.9	177.4	174.2ab
Average	132.8b	177.4a	165.9a	162.7a	171.5a	

[1] Averages with same letter(s) in the same column and in the same row are not significantly different according to the Waller Duncan Test

5.0 DISCUSSION

The efficient production of *B. rapa,* DH lines through microspore culture as developed by Baillie *et al.* (1992), has provided breeders with a tool for the production of hybrid cultivars. The research embodied in this thesis is the first report on the evaluation and utilization of *B. rapa* DH lines. In addition, the use of *B. rapa* DH lines in top cross, polycross and single cross hybrids is an entirely new application for which no other direct comparative literature is available. However, observation made on other open pollinated crops closely relate to the observations made in the present study on *B. rapa* DH lines and their hybrids. Based on the results of these investigations with DH lines and their test cross progeny a breeding method for cultivar improvement, utilizing *B. rapa* DH lines, is proposed and a scheme to produce hybrids, using a SI pollen control system is outlined.

5.1 Performance of DH lines

5.1.1 Selection of high yielding doubled haploid lines

Seed yield of DH lines tested in this study ranged from <1 to 188g per three metre row (Table 4.11). Seed yield was positively associated with number of seeds/pod, leaf color index, early flowering, long pod filling period, plant height, plants/plot, 100 seed weight and pod length (Table 4.7). These traits contributed to high yield either alone or in combination

with each other and are discussed below.

5.1.1.1 Effect of number of seeds/pod

A strong, positive association of number of seeds per pod with seed yield in *B. rapa* DH lines was observed (Table 4.7). The number of seeds per pod in *B. rapa* DH lines was, on average, only one half of that of the donor populations indicating that female fertility was reduced as a result of inbreeding (Table 4.6). However, a few DH lines were identified that produced as many seeds per pod as their donors, indicating the possibility of selecting highly fertile DH lines (Table 4.11, Appendix B Table 5, Appendix C Table 3). A similar association of number of seeds per pod with high yield was reported for *B. rapa* open pollinated cultivars (Mendham *et al.* 1984, Allen and Morgan 1972). Thurling (1974) reported that the number of seeds/pod was the main determinant of seed yield in open pollinated cultivars of *B. rapa.*

5.1.1.2 Chlorophyll deficiency

All DH lines that were chlorophyll deficient (LCI-1 and LCI-2) were low yielding (Table 4.11, Appendix B Table 5, Appendix C Table 3, Appendix D Table 2). Observations on chlorophyll deficiencies in the greenhouse or growth chamber and field corresponded closely even with the difference in the amount and the quality of light in the greenhouse and field conditions. Under field condition, DH lines that exhibited yellow leaves, were late to flower and produced only a small amount of seed (Table 4.11) and formed a distinctly low yielding group of DH plants in all three years of testing (Fig. 4.1, Appendix B Table 5, Appendix C Table 3, Appendix D Table 2). These chlorophyll deficient lines (LCI-1) were usually short in height and small in stature (low biological yield). Such plants could be

identified and discarded in the greenhouse prior to producing DH_1 seeds for field testing, thus, saving greenhouse space and labour. Among the DH lines having normal green leaves (LCI-3), both high and low yielding lines were identified, indicating that green leaf color *per se* would not be an effective selection criteria for high yield (Table 4.11). However, it should be noted that the three DH lines rated as having deep green leaves (LCI-4) all produced high seed yields in both test years. A much larger number of DH lines with deep green leaves (LCI-4) would be necessary to establish whether this characteristic is closely associated with high seed yield.

Leaf chlorophyll concentration in maize inbreds and the yielding ability of their hybrids was positively correlated (Jenkins 1929, Sprague and Curtis 1933). It was suggested that the leaf chlorophyll concentration might be used as an index for productivity of maize inbreds and their hybrids (Sprague and Curtis 1933). However, this view was opposed by Miller and Johnson (1938) as no significant correlation between leaf chlorophyll concentration and the yield of inbreds was observed by the authors. They concluded that leaf color could not be a deciding factor in a complex trait such as yield.

5.1.1.3 Days to flower, days to mature, pod filling period and seed yield

Both high and low yielding DH lines exhibited long pod filling periods, however, DH lines with short pod filling periods were usually low yielding (Table 4.11, Appendix B Table 4, Appendix C Table 2, Appendix D Table 2,). Physiological limitations imposed on the plant by the short period for seed development contributed to their low yield. It is concluded that early flowering contributed to increased seed yield of *B. rapa* DH lines by extending the pod filling period and therefore could be used as one of the selection criteria in identifying

high yielding DH lines. The relative time to flower among the DH lines in the greenhouse and field were closely related, although the actual number of days to flower in the greenhouse and field were different. Thus, the actual time required to flower in the field cannot be assessed on greenhouse grown plants.

Campbell and Kondra (1978) observed that plants from the early flowering *B. napus* cultivar Target were higher yielding than plants from the late flowering cultivars Oro and Nugget. These authors also reported that the period from first flowering on the main raceme to maturity was longer in the cultivar Target than the other two cultivars because of its early flowering. Their findings support the conclusion of the present study that flowering time was the main determinant of the pod filling period. It has also been noted that early flowering, short cycle *B. napus* cultivars could be developed without loss of yield (King and Kondra 1986).

5.1.1.4 Plant height and yield

Many short DH lines were chlorophyll deficient (LCI-1) and low yielding. Seed yield of the DH lines increased with plant height (Table 4.7), however, several tall, low yielding DH lines were also observed (Table 4.11, Appendix B Table 4, Appendix C Table 2, Appendix D Table 2). DH lines need to reach a certain height to be productive and high yielding, as indicated by a preponderance of tall plant types among high yielding DH lines and by the absence of short, high yielding DH lines (Table 4.11, Fig. 4.1). In the greenhouse, short DH lines exhibiting chlorophyll deficiency, were also short and chlorophyll deficient under field conditions and could be screened out in the greenhouse by measuring or rating plant height and/or chlorosis at the rosette stage. However, ranking of DH lines for plant

height in the greenhouse cannot substitute for field data on plant height. Taller plants lodged more easily than shorter plants as evidenced by higher lodging scores of tall DH lines from the CB donor population in the 1993 test (Appendix B Table 5).

5.1.1.5 Maturity

Time to maturity under field and greenhouse conditions differed. In the greenhouse, chlorophyll deficient DH plants continued to flower over a long period, produced a good amount of seed upon bud selfing but matured late. Under field conditions, the same chlorophyll deficient DH lines also flowered late but matured earlier than normal green DH lines and their donor populations (Table 4.6, Table 4.11, Appendix B Table 4, Appendix C Table 2, Appendix D Table 2). A possible explanation for this difference in time of maturity of the chlorophyll deficient plants in the greenhouse and in the field is that, in the greenhouse, with an ample nutrient supply and ideal growing conditions, the chlorophyll deficient DH plants were able to support the developing seeds over a long time period. On the other hand, due to less favourable growing conditions in the field, chlorophyll deficient DH lines could not support late formed flowers and pods resulting in many empty and shrivelled pods in the upper portion of the inflorescence.

5.1.1.6 Pod abortion and early leaf fall

DH lines produced many flowers and pods but many of these pods aborted. Pod abortion was greater in DH lines than in donor populations (Fig. 4.2b, Appendix B Table 3, 5). This could be due to the physiological inability of the DH plant to support a large sink (Tayo and Morgan 1975, 1979, McGregor 1981). A further effect of inbreeding was that DH lines showed early leaf senescence shortly after the beginning of flowering which was

especially evident in DH lines of the CB group (Fig. 4.2a, Appendix B Table 2, 3). Early leaf senescence was also observed in the CB group under well fertilized greenhouse conditions indicating that sink size and the competition between plant parts was not the reason for early leaf senescence, since in the greenhouse when the selfed pods were set any flowers or open pollinated pods were regularly removed. The importance of leaf area during the period when fertilization and development of young pods are taking place in *B. napus* cultivars was noted by Allen and Morgan (1972).

5.1.1.7 Hundred seed weight

Hundred seed weight in *B. rapa* DH lines in field tests was not correlated with seed yield/plant, but was positively correlated to seed yield/plot (Table 4.7). This suggested that larger seeds could increase seed yield on an area basis. However, seed yield and seed size were genetically independent as indicated by the many low yielding lines that had a high 100 seed weight (Appendix B Table 5, Appendix C Table 3). It is assumed that larger seed size is an indicator of a good nutritional status of DH plants.

5.1.1.8 Number of plants/plot

A group of DH lines was identified that had a low number of plants/plot and a low seed yield while another group were observed that had a high number of plants/plot and a high seed yield (Table 4.11, Appendix B Table 4, Appendix C Table 2, Appendix D Table 2). A low number of plants/plot resulting into low yields and a high number of plants/plot resulting in high yields reflected the differences in the number of seeds produced per unit area. Chlorophyll deficient DH lines formed a third group that had a high number of plants/plot, but were low yielding. The presence of such a group indicated that the ability to

germinate and establish was not closely associated with chlorophyll deficiency (Appendix B Table 4, Appendix C Table 2, Appendix D Table 2).

The environment at the time of germination and plant establishment had a marked effect on the number of plants/plot in *B. rapa* DH lines. For example, in 1994, the average number of plants/plot for all DH lines was not significantly different from the average number of plants/plot for their donors (Table 4.10). However, in 1995, under drought stress shortly after emergence, DH lines were much less capable of tolerating drought than their donor populations, as indicated by significant differences between the DH and their donor populations (Table 4.10).

5.1.1.9 Seed yield and biological yield

Inbreeding affects the traits which are related to fitness (Falconer 1988). The most important fitness trait is number of seeds produced per plant i.e., seed yield. Seed yield of DH lines was highly depressed while biological yield was affected to a lesser degree (Table 4.6). The majority of DH lines were tall (Fig. 4.1a) with many branches, however, only a few DH lines produced high seed yields (Table 4.11, Appendix B Table 4, Appendix C Table 2, Appendix D Table 2). Seed yield is a important component of biological yield. A high correlation between these two traits would be expected. However, correlations in 1993, 1994 and 1995 were 0.64, 0.78, 0.84, respectively indicating that biological yield of DH plants and plots is not strong indicator of their seed yielding potential (Table 4.7). In 1993, when seed yield was determined on a per plant basis, seed and biological yields were inversely related to the number of plants/plot (Table 4.7).

The stability of seed yield among *B. rapa* DH lines was indicated by a highly

significant value for the rank correlation between seed yield of DH lines in 1994 and 1995 (Table 4.9). In both years, high yielding entries were high yielding and low yielding entries were low yielding resulting a positive and significant rank correlation (Tables 4.9, 4.11). However, some DH lines that yielded well in 1994 were comparatively lower yielding under the more severe growing conditions of 1995.

Considering the consistent performance of the DH lines over the two years, a single year evaluation of DH lines may be sufficient to identify the high yielding lines for further testing for GCA, although the yield ranking of DH lines from year to year may not be exactly the same (Table 4.11). Similar consistent yields of *B. napus* inbred lines, over three environments, was reported by Brandle and McVetty (1989b).

5.1.1.10 Plant morphological types

Each DH line exhibited distinct plant morphological features due to their complete homozygosity. This distinctiveness could be used as an aid in the selection of parents for hybrids (Figs. 4.7, 4.9, 4.10). Selection among heterozygous plants would be largely ineffective and indeed difficult since, for example, plants of the open pollinated donor populations all had the same general appearance. Distinct morphological types in DH lines could be utilised to produce hybrid cultivars with novel plant architecture and would also be useful in establishing a plant breeder's right. The morphological characteristics identified within the DH populations could also be useful in defining the inheritance of certain traits and to determine levels of outcrossing. For example, it was observed that a single microspore donor plant gave rise to DH lines with different seed colors (Fig. 4.13). Such DH lines provide an excellent reference population to classify the genetics of seed coat color. DH lines

could also serve as a reference library for specific traits such as, SI alleles, seed coat color and specific glucosinolate compositions. Plant morphological traits that may appear similar to one another may be independently inherited, for example the appressed branching habit exhibited by some DH lines was not always associated with the appressed podding habit (Appendix C Table 3, Figs. 4.9, 4.10). Such information and a trait reference library may be very important for future *B. rapa* breeding and gene mapping projects.

5.1.2 Seed production of DH lines for maintenance and evaluation

Since the DH lines of *B. rapa* were self incompatible, their maintenance involved the use of bud selfing. DH_0 plants produced a variable number of seeds/pod upon bud selfing indicating genotypic differences in fertility (Table 4.2, Appendix A). The two largest groups of DH plants were those that produced no seed and those that produced more than 10 selfed seeds (Appendix A Table 1, 3, 5). The failure of DH_0 plants to set any seed upon bud selfing could be due to the presence of very strong SI alleles in these homozygous plants and /or the stress associated with regeneration and colchicine treatment involved in producing the DH_0 plants. Generally, plants which produced no seed appeared normal with only a few plants having a limited amount of pollen. Since, these plants were not outcrossed it is not known whether these non seed producing plants were too weak to support developing embryos or whether they were expressing very strong self incompatibility. The initial objective of bud selfing was to obtain sufficient seed for field evaluation of DH lines. However, since considerable resources are required to obtained each DH plant and only a few selfed seeds may be required for maintenance in future DH breeding programs, other more intensive bud selfing techniques could be applied to plants that readily set pods upon outcrossing. To

obtain a few selfed seeds from plants that do not respond to standard bud selfing, stigma mutilation or steel brush pollination, coupled with high humidity could be effective in overcoming this constraint, since such procedures would remove the SI stigma barrier (Roggen and vanDijk 1972, Carter and McNeilly 1975). Since bud selfing on the seed producing DH plants resulted in an average of 2 to 4 seeds/pod and intercrossing resulted in 19 seeds/pod, weak or infertile plants could be readily distinguished from strong SI plants at an early flowering stage (Table 4.1, 4.2, Appendix A Table 1-9).

5.1.3 Inbreeding effects in *B. rapa*

As *B. rapa* DH plants are 100% homozygous, all recessive genes are expressed and as a result, a great range of variability is exposed (Fig. 4.1, Appendices B, C, D). Similar observations have been made in maize inbreds (Jones 1917). The low vigour of *B. rapa* DH lines is believed to be due to the expression of deleterious recessive genes (Tables 4.6, 4.11, Appendices B, C, D).

Many DH lines equalled their open pollinated heterozygous donors in size, weight and number of plant parts in the rosette and flowering stages (Table 4.19, Appendix B Tables 1, 2, 3, Appendix C Table 1, Appendix D Table 1). However, most of the DH lines reached the reproductive developmental stage later than their donors. Since the data were recorded on a growth stage basis, many DH lines were taller and larger in size at the beginning of flowering compared to their donors. In the later part of the growing season, very few of the DH lines were able to continue to support a large number of flowers, pods and developing seeds and the abortion of many pods and early cessation of growth occurred. In contrast, donors produced flowers early in the season, supported pod and seed growth and continued

to gain weight until maturity (Tables 4.6, 4.11, 4.19, Appendix B Tables 1, 2, 3, Appendix C Table 1, Appendix D Table 1). This observation suggests that poor performance of DH lines compared to their donors is due to their slower growth. Similar differences in plant sizes during the early growing stages, as well as differences in the rapidity of growth, between maize inbreds and non inbreds have also been reported (Ashby 1930, 1932, 1936, Rabideau *et al.* 1950, Whaley 1944, 1952).

Brassica rapa DH lines are produced from a single gamete. During the production of a gamete, one recombination event takes place. Thus, the number of dominant alleles that will be assembled in one gamete, which is known as coupling linkage, is restricted. Coupling linkage is believed to be one of the determining factors of high yield in DH lines compared to conventional inbreds (Snape 1976, Riggs and Snape 1977, Jinks and Pooni 1981). Assembling a large number of favourable factors for high seed yield in one gamete is also limited by the number of crossovers (about 20) per meiosis in *B. rapa* (Lydiate, D., personal communication). These theoretical genetic considerations are offered to explain the low average yield of *B. rapa* DH lines compared to the yield of their open pollinated source populations. A similar dispersion of favourable factors for high seed yield among tobacco inbred lines was believed to be the reason for their lower yield compared to their source populations (Jinks 1983).

One *B. rapa* DH line, BC-3015Y, was identified that equalled its donor population, BC86-18, in seed yield/plot in both test years. This indicated that high yielding *B. rapa* DH lines can be extracted from open pollinated sources of *B. rapa*. However, this observation must be confirmed in further tests before drawing any final conclusion. In early maize

breeding studies, no inbred lines were produced that were equal in yield to their open pollinated source populations (Hallauer and Miranda 1988) and no published reports of such a line has appeared since. However, in *B. napus,* DH lines have been reported to equal the yield of their source populations (Scarth *et al.* 1991, Thompson 1979, 1984). This situation is not comparable to *B. rapa,* since *B. napus* is an amphidiploid and a predominantly self pollinating species. In self pollinated crops, dominant alleles are present in both homologous chromosomes while in cross pollinated crops, such as *B. rapa*, dominant alleles present in one homologue may be absent in another, but can be brought together in one homologue by assortative mating. The breeding history of BC86-18 is that, only the five best plants in the population were selected in each of four recurrent selection cycles (Hutcheson, D., personal communication). Thus, the donor population BC86-18 had already been subjected to a mild form of inbreeding and assortative mating which would bring favourable dominant factors for high yield into a coupling linkage. Thus, only 41 DH lines sampled from BC86-18 were sufficient to identify one high yielding DH line. This observation suggested that hybrid vigour in *B. rapa* is the result of dominance deviation rather than overdominance. A similar situation was reported in tobacco where an inbred line was found to be taller than its open pollinated source population and dominance rather than overdominance was put forward as the explanation (Jinks 1983).

Forty to 45 DH lines may be adequate to sample the genetic variation of a population. A study with barley doubled haploids indicated that sampling of 20 DH lines from a cross was as effective as sampling of 100 DH lines in identifying the yield potential of that cross (Reinbergs *et al.* 1976). Since desired genes are present in repulsion phase linkage in open

pollinated *B. rapa* populations, many different microspore donor plants should be used for DH production. However, assortative mating among selected microspore donor plants before production of DH lines could be effective in bringing about the desired coupling linkage. Since, favourable dominant alleles, present in a donor population, are dispersed among DH lines produced from it, crossing of superior DH lines and producing DH lines from complex crosses is suggested as a means of assembling many dominant alleles in a single DH line. However, to combine two or more specific traits from two parents, a high number of DH lines should be drawn from the F_1 plant(s).

5.2 Combining ability testing

5.2.1 Top cross and polycross

5.2.1.1 Comparison of effectiveness

The DH lines EPD-2975, EPD-2978, EPD-2988 and EPD-2989, exhibited high levels of GCA for seed yield in both the top cross and polycross multi-location trials, indicating similar efficiencies of these two methods in ranking DH lines as to their GCA (Tables 4.21, 4.25). In addition, the average yielding ability of three groups (EPD, BC, CB) were ranked similarly in both top cross and polycross multi-location trials (Table 4.21, 4.25). Similar efficiencies of the top cross and polycross methods in predicting GCA for seed yield were also observed in the single location trials that identified DH lines BC-2588, BC-2648 and BC-2678 as having high levels of GCA for seed yield (Tables 4.23, 4.27). Similar results were obtained in alfalfa where the top cross and polycross methods were equally efficient in ranking clones for combining ability for forage yield (Tysdal and Crandall 1948).

5.2.1.2 Comparisons of seed production methods

The production of test cross seed by the top cross and polycross methods requires different field experimental procedures. These differences in experimental design will affect plant breeder's choice of methods. Seed production by the top cross method requires a large land base because each DH line must be surrounded by a wide pollen block to avoid crossing between female DH lines. In the present study, the size of this pollen block was seven metres which was found effective in producing hybrid seed on DH lines (Table 4.4). In contrast, seed production by the polycross method was accomplished on a small land base with hill plots of four plants each. However, hand planting and harvesting of individual hills was labour intensive compared to the top cross nursery where machine planting and harvesting is possible. The top cross nursery also required more seed than polycross nursery. In the present study, a total of 225 bud selfed seeds were planted in one replicate of the top cross seed production nursery while only 144 seeds were needed to plant the 12 replicates of the polycross nursery.

The polycross method produced more test cross seeds on the female DH lines than the top cross method under the experimental procedures used in this study (Tables 4.3, 4.5), which allowed a more intensive testing and evaluation of the polycross progenies (Tables 4.21, 4.25, 4.23, 4.27). However, the wide range in flowering (one month) among DH lines in the polycross nursery may have resulted in non random pollination among DH lines. In order to achieve synchrony of flowering, DH lines need to be selected for flowering time to ensure random pollination. This selection would also require a field trial prior to the inclusion of DH lines in a polycross nursery. However, the polycross method has two

advantages over the top cross method. First, DH lines which would be used as parents in the production of a future hybrid are contributing to the performance of their polycross progenies which in turn is reflected in their general combining ability. Second, the performance of DH lines is not masked by the contribution of a vigourous tester. Thus, disease and herbicide susceptibilities would more likely be exposed in the resulting polycross progeny. A similar opinion about the polycross method was expressed by Stoskopf *et al.* (1993) in assessing the advantages of the polycross method.

The low seed production in the top cross nursery compared to the polycross nursery was attributed to shading of DH lines by the vigourous pollinator plants. Such competition could be avoided by using greater spacing between DH and pollinator rows or by using a low vigour, recessive tester which would minimize competition between DH lines and the tester.

5.2.1.3 Test cross progeny performance

Top cross progenies yielded more seed than their corresponding polycross progenies when compared to the check cultivar Tobin. The higher seed yields of top cross progenies can be attributed to the contribution of genetic factors for high yield from the two high yielding well adapted, pollen parent cultivars, Echo and AC Parkland (Table 3.1). It has been reported in maize that one third of the yield of a top cross progeny is imparted by the tester (Horner 1973). It has been suggested that a tester with homozygous recessive alleles at a majority of the loci would be the most efficient tester since the contribution of such a tester in top crosses would be minimal and would therefore allow a more accurate ranking of combining ability of the inbred lines based on their test cross performance (Hull 1945, 1946, 1952). Subsequent experimental evidence in maize confirmed that an inbred line tester with

recessive alleles was more effective for yield improvement than the progeny selection method (Horner 1973). The importance of using a low vigour tester was also reported by many maize workers (Matzinger 1953, Rawlings and Thompson 1962, Allison and Curnow 1966, Hallauer and Lopez-perez 1979, Hallauer and Miranda 1988).

For *B. rapa* DH lines a self propagating, broad based, recessive tester could be produced by crossing late flowering DH lines with low seed and biomass yield that have small pods containing only a few small seeds. However, synchronization of flowering time between the recessive tester and DH lines is important and may have to be adjusted under field conditions. Another approach is to produce test cross seed in the greenhouse using a recessive tester and thus avoid the problem of flower synchrony in the field. This suggestion is based on the finding that crossing two unrelated DH lines produced 19 seeds/pollinated bud, whereas, bud selfing produced only 4 seeds/pollinated bud (Tables 4.1, 4.2). Thus, one hundred bud pollinations would produce on average 400 selfed seeds for DH field evaluation, whereas, those same 100 buds, when pollinated by an unrelated tester, would produce an average of 1900 top cross seeds, sufficient for multi-location plot trials. The greenhouse test cross approach would save time and resources as self seed production for evaluation of DH lines and field production of top cross or polycross seed would be eliminated (Table 5.1). This proposed method would also avoid the unconscious selection of DH plants with weak SI alleles that easily produce selfed seed.

A broad based recessive tester can be developed using the low vigour DH lines from many DH parent populations or specific testers can be developed depending on the pedigree and previous experience with heterotic groups.

The lower yield of polycross progenies compared to the top cross progenies was attributed to the low genetic potential of the male pollen population produced by comparatively lower yielding DH lines. Non random pollination among DH lines in the polycross nursery might also been a contributing factor to the lower yield of the polycross progenies.

Table 5.1 Time comparison of the conventional and proposed methods for general combining ability testing of 1000 DH lines

Year	Conventional method	Proposed method
1 Winter	Bud selfing of DH lines in the greenhouse	Top cross seed production on DH lines in the greenhouse
Summer	Bud selfing of DH lines in the greenhouse	Top cross seed evaluation in the field. Selection for GCA
		⇓
2 Winter	Bud selfing of DH lines in the greenhouse	**SCA testing**[1]
3 Summer	DH lines evaluation in the field. Selection of DH lines.	
4 Summer	Top cross or polycross seed production in the field	
5 Summer	Top cross seed or polycross seed evaluation in the field. Selection for GCA	
	⇓	
	SCA testing[1]	

[1] Time was not calculated for single cross seed production

5.2.1.4 Progeny performance from high- and low-vigour females

Low vigour DH females in the test cross seed production nurseries produced little seed. Therefore, multi-location trials were conducted mainly with the seed produced on high

vigour DH females while single location trials were sown with seed from low vigour DH females (Tables 4.3, 4.5). The average performance of progenies produced from both the high and low vigour DH females was comparable (Tables 4.21, 4.23, 4.25, 4.27). However, commercial heterosis was obtained only from the progeny of a single high vigour DH female in the multi-location top cross trials (Table 4.21) suggesting that selection for high vigour DH females could be useful. Similar visual selection of maize inbred lines is a common practice in maize hybrid breeding programs (Hallauer and Miranda 1988).

5.2.1.5 Degree of outcrossing in the top cross nursery

Outcrossing ranged from 77-97% in the BC group and from 47-97% in the CB group of DH lines (Table 4.3). The low level of outcrossing (53 percent self or intra DH fertilization) in the CB group could be due to unconscious selection of self compatible DH lines, given the difficulty in obtaining sufficient quantities of selfed seeds in the greenhouse for field evaluation. It is also possible that some DH lines received pollen from other DH lines with different SI alleles or pollen containing zero erucic allele from the pollinator cultivar Echo. All the DH lines should be tested for the strength of their SI alleles, if SI is to be used in the production of *B. rapa* hybrids. However, several highly incompatible DH lines were noted in this study and a method to utilize self incompatible inbred lines to make single crosses, three-way or partial hybrids is proposed in sections 5.3.1 and 5.3.2.

The top cross lines, CB-2736 and CB-2940 produced seed with very high erucic acid levels (34-59%) (Table 4.4). These DH lines were derived from the same donor plant as were other DH lines (CB-2740 through CB-2940) which produced top cross seed with the expected range of <1-27%. It is concluded that the donor parent was heterozygous for genes

controlling erucic acid production with one allele coding for zero erucic acid and the other allele coding for approximately 25% erucic acid. Since the CB donor population is known to have the yellow sarson cultivar R-500 as one of its putative parents and R-500 has an erucic acid content of 48-50% it can be assumed that range in erucic acid found in the top cross seeds from these two high erucic DH lines is due to the presence of the 25% erucic acid allele from R-500.

5.2.2 Single cross hybrids

5.2.2.1 Testing of specific and general combining ability

Single cross hybrids were tested to identify the merit of specific cross combinations as well as the general combining ability of DH parents. A specific cross between an average DH and a good general combiner was found to be equal to a cross between the best male and female general combiners (Table 4.29, 4.31, Appendix E), which emphasises the need to test for specific combining ability. However, in all high yielding crosses, one parent was a good general combiner. The need for specific combining ability testing was also noted for cultivar crosses involving self incompatible Indian *B. rapa* (brown sarson) (Rao 1970, Patnaik and Murty 1978, Yadav *et al.* 1988).

General combining ability for seed yield in single cross hybrids was calculated using five DH pollen parents (Table 4.31). These male parents were from the EPD group which is genetically more distant from the BC and CB groups than BC and CB are to one another. The five pollen parents were the best general combiners, as indicated by previous progeny trials (Tables 4.21, 4.25). In contrast, pollen parents in the top cross nursery were Echo and AC Parkland, two high yielding open pollinated cultivars while in the polycross nursery the

pollen parents were 42 DH lines which included both low and high vigour lines (Tables 4.3, 4.5).

The DH lines CB-2857, CB-2940 and CB-2941, were high yielding in single crosses but their top and polycross progenies were low yielding. The percent hybridity for these lines, as determined from analyses of top cross seeds, was respectively 94 and 47% for CB-2857 and CB-2940, but for CB-2941 the per cent of crossing was undefined as it was a high erucic DH line (Table 4.4). Thus, the inclusion of selfed seed from CB-2857 in the top cross progeny could not have been the reason for its relatively poor performance in the top cross trial compared to the single cross test. Since the other two CB lines, CB-2940, CB-2941, performed in a similar manner to CB-2857 in both the top cross and polycross, it is unlikely that self seed produced in the top cross nursery is the reason for their relatively poor performance in the top cross progeny trials. The high yield of these three CB lines in single crosses could be attributed to the contribution of the best male parents whereas, their poor performance in top and polycross trials might be attributed to the variable contribution of many male parents.

Only a limited number of pollen parents can be used in single cross evaluations. Therefore, in maize inbreds, the single cross test was found to be less efficient in determining GCA than top cross tests (Sprague and Tatum 1942). However, single cross tests were found to be necessary for the identification of productive hybrids (specific combining ability) at the final testing stage (Sprague and Tatum 1942).

5.2.2.2 Maturity of *B. rapa* hybrids

Productivity is not the only attribute that must be considered in developing *B. rapa*

hybrids for the short growing season zone in Western Canada. Previous researchers noted a small degree of dominance for lateness over early maturity in *B. rapa* cultivar derived hybrids and expressed concern that *B. rapa* hybrids may not be as well adapted as the present open pollinated cultivars (Schuler *et al.* 1992). However, the DH lines in the present study were earlier maturing than their donors and their hybrids were also earlier than their donors and the cultivar Tobin (Table 4.29, Appendix E Table 1). Thus, it should be possible to produce hybrids that are both productive and as early or earlier than the present open pollinated cultivars. For conclusive results, multi-location and multi-year trials of *B. rapa* DH line derived hybrids would need to be conducted.

5.2.2.3 Normal distribution and genetic nature of combining ability

Combining ability for seed yield in DH lines, derived from one source population, were normally distributed, for example, the seed yield of *B. rapa* hybrids derived from crosses between DH lines from the BC (♀) and EPD(♂) group. Maize workers (Green 1948, Sprague 1946, Cowan 1943, Johnson and Hayes 1940) also concluded that "combining ability is a heritable trait" and "an approximately normal distribution may be expected for combining ability of inbred lines drawn from a population". Thus, combining ability is a genetic property and should change with changes in the genetic composition of the parents. Any change in the genetic make up of inbred lines during commercial hybrid production, such as the introduction of cytoplasmic male sterility into a selected inbred (or DH line) by conventional backcrossing, would change the combining ability of the inbred (or DH line). Introduction of cytoplasmic male sterility into a selected DH line through cybrid production or through the Plant Genetic System's pollen control method (Mariani 1992, 1990) may not

change the genetic property of the inbred (or DH line), but genetic changes as a result of the tissue culture system used may occur (Kumar 1997).

5.2.2.4 Heterotic group identification

Combining ability testing and heterotic group identification occupies the major part of hybrid breeding programs in maize and sorghum. The heterotic groups identified in maize (Hallauer and Miranda 1988) and sorghum (Doggett 1988) were based on plant morphology which reflected genetic differences. Identification of genetic differences in canola quality types of *B. rapa* would require much effort because of its narrow genetic base. Molecular markers can be used to identify genetic differences. Another avenue of utilizing genetic difference is by crossing different subspecies of *B. rapa* for the development of heterotic groups. Hybrids between the subspecies *B. chinensis* and *B. rapa* were reported to be high yielding on plant basis in India (Chaudhury *et al.* 1987).

Another means of identifying heterotic groups is to utilize geographical differences (Beal 1880 in maize, Grant 1984 in *B. napus*, Schuler *et al.* 1992 in *B. rapa*). Heterotic group identification and improvement of heterotic gene pools is the most important aspect of hybrid breeding. Production of DH lines from any commercial cultivar without prior characterization of its heterotic group classification and testing of the combining ability of such DH lines would be a time consuming and inefficient way of identifying a productive hybrid.

5.2.2.5 Selection of parents of inbreds

All BC and CB DH lines used as parents in single crosses died after the field application of herbicide 'muster', whereas the DH lines from the EPD group as well as the

three donor populations (CB, BC, EPD) and all single cross hybrids and the cultivar Tobin were not affected by the herbicide spray. This observation indicated that the BC and CB populations were genetically related and were heterozygous for the herbicide susceptibility factor. This observation indicated that herbicide susceptibility could be an important criterion for assessing *B. rapa* DH lines, and the reaction of DH lines to other canola herbicides currently in use should also be tested. Thus, it is recommended that the population which will donate microspores for DH production be carefully evaluated for desirable traits. For maize hybrid breeding, Hallauer and Miranda (1988) concluded, "It is generally accepted that a ceiling on the assemblage of genes is imposed by the particular S_0 plant selected for self pollination. Recombination of genes permits some additional selection in later generations, but it is minor compared to original selection of S_0 plants."

5.3 Utilization of *B. rapa* doubled haploid lines for hybrid production and population improvement

A systematic approach for the development of *B. rapa* hybrids is outlined below:

Step 1. Identify heterotic populations by using geographical or sub-species divergence.

Step 2. Derive DH lines from two heterotic populations or selected microspore donor plants and screen for green, vigourous DH lines in the greenhouse.

Step 3. Evaluate DH lines by producing top cross seed using a weak, low vigour (recessive) tester.

Step 4. Combine desirable traits of two or more DH lines by making complex crosses with all the lines following a Doubled Haploid Recurrent Selection (DHRS) procedure (see section 5.3.3) or allow assortative mating.

Step 5. Once the best DH lines are identified, cross the DH lines

from the two heterotic groups and evaluate single crosses in the field. Identify the best hybrid combination(s).

Step 6. Introduce a pollen control system through cybrid formation or use a transgenic pollen control system or use SI to produce a 4-way hybrid.

5.3.1 Maintenance of self incompatible DH lines

For production of hybrids, maintenance of DH parental lines and large scale seed production is required. This could be accomplished using the hierarchy of dominance within the S allelic series. For example in *B. oleracea*, a group of strong S alleles are found which are always dominant over another group of weak S alleles. However, a few S alleles are also present which are intermediate in the dominance series (Thompson and Taylor 1966). Strong and weak S alleles are also found in *B. rapa* (Kott 1995). The strong (known as unsuppressible SI) group being dominant over the weak (known as suppressible SI) group of S alleles. However, further studies on the hierarchy of these dominance relationships is needed to implement the following scheme for the maintenance of *B. rapa* DH lines.

Maintenance of self incompatible DH lines as parents for hybrid production

Generation	S allele genotype	S allele relationships
DH Parents	S_1S_1 X S_2S_2	Dominance relation $S_1 > S_2$
	|	
F_1	S_1S_2	Bud selfing
	|	
F_2	1 S_1S_1	S_1S_1 pollinates S_2S_2
	2 S_1S_2	S_1S_2 pollinates S_2S_2 as both gametes (S_1, S_2)
	1 S_2S_2	behave as S_1
	|	
	|	Allow inter-pollination in the greenhouse
	|	

F_3	2 S_1 S_2 1 S_2 S_2 | | |	If dominance is complete and no codominance is expressed in the stigma, then gametes from S_1S_2 will behave as S_1 and pollinate S_2S_2
F_4	1 S_1S_2 1 S_2S_2	Population in equilibrium and can be maintained indefinitely in the greenhouse or grown on a large scale in the field for hybrid seed production.

A second set of DH lines, S_3S_3 X S_4S_4 can be similarly maintained, provided S_3 is completely dominant over S_4. Thus as in the first example, the the population will reach equilibrium in the F_4 generation and will be composed of 1 S_3S_4 :1 S_4S_4. In this way several population sets with two selected lines can be made which will be self propagating and also show some hybrid vigour, since 50% of the genotypes will be hybrid in each population set. Such population sets can be used to produce 4-way hybrids under field conditions, provided the S alleles are properly matched. If more than two SI alleles are present in two DH lines then the population will not reach equilibrium in four generations. Thus, this method is easy to apply on DH lines where homozygosity is complete. Mutual weakening of SI alleles in a heterozygote, or any relationships between SI alleles other than dominance, is not desirable as a lower percentage of hybrid seed would result.

5.3.2 Production of hybrid cultivars/synthetics

The use of advanced generations of single crosses as parents of double crosses in maize was reported by Hayes *et al.* (1931) and Kiesselbach (1930). They reported that double cross hybrids and 4-way crosses between the F_2 or F_3 generations were equal in seed yield. Based on this information, a partial hybrid production scheme is proposed here. Four

S alleles (S_1, S_2, S_3, S_4) are involved in this scheme. S_1 is dominant over S_2 while S_3 is dominant over S_4. Also, S_1 and S_2 as a group are dominant over S_3 and S_4. Maintenance of the four lines would follow the scheme presented in the previous section (5.3.1).

For seed production of partial hybrids, equal quantities of the various S genotypes produced as outlined in the previous section (5.3.1) are mixed and field grown as follows:

Genotypes	S_1S_2	S_2S_2	S_3S_4	S_4S_4
Ratio	1	1	1	1
SI relations	$S_1 > S_2$, $S_3 > S_4$, S_1 and $S_2 > S_3$ and S_4, no codominance present			

Thus, if random pollination occurs, of the resulting genotypes 16.6% will have the S allele makeup of the original DH parental genotypes and 83.4% would be hybrid genotypes as noted below:

DH genotypes	Hybrid genotypes
2 S_2S_2 - 8.3	2 S_1S_2 - 8.3
2 S_4S_4 - 8.3	1 S_1S_3 - 4.2
	3 S_1S_4 - 12.5
Total 16.6%	3 S_2S_3 - 12.5
	9 S_2S_4 - 37.5
	2 S_3S_4 - 8.3
	Total 83.4%

Several researchers have proposed different SI based schemes for hybrid *Brassica* production. A triple cross hybrid production system using six SI alleles was described by Thompson (1964) in kale. In his method bud selfed inbred seeds had to be planted in the field for hybrid seed production. For the method described in the present study, no bud

selfed seed is used in the hybrid seed production field. The use of a high concentration of CO_2 to produce self seed and thus, maintain self incompatible *B. oleracea* lines was proposed by Taylor (1982). Thompson *et al.* (1983) also proposed the use of two lines, one with a recessive SI allele and another with self compatible allele, as a method to produce 3-way hybrids. Using dominant SI alleles and recessive self compatible alleles, different hybrid production methods were proposed for *B. napus* (Kott 1995, Werner and Jennaway 1995). Other methods to produce self seed on *B. napus* plants by spraying salt water has been proposed by Fu (1981) and Fu *et al.* (1992). However, none of these schemes utilize only dominance relations of SI alleles. The scheme proposed in the present study differs from those previously put forward in that the parents are maintained through open pollination under isolated field conditions, thus making hybrid seed production more cost effective.

5.3.3 Use of recessive tester in DH evaluation

In this study, production of a recessive tester is proposed by inter crossing short, late flowering and small sized DH lines with a low number of seeds/pod and a low seed yield/plot. A broad based tester can be constituted by crossing selected DH lines from many populations exhibiting the desired traits or by developing specific tester(s) from different identified heterotic groups. Such a tester(s) can be used in DH lines evaluation in the following manner.

Doubled haploid recurrent selection (DHRS)

A, B, C and D represent populations from two heterotic groups, 1 and 2. In the initial step, plants of the A and B populations of group 1 are crossed to combine two (or more) desirable traits, similarly plants of B and C from group 2 are crossed.

Group 1	Group 2
A x B	C x D
|	|
20 F_1	20 F_1

(Keep a few F_1 seeds in reserve) (optional).

Make 20 DH plants from each F_1. Grow 800 DH lines in the GH and discard 1/2 to 1/3 of the plants on the basis of vigour, chlorosis and late flowering.

Keep a few selfed seeds from all DH plants. Cover one raceme with a selfing bag to test the level of self incompatibility.

Cross DH lines grown in the greenhouse with a broad based (or specific) recessive tester to produce 2000 seeds from each line by crossing 100 buds (or open flowers). If open flowers are crossed the raceme should be covered beforehand to avoid unwanted pollen contamination.

Grow the top cross seeds in the field and select for high yield. Go back to the selfed seed of the DH plant(s) from which the high yielding top cross progeny were produced. If one DH line with all desired traits or high yield is not found, cross selected DH lines in all possible combinations or make complex crosses or allow inter-pollination. For hybrid production keep the heterotic groups separate, i.e. do not use DH lines from two heterotic groups to make the complex cross. This rule is not applicable for production of synthetics. Make 30-40 DH lines from F_1 plants or complex crosses.

Cross DH lines with a specific recessive tester known to be heterotic. Produce 300 top cross (100 x 3 reps) seeds from each DH and grow in the field to determine GCA. A total of 12000 crossed seeds are needed to evaluate 40 DH lines. Crossing of 632 buds (or open flowers) should produce the required seed.

Repeat the cycle

The doubled haploid recurrent selection scheme is based on the following principles:

1. Theoretically, a completely recessive tester should allow expression of all the genes present in a DH line.

2. A recessive or weak tester is capable of detecting dominance and overdominance

3. Combining ability is heritable and normally distributed among the inbreds drawn from one source population.

6.0 SUMMARY AND CONCLUSIONS

The present study is the first report on the testing and evaluation of *B. rapa* DH lines under field conditions and their possible use as parents in the breeding of improved cultivars of *B. rapa.* Although the number of DH plants and breeding populations sampled were limited, a number of important findings were made which are summarised below.

6.1 Evaluation of DH lines

i) DH lines exhibited characteristics typical of inbreeding depression in other open pollinated crops and in many respects paralleled observations made in maize inbreds by early maize breeders.

ii) Maintenance of DH lines by bud selfing was labour intensive. Bud selfing on DH plants yielded two to four seeds per pollinated bud while outcrossing DH lines yielded an average of 19 seeds per pollinated bud. A large population of the DH_0 plants failed to produce selfed seed when up to 25 buds were selfed.

iii) DH lines exhibited distinct plant morphological features. It may be possible to utilize certain morphological characteristics in selecting desirable DH parents for use in hybrids. The morphological characteristics identified in the DH populations will also be useful in

inheritance and outcrossing studies, gene mapping and the establishment of a reference library for SI alleles, seed coat color, different glucosinolate genotypes etc.

iv) Varying degrees of chlorophyll deficiency were observed in some lines of all DH groups. The chlorophyll deficiency observed in the greenhouse and field closely corresponded. Chlorophyll deficient plants were low in vigour and productivity and can be safely discarded in the greenhouse at an early developmental stage with a considerable saving in time and resources to the breeding program.

v) Strong inbreeding depression in DH lines was evidenced by chlorophyll deficiency, low number of seeds/pod, late flowering and low seed and biomass yield. Germination and establishment was reduced under cold stress. Inbreeding depression was also evident, but to a lesser degree, in seed size, pod length and days to mature.

vi) The traits that contributed most to seed yield in DH plants at Saskatoon were (1) germinability, seedling vigour and plant establishment, (2) green (non chlorotic) leaves for efficient carbohydrate fixation, (3) early flowering, (4) moderate plant height, (5) a long pod filling period and (6) a high number of seeds/pod which reflected the fertility status of the DH plant.

vii) Considering the consistent performance of DH lines over two years, a single year evaluation of DH lines may be sufficient to identify the high yielding DH lines, although the ranking of DH lines in one year may not be exactly the same in the second year.

viii) The DH line BC-3015 equalled its donor population BC86-18 in seed yield in each of the two test years suggesting that dominance deviation, not over dominance is the genetic basis for high yield in *B. rapa*.

6.2 Combining ability of *B. rapa* doubled haploids

i) Both, the top cross and polycross progeny tests were effective in identifying DH lines with good GCA, but a single cross evaluation is required to identify those lines with good SCA. It is suggested that one or more weak, low yielding line(s) should be developed and used as a top cross tester.

ii) The polycross method required only a limited number of selfed DH seeds and a small nursery to produce sufficient seed for multi-location trials. In addition, the polycross progeny reflected the contributions of DH lines that would be involved as parents of future hybrids in contrast to a single tester used in the top cross system. However, the polycross method would require a field evaluation of the DH lines prior to their inclusion in a polycross nursery to ensure that all DH lines flower at the same time. In addition, lines to be included in the polycross should be tested to ensure that they have a high level of self incompatibility.

iii) Top cross seed can be effectively produced in the greenhouse on DH_1 plants, thus saving the time and resources required to produce a large quantity of bud selfed seed needed for DH evaluation. For top cross testing to be effective, a weak tester line containing many recessive traits (such as, late flowering, low seed and biological yield, short height, small pod, small seed size) should be developed and used to avoid the masking effect of the tester on the genetic potential of the DH lines. Using a weak tester in a field grown top cross nursery would also avoid inter plot competition between DH lines and the top cross tester provided flowering was synchronised.

iv) Considerable variation in the degree of inbreeding depression was present among DH lines. Unconscious selection to produce selfed seeds on the more self compatible DH plants

may have occurred. If SI is used in hybrid seed production, DH lines should be tested for the strength of their SI alleles. However, on the basis of the high level of self incompatibility identified in some DH lines, a method of utilizing SI to produce hybrids was proposed.

v) One DH parent was a good general combiner in all high yielding hybrids. A cross between the two best general combiners was as high yielding as a cross between the best general combiner and another good inbred emphasizing the need for single cross evaluation.

vi) The fact that one top cross line averaged over three locations, yielded significantly more seed (14%) than the cultivar Tobin, and the fact that another single cross hybrid was also higher yielding than Tobin (30%) implies that development of hybrids from selected high yielding DH parents would be commercially feasible.

6.3 Conclusions

It is concluded that with the technique to produce *B. rapa* DH plants on a large scale (Baillie *et al.* 1992) and the identification in this thesis of methods to evaluate large numbers of DH plants as to their GCA, as well as a scheme to maintain and provide parental stocks, the major constraints to the production of commercial hybrids in this self incompatible species have been overcome. Further studies are needed to confirm the feasibility of the proposed methods.

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APPENDICES

Appendix A. Production of selfed seeds on DH_0 and DH_1 plants and crossed seed on advanced generation doubled haploid (DH) plants

Appendix A Table 1 Production of selfed seeds on *B. rapa* colchicine treated doubled haploid (DH_0) plants of the BC group, 1992-93

Line [1]	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod	Line	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod
BC2459	*10*	*5*	*9*	*1.80*	*BC2665*	*15*	*12*	*47*	*3.92*
BC2467	10	10	11	1.10	BC2666	10	5	40	8.00
BC2469	10	1	0	0.00	BC2667	20	3	3	1.00
BC2503	10	7	13	1.86	*BC2668*	*10*	*3*	*46*	*9.20*
BC2515	20	10	1	0.10	BC2669	10	8	24	3.00
BC2519	20	10	5	0.50	BC2672	20	4	0	0.00
BC2520	20	10	1	0.10	BC2674	10	7	47	6.71
BC2524	10	9	28	3.11	BC2676	10	7	0	0.00
BC2525	*10*	*6*	*20*	*3.33*	BC2677	15	12	24	2.00
BC2528	25	0	0	0.00	*BC2678*	*10*	*7*	*85*	*12.14*
BC2530	25	5	0	0.00	*BC2679*	*15*	*11*	*42*	*3.82*
BC2537	10	2	4	2.00	BC2680	10	5	16	3.20
BC2558	10	8	30	3.75	BC2681	10	9	22	2.44
BC2564	10	3	7	2.33	BC2696	20	3	0	0.00
BC2566	10	6	11	1.83	BC2697	10	6	14	2.33
BC2573	*15*	*11*	*100*	*9.09*	BC2700	20	0	0	0.00
BC2576	*10*	*7*	*74*	*10.57*	BC2701	10	6	43	7.17
BC2588	*10*	*10*	*105*	*10.5*	BC2702	5	4	16	4.00
BC2595	*10*	*4*	*16*	*4.00*	BC2703	20	3	2	0.67
BC2596	20	0	0	0.00	*BC2705*	*10*	*6*	*18*	*3.00*
BC2598	10	6	14	2.33	BC2706	20	9	0	0.00
BC2603	20	5	0	0.00	BC2709	20	1	6	6.00
BC2606	15	12	18	1.50	BC2708	20	3	7	2.33
BC2608	20	6	0	0.00	BC2722	10	5	34	6.80
BC2611	20	0	0	0.00	*BC2723*	*10*	*5*	*42*	*8.40*
BC2618	*15*	*10*	*55*	*5.50*	*BC2725*	*15*	*11*	*118*	*10.73*
BC2620	20	1	1	1.00	BC2728	20	4	0	0.00
BC2643	20	4	0	0.00	BC2730	20	5	1	0.20
BC2647	*10*	*8*	*15*	*1.88*	BC2731	20	2	0	0.00
BC2648	*10*	*9*	*56*	*6.22*	BC2733	10	7	5	0.71
BC2655	25	0	0	0.00	BC2746	20	2	0	0.00
BC2657	20	4	3	0.75	BC2749	20	9	0	0.00
BC2658	20	6	4	0.67	BC2751	20	0	0	0.00
BC2659	20	4	1	0.25	BC2752	5	3	9	3.00
BC2660	*15*	*11*	*63*	*5.73*	BC2753	20	10	1	0.10
BC2664	15	11	30	2.73	*BC2754*	*10*	*6*	*29*	*4.83*

Appendix A Table 1 Contd.

Line [1]	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod	Line	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod
BC2755	5	4	42	10.50	BC2824	10	8	18	2.25
BC2758	20	6	1	0.17	BC2825	20	6	0	0.00
BC2759	20	4	0	0.00	BC2825	20	1	2	2.00
BC2761	20	2	0	0.00	BC2827	10	9	13	1.44
BC2764	20	4	0	0.00	BC2831	20	3	0	0.00
BC2766	10	8	32	4.00	*BC2850*	*10*	*7*	*31*	*4.23*
BC2767	20	11	0	0.00	BC2870	20	0	0	0.00
BC2770	20	2	0	0.00	BC2874	10	4	10	2.50
BC2771	10	6	25	4.17	BC2875	20	3	0	0.00
BC2772	10	4	19	4.75	BC2876	20	8	0	0.00
BC2774	*15*	*12*	*86*	*7.17*	BC2877	25	8	1	0.13
BC2776	25	0	0	0.00	BC2884	10	0	0	0.00
BC2777	10	5	64	12.80	*BC2886*	*10*	*9*	*58*	*6.44*
BC2778	10	7	29	4.14	BC2887	10	3	5	1.67
BC2779	15	13	0	0.00	*BC2889*	*15*	*9*	*63*	*7.00*
BC2780	15	7	0	0.00	BC2895	20	6	4	0.67
BC2785	20	0	0	0.00	BC2896	20	2	1	0.50
BC2786	20	17	33	1.94	BC2901	20	0	0	0.00
BC2787	20	0	0	0.00	BC2903	25	0	0	0.00
BC2788	20	0	0	0.00	BC2909	20	0	0	0.00
BC2789	20	1	3	3.00	BC2912	25	0	0	0.00
BC2791	*20*	*18*	*80*	*4.44*	*BC2913*	*10*	*7*	*38*	*5.43*
BC2794	20	5	0	0.00	*BC2916*	*15*	*15*	*67*	*4.47*
BC2795	25	0	0	0.00	BC2917	10	5	8	1.60
BC2799	20	6	0	0.00	BC2919	20	3	0	0.00
BC2800	25	0	0	0.00	BC2925	10	7	7	1.00
BC2804	25	0	0	0.00	BC2926	10	7	10	1.43
BC2809	20	7	0	0.00	*BC2927*	*10*	*8*	*17*	*2.13*
BC2811	20	0	0	0.00	BC2929	10	7	49	7.00
BC2812	20	16	20	1.25	BC2943	5	2	22	11.00
BC2814	10	6	10	1.67	*BC2944*	*10*	*7*	*23*	*3.29*
BC2815	10	7	0	0.00	BC2945	20	2	0	0.00
BC2817	10	5	11	2.20	BC2946	25	0	0	0.00
BC2818	20	0	0	0.00	BC2948	20	8	0	0.00
BC2821	20	5	0	0.00	BC2949	20	0	0	0.00
BC2822	10	6	11	1.83	BC2950	10	10	79	7.90

Appendix A Table 1 Contd.

Line [1]	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod	Line	Number of Buds selfed	Pods formed	Seeds formed	Seeds /pod
BC2951	5	4	15	3.75	*BC3028*	*10*	*5*	*42*	*8.40*
BC2952	20	9	0	0.00	BC3029	25	2	0	0.00
BC2953	*5*	*4*	*19*	*4.75*	BC3033	20	0	0	0.00
BC2956	*15*	*12*	*44*	*3.67*	*BC3034*	*10*	*8*	*8*	*1.00*
BC2957	10	4	10	2.50	BC3035	20	4	2	0.50
BC2959	10	9	14	1.56					
BC2960	*10*	*8*	*21*	*2.63*					
BC2961	10	8	13	1.63					
BC2962	*5*	*4*	*22*	*5.50*					
BC2963	20	2	4	0.50					
BC2964	20	1	0	0.00					
BC2965	*15*	*13*	*50*	*3.85*					
BC2966	20	3	4	1.33					
BC2967	10	9	13	1.44					
BC2968	20	1	3	3.00					
BC2969	20	3	0	0.00					
BC2971	*10*	*3*	*9*	*3.00*					
BC2972	10	6	6	1.00					
BC2973	20	4	0	0.00					
BC2999	10	6	11	1.83					
BC3000	20	1	0	0.00					
BC3002	10	6	34	5.67					
BC3004	10	6	9	1.50					
BC3005	20	0	0	0.00					
BC3008	10	9	1	0.11					
BC3010	15	14	14	1.00					
BC3011	*10*	*8*	*6*	*0.75*					
BC3012	10	6	18	3.00					
BC3014	10	6	44	7.30					
BC3015	*10*	*8*	*21*	*2.63*					
BC3016	*10*	*10*	*62*	*6.20*					
BC3017	20	5	0	0.00					
BC3020	20	3	0	0.00					
BC3022	*10*	*5*	*21*	*4.20*					
BC3025	10	7	30	4.29					
BC3027	10	3	8	0.89					

[1] Lines in italic were evaluated in the field for at least one year

Appendix A Table 2 Production of selfed seeds on first (DH_1) and later generation doubled haploid plants of *B. rapa* from the BC donor group, 1993-1994

Line	Number of Pods	Number of Seeds	Seeds/pod	Line	Number of Pods	Number of Seeds	Seeds/posd
BC13	260	300	1.15	BC2525	90	415	4.61
BC15	2	23	11.5	BC2573	501	968	1.93
BC29	145	335	2.31	BC2588	936	6300	6.73
BC42	200	400	4.12	BC2576	607	3095	5.09
BC43	93	312	3.36	BC2595	282	1309	4.64
BC51	57	0	0.00	BC2595A	72	300	4.17
BC54	6	0	0.00	BC2618	920	1278	1.39
BC61	166	84	0.51	BC2647	208	423	2.03
BC69	63	332	5.27	BC2648	327	1200	3.67
BC72	86	0	0.00	BC2660	1120	3300	3.00
BC84	200	346	1.73	BC2665	478	2600	5.44
BC93	46	0	0.00	BC2677	90	700	7.78
BC94	6	49	8.16	BC2668	849	2637	3.11
BC115	150	35	0.23	BC2678	661	2150	3.25
BC111	124	757	6.10	BC2679	456	1937	4.25
BC122	2	0	0.00	BC2705	536	700	1.31
BC150	4	2	0.50	BC2723	323	2400	7.43
BC156	60	38	0.63	BC2725	1031	14888	14.44
BC161	171	0	0.00	BC2754	177	500	2.82
BC169	295	850	2.88	BC2774	970	2899	2.99
BC186	4	15	3.75	BC2786	9	10	1.11
BC196	29	34	1.17	BC2791	1057	9500	8.99
BC204	260	650	2.50	BC2850	411	453	1.10
BC207	39	80	2.05	BC2886	228	850	3.73
BC208	365	0	0.00	BC2889	790	3361	4.25
BC249	278	740	4.13	BC2913	242	745	3.08
BC250	177	189	1.07	BC2916	1341	4288	3.20
BC263	196	80	0.41	BC2927	623	1500	2.41
BC275	48	10	0.21	BC2944	204	300	1.47
BC276	300	1100	3.67	BC2953	296	900	3.04
BC278	200	300	1.50	BC2956	388	403	1.04
BC295	281	590	2.10	BC2960	200	800	4.00
BC360	217	700	3.23	BC2962	175	600	3.43
BC964	95	359	3.78	BC2965	558	850	1.52
BC2459	384	859	2.24	BC2965A	75	300	4.00
BC2507	190	730	3.84	BC2979	100	98	0.98

Appendix A Table 2 Contd.

Line	Number of Pods	Seeds	Seeds/pod
BC3011	341	1827	5.36
BC3014	140	0	0.00
BC3015Y	128	1800	14.06
BC3015B	241	2889	12.00
BC3015G	333	4650	13.96
BC3016	870	2593	2.98
BC3022	267	400	1.50
BC3025	68	218	3.21
BC3028	91	404	4.44
BC3034	140	1000	7.14

Appendix A Table 3 Production of selfed seeds on *B. rapa* colchicine treated doubled haploid (DH_0) plants of the CB group, 1992-1993

Line [1]	Number of				Line	Number of			
	Buds selfed	Pods formed	Seeds formed	Seeds /pod		Buds selfed	Pods formed	Seeds formed	Seeds /pod
CB2161	20	6	4	0.67	*CB2689*	*10*	*10*	*24*	*2.40*
CB2168	20	5	4	0.80	*CB2690*	*15*	*15*	*149*	*9.93*
CB2484	25	4	0	0.00	*CB2736*	*10*	*9*	*91*	*10.11*
CB2488	20	1	0	0.00	CB2737	10	8	0	0.00
CB2499	20	2	0	0.00	*CB2740*	*10*	*8*	*106*	*13.25*
CB2501	20	3	0	0.00	*CB2741*	*10*	*7*	*67*	*9.57*
CB2509	20	6	0	0.00	CB2744	20	6	0	0.00
CB2624	*10*	*8*	*58*	*7.25*	CB2745	10	9	38	12.67
CB2625	*15*	*11*	*84*	*7.64*	CB2852	10	8	0	0.00
CB2627	*10*	*10*	*35*	*3.50*	CB2854	20	6	0	0.00
CB2628	*15*	*11*	*40*	*3.64*	CB2855	25	0	0	0.00
CB2629	10	9	0	0.00	CB2856	20	6	1	0.17
CB2630	*10*	*10*	*20*	*2.00*	*CB2857*	*10*	*7*	*21*	*3.00*
CB2631	10	9	0	0.00	*CB2940*	*10*	*10*	*135*	*13.50*
CB2645	20	3	0	0.00	*CB2941*	*15*	*11*	*35*	*3.18*

[1] Lines in italic were evaluated in the field for at least one year

Appendix A Table 4 Production of selfed seeds on DH_1 and later generation plants of *B. rapa* doubled haploid lines of the CB donor group, 1993-1994

Line	Number of Pods	Seeds	Seeds/pod	Line	Number of Pods	Seeds	Seeds/pod
CB1	115	408	3.55	CB2161	387	50	0.13
CB2	203	106	0.52	CB2524	196	900	4.59
CB6	425	44	0.10	CB2624	752	1315	1.75
CB7	4	0	0.00	CB2625	732	1749	2.39
CB10	170	0	0.00	CB2627	816	4730	5.80
CB11	290	0	0.00	CB2628	856	1223	1.43
CB13	177	2900	16.38	CB2630	721	1530	2.12
CB15	247	1950	7.89	CB2689	371	910	2.45
CB17	350	100	0.29	CB2690	1024	2404	2.35
CB20	5	0	0.00	CB2736	518	869	1.68
CB21	5	0	0.00	CB2740	663	2454	3.70
CB25	203	423	2.08	CB2741	802	6050	7.54
CB26	80	0	0.00	CB2857	1001	7670	7.66
CB28	4	0	0.00	CB2940	669	2385	3.57
CB29	145	0	0.00	CB2941	817	6400	7.83
CB30	2	0	0.00				
CB31	198	0	0.00				
CB41	5	0	0.00				
CB42	404	1600	3.96				
CB43	157	71	0.45				
CB46	6	11	1.83				
CB49	68	0	0.00				
CB51	160	107	0.67				
CB56	223	1490	6.68				
CB60	107	74	0.69				
CB61	291	0	0.00				
CB62	6	0	0.00				
CB66	6	0	0.00				
CB67	4	0	0.00				
CB69	5	14	2.80				
CB72	86	0	0.00				
CB73	2	0	0.00				
CB75	4	0	0.00				
CB77	192	300	1.56				
CB93	272	0	0.00				
CB186	18	8	0.44				

Appendix A Table 5 Production of selfed seeds on colchicine treated doubled haploid (DH_0) plants of *B. rapa* from the EPD group, 1992-1993

Line [1]	Number of				Line	Number of			
	Buds selfed	Pods formed	Seeds formed	Seeds /pod		Buds selfed	Pods formed	Seeds formed	Seeds /pod
EPD2639	*10*	*5*	*14*	*2.80*	EPD2846	20	11	0	0.00
EPD2682	20	4	0	0.00	*EPD2932*	*10*	*5*	*50*	*10.00*
EPD2684	*10*	*6*	*15*	*2.50*	*EPD2933*	*10*	*9*	*57*	*6.33*
EPD2685	*10*	*5*	*12*	*2.40*	*EPD2935*	*10*	*8*	*28*	*3.50*
EPD2686	20	11	0	0.00	EPD2936	10	8	0	0.00
EPD2712	*10*	*8*	*65*	*8.13*	EPD2938	10	6	3	0.50
EPD2713	*10*	*6*	*23*	*3.83*	EPD2939	20	0	0	0.00
EPD2715	20	4	2	0.50	*EPD2975*	*10*	*10*	*71*	*7.10*
EPD2716	*10*	*9*	*25*	*2.78*	*EPD2978*	*10*	*6*	*40*	*6.67*
EPD2717	20	7	0	0.00	EPD2979	10	3	9	3.00
EPD2832	20	16	0	0.00	EPD2981	20	0	0	0.00
EPD2835	20	8	0	0.00	EPD2982	20	5	0	0.00
EPD2836	20	11	4	0.36	*EPD2985*	*10*	*7*	*37*	*5.29*
EPD2837	20	2	4	2.00	EPD2986	10	9	5	0.56
EPD2838	20	9	0	0.00	*EPD2987*	*10*	*9*	*82*	*9.11*
EPD2841	20	15	0	0.00	*EPD2988*	*15*	*11*	*52*	*4.73*
EPD2842	*10*	*8*	*14*	*1.75*	*EPD2989*	*10*	*2*	*15*	*7.50*
EPD2843	20	5	0	0.00	EPD3003	20	3	1	0.33
EPD2844	20	3	0	0.00					

[1] Lines in italic were evaluated in the field for at least one year

Appendix A Table 6 Production of selfed seeds on DH_1 and later generation plants of *B. rapa* doubled haploid lines of the EPD donor group, 1993-1994

Line	Number of Pods	Seeds	Seeds/pod
EPD1	160	1200	7.50
EPD2	122	420	3.44
EPD3	112	602	5.38
EPD4	200	83	0.42
EPD5	107	589	5.51
EPD6	183	441	2.41
EPD7	83	700	8.43
EPD8	107	473	4.42
EPD9	130	900	6.92
EPD10	80	300	3.75
EPD2639	461	1101	2.39
EPD2684	1020	2550	2.50
EPD2685	355	150	0.42
EPD2712	918	840	0.92
EPD2713	954	1500	1.57
EPD2716	667	1200	1.80
EPD2842	1398	3000	2.15
EPD2932	1019	2000	1.96
EPD2933	1052	4700	4.47
EPD2935	1089	3326	3.05
EPD2965	250	500	2.00
EPD2975	752	7200	9.57
EPD2978	800	9400	11.75
EPD2985	600	2250	3.75
EPD2987	853	3453	4.05
EPD2988	727	2900	3.99
EPD2989	1187	7800	6.57
EPD3025	68	0	0.00

Appendix A Table 7 Production of selfed seeds on DH_1 and later generation plants of *B. rapa* doubled haploid lines of the CBR donor group, 1993-1994

Line	Number of Pods	Seeds	Seeds/pod	Line	Number of Pods	Seeds	Seeds/pod
CBR2	272	2100	7.72	CBR88	6	14	2.33
CBR3	303	0	0.00	CBR99	185	600	3.24
CBR6	10	1	0.10	CBR100	6	2	3.00
CBR7	118	46	0.39	CBR103	248	478	1.93
CBR8	122	0	0.00	CBR106	220	753	3.42
CBR11	212	1183	5.58	CBR108	4	4	1.00
CBR13	121	706	5.84	CBR109	271	80	0.30
CBR14	131	700	5.34	CBR156	130	400	3.08
CBR21	105	400	3.81	CBR169	150	400	2.67
CBR25	155	486	3.14	CBR204	143	400	2.80
CBR26	195	503	2.58	CBR210	180	1700	9.44
CBR29	150	400	2.67	CBR241	159	120	0.76
CBR30	199	470	2.36	CBR249	148	400	2.70
CBR31	256	0	0.00	CBR263	119	400	3.36
CBR33	395	1580	4.00	CBR295	116	400	3.45
CBR55	57	42	0.74	CBR406	36	402	11.17
CBR58	5	0	0.00	CBR452	156	1300	8.33
CBR59	3	0	0.00	CBR455	169	1020	6.04
CBR60	198	1100	5.56	CBR462	192	702	3.66
CBR61	145	1100	7.59	CBR464	205	1350	6.59
CBR63	267	300	1.12	CBR465	240	2000	8.33
CBR66	49	190	3.88	CBR466	166	846	5.10
CBR67	6	0	0.00	CBR469	90	0	0.00
CBR68	133	340	2.56	CBR488	260	40	0.15
CBR69	151	300	1.59	CBR490	120	900	7.50
CBR70	293	0	0.00	CBR492	147	595	4.05
CBR71	131	400	3.05	CBR494	234	712	3.04
CBR74	137	75	0.55	CBR495	163	100	0.61
CBR77	6	72	12.00	CBR497	170	157	0.93
CBR80	19	0	0.00	CBR498	158	280	1.77
CBR81	100	415	4.15	CBR507	227	851	3.75
CBR82	7	0	0.00	CBR519	142	847	5.97
CBR83	298	1055	3.54	CBR536	21	0	0.00
CBR84	200	400	2.00	CBR538	165	500	3.03
CBR85	146	1046	7.16	CBR539	71	45	0.63
CBR85A	161	2460	15.28	CBR581	145	950	6.55

Appendix A Table 7 Contd.

Line	Number of Pods	Seeds	Seeds/pod
CBR586	56	25	0.45
CBR591	128	550	4.30
CBR592	170	1000	5.88
CBR597	211	2000	9.48
CBR623	74	400	5.41
CBR631	80	500	6.25
CBR637	95	560	5.90
CBR643	146	1000	6.85
CBR659	100	55	0.55
CBR688	5	6	1.20
CBR675	180	400	2.22
CBR705	124	749	6.04
CBR765	138	595	4.31

Appendix A Table 8 Production of selfed seeds on colchicine treated doubled haploid (DH_0) plants of *B. rapa* from the Tobin group, 1993-1994

Line	Number of Pods	Seeds	Seeds/pod	Line	Number of Pods	Seeds	Seeds/pod
T-34	14	3	0.21	T-101	5	0	0.00
T-37	9	3	0.33	T-102	12	0	0.00
T-38	16	8	0.50	T-103	5	1	0.20
T-40	6	1	0.17	T-104	40	0	0.00
T-44	9	0	0.00	T-105	20	0	0.00
T-45	6	0	0.17	T-107	5	6	1.20
T-52	125	0	0.00	T-108	7	8	1.14
T-53	81	15	0.19	T-109	13	10	0.77
T-54	7	0	0.00	T-111	6	8	1.33
T-55	21	0	0.00	T-112	20	10	0.50
T-56	41	4	0.10	T-120	11	10	0.91
T-57	82	10	0.12	T-50	Dead [1]		
T-58	114	3	0.03	T-59	Dead		
T-63	203	1	0.01	T-65	Dead		
T-64	10	0	0.00	T-69	Dead		
T-66	7	7	1.00	T-72	Dead		
T-68	10	0	0.10	T-76	Dead		
T-70	17	0	0.00	T-80	Dead		
T-75	18	0	0.00	T-81	Dead		
T-77	11	0	0.00	T-85	Dead		
T-79	8	0	0.00	T-104	Dead		
T-80	4	4	1.00	T-106	Dead		
T-84	32	2	0.06	T-107	Dead		
T-86	25	33	1.32	T-110	Dead		
T-87	6	1	0.17	T-113	Dead		
T-88	10	33	3.30	T-114	Dead		
T-89	67	2	0.03	T-119	Dead		
T-90	129	2	0.02	T-121	Dead		
T-100	11	0	0.00	T-125	Dead		

[1] Accidental death

Appendix A Table 9 Production of crossed seeds on *B. rapa* doubled haploid lines, 1993-1994

Cross	Number of Pods	Seeds	Seeds /pod
CB2625 x EPD2932	185	2035	11
CB2625 x EPD2975	145	3190	22
CB2625 x EPD2987	130	2600	20
CB2625 x EPD2988	125	2500	20
CB2625 x EPD2989	130	2470	19
CB2736 x EPD2932	21	252	12
CB2736 x EPD2975	110	2420	22
CB2736 x EPD2987	15	270	18
CB2736 x EPD2988	110	2090	19
CB2736 x EPD2989	115	2300	20
CB2740 x CB2736	340	3740	11
CB2740 x EPD2932	205	2050	10
CB2740 x EPD2975	150	3450	23
CB2740 x EPD2987	165	3300	20
CB2740 x EPD2988	165	3630	22
CB2740 x EPD2989	130	2730	21
CB2741 x EPD2932	205	2255	11
CB2741 x EPD2975	180	3960	22
CB2741 x EPD2987	175	3500	20
CB2741 x EPD2988	160	3520	22
CB2741 x EPD2989	170	3740	22
CB2857 x EPD2932	175	2275	13
CB2857 x EPD2975	190	3990	21
CB2857 x EPD2987	195	3900	20
CB2857 x EPD2988	185	3700	20
CB2857 x EPD2989	145	2900	20
CB2940 x EPD2932	115	2070	18
CB2940 x EPD2975	180	4680	26
CB2940 x EPD2987	190	3800	20
CB2940 x EPD2988	180	4140	23
CB2940 x EPD2989	205	4920	24
CB2941 x EPD2932	115	2185	19
CB2941 x EPD2975	180	4500	25
CB2941 x EPD2987	180	3780	21
CB2941 x EPD2988	195	4290	22
CB2941 x EPD2989	220	5060	23

Cross	Number of Pods	Seeds	Seeds /pod
BC2573 x EPD2932	200	2000	10
BC2573 x EPD2975	250	5000	20
BC2573 x EPD2987	153	2601	17
BC2573 x EPD2988	17	272	16
BC2573 x EPD2989	19	285	15
BC2668 x EPD2932	11	209	19
BC2668 x EPD2975	135	3375	25
BC2668 x EPD2987	155	2945	19
BC2668 x EPD2988	150	3000	20
BC2668 x EPD2989	155	3100	20
BC2791 x EPD2932	215	2365	11
BC2791 x EPD2975	180	3960	22
BC2791 x EPD2987	13	247	19
BC2791 x EPD2988	175	3675	21
BC2791 x EPD2989	110	2200	20

Appendix B. Performance of *B. rapa* doubled haploid (DH) lines in field tests, Saskatoon, 1993

Appendix B Table 1 Plant height, number of leaves and leaf weight of 43 *B. rapa* doubled haploid lines and their donor populations at the rosette stage, Saskatoon, 1993

Line and population	Plant height (cm)	No. of leaves	Leaf [1] weight (g)
BC2573	9	7	3
BC2576	5	7	1
BC2588	8	6	2
BC2648	9	6	3
BC2660	10	7	5
BC2668	10	7	5
BC2678	6	6	2
BC2725	11	7	3
BC2774	10	6	2
BC2791	10	8	4
BC2889	4	2	3
BC2916	5	6	1
BC3016	7	7	3
BC donor[2]	10	7	4
CB2624	12	8	5
CB2625	10	7	4
CB2627	8	6	2
CB2628	7	7	2
CB2630	10	6	5
CB2689	12	8	4
CB2690	9	6	4
CB2736	7	7	3
CB2740	13	7	4
CB2741	13	7	5
CB2857	14	8	6
CB2940	11	9	4
CB2941	12	8	4

Appendix B Table 1 Contd.

Line and population	Plant height (cm)	No. of leaves	Leaf [1] weight (g)
CB donor[2]	13	7	6
EPD2639	6	2	1
EPD2684	7	6	4
EPD2712	10	8	4
EPD2713	6	10	2
EPD2716	5	6	1
EPD2842	10	8	3
EPD2932	14	7	4
EPD2933	11	9	3
EPD2935	11	6	3
EPD2975	11	7	3
EPD2978	5	7	2
EPD2985	6	3	1
EPD2987	7	7	5
EPD2988	12	7	5
EPD2989	11	9	4
Echo[2]	16	8	6
LSD (0.05)	2	1	1

[1] Fresh weight [2] Average of three plots/replication

Appendix B Table 2 Plant height, number of leaves and branches per plant, leaf and stem weight of 43 *B. rapa* doubled haploid lines and donor populations at the flowering stage, Saskatoon, 1993

Line and population	Plant height (cm)	No. of leaves	No. of branches /plant	Leaf[1] weight (g)	Stem[1] weight (g)
BC2573	47	19	14	12	27
BC2576	52	38	32	28	69
BC2588	43	14	13	8	15
BC2648	65	80	46	58	34
BC2660	52	27	20	14	39
BC2668	48	26	12	24	46
BC2678	42	36	28	19	43
BC2725	46	24	14	14	34
BC2774	40	17	13	7	15
BC2791	68	52	44	29	91
BC2889	51	30	21	6	28
BC2916	74	27	23	11	45
BC3016	77	35	26	20	71
BC donor[2]	49	26	17	30	56
CB2624	77	30	25	18	53
CB2625	62	35	29	36	70
CB2627	65	23	19	15	35
CB2628	84	32	22	19	73
CB2630	80	34	27	18	64
CB2689	76	44	33	54	103
CB2690	77	42	32	29	71
CB2736	62	24	17	27	58
CB2740	68	26	15	21	50
CB2741	68	26	17	18	51
CB2857	65	35	16	19	47
CB2940	75	43	34	28	78
CB2941	64	26	12	12	30
CB donor[2]	61	26	16	20	45

Appendix B Table 2 Contd.

Line and population	Plant height (cm)	No. of leaves	No. of branches /plant	Leaf[1] weight (g)	Stem[1] weight (g)
EPD2639	26	18	15	2	7
EPD2684	51	20	12	15	37
EPD2712	71	44	31	18	74
EPD2713	61	58	50	42	104
EPD2716	65	53	35	29	82
EPD2842	65	36	31	17	69
EPD2932	53	13	10	11	28
EPD2933	77	36	29	13	49
EPD2935	58	31	20	18	37
EPD2975	49	15	9	6	17
EPD2978	62	37	31	18	47
EPD2985	37	28	24	4	14
EPD2987	71	36	28	15	43
EPD2988	51	18	19	8	25
EPD2989	60	20	15	6	27
Echo[2]	59	28	17	13	31
LSD (0.05)[3]	15	15	11	9	27
LSD (0.05)[4]	12	12	9	7	22

[1] Fresh weight
[2] Average of three plots/replication
[3] LSD for comparing DH vs. DH
[4] LSD for comparing DP vs. DH

Appendix B Table 3 Plant height, number of branches and pods/plant, pod and stem weight and number of leaves of 43 *B. rapa* doubled haploid lines and donor populations at the podding stage, Saskatoon, 1993

Line and population	Plant height (cm)	No. of branches /plant	No. of pods /plant	Pod[1] weight (g)	Stem[1] weight (g)	No. of leaves
BC2573	89	32	421	19	14	0
BC2576	84	22	297	30	66	0
BC2588	45	7	129	5	11	4
BC2648	92	32	311	45	100	0
BC2660	86	35	620	46	94	0
BC2668	100	37	640	24	68	12
BC2678	69	23	251	15	42	0
BC2725	94	28	552	30	64	0
BC2774	82	21	363	16	30	16
BC2791	88	26	533	11	22	0
BC2889	72	10	103	4	12	0
BC2916	106	32	525	46	97	0
BC3016	109	24	579	24	55	0
BC donor[2]	121	41	710	72	111	44
CB2624	110	41	835	43	106	0
CB2625	101	12	200	4	12	0
CB2627	103	37	1132	25	58	0
CB2628	103	18	356	55	50	0
CB2630	89	13	281	10	22	0
CB2689	119	43	752	46	92	7
CB2690	100	33	653	27	62	0
CB2736	85	49	437	18	57	0
CB2740	109	21	282	18	50	0
CB2741	99	47	289	25	49	0
CB2857	108	19	299	10	37	0
CB2940	100	33	316	26	45	0
CB2941	80	22	319	49	94	0
CB donor[2]	107	34	366	43	74	52

Appendix B Table 3 Contd.

Line and population	Plant height (cm)	No. of branches /plant	Pods plant (g)	Pod[1] weight (g)	Stem[1] weight (g)	No. of leaves
EPD2639	34	6	19	1	2	0
EPD2684	115	33	723	75	174	0
EPD2712	96	49	485	29	73	0
EPD2713	89	41	697	23	50	0
EPD2716	101	36	256	8	32	0
EPD2842	92	33	720	17	44	0
EPD2932	100	18	339	13	38	0
EPD2933	96	25	317	9	23	0
EPD2935	87	15	353	23	49	0
EPD2975	90	20	247	17	36	0
EPD2978	82	35	308	24	60	0
EPD2985	44	15	71	2	6	0
EPD2987	94	31	308	27	55	18
EPD2988	81	35	345	31	54	13
EPD2989	90	31	235	16	48	15
Echo[2]	94	33	265	34	57	50
LSD (0.05)[3]	9	5	64	4	12	1
LSD (0.05)[4]	7	4	53	3	10	1

[1] Fresh weight
[2] Average of three plots/replication
[3] LSD for comparing DH with DH
[4] LSD for comparing DP with DH

Appendix B Table 4 Plants/plot, seed and biological yield/plant, harvest index, plant height, days to flower and mature and pod filling period of 43 *B. rapa* doubled haploid lines at maturity, Saskatoon, 1993

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest Index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
BC2618[1]	5	1.0	9	0.110	75	40	93	53
BC2950[1]	5	1.0	10	0.110	77	40	93	53
BC2573	73	4.9	19	0.270	89	42	100	58
BC2576	92	1.8	12	0.156	93	57	101	45
BC2588	138	0.9	5	0.216	50	49	95	46
BC2648	43	5.7	20	0.293	75	44	102	49
BC2660	58	2.7	9	0.285	80	41	101	60
BC2668	77	5.1	20	0.257	101	37	100	63
BC2678	87	1.3	7	0.186	43	46	101	55
BC2725	110	3.6	21	0.204	91	38	97	59
BC2774	134	2.1	10	0.224	73	38	99	61
BC2791	84	4.2	14	0.309	89	46	101	56
BC2889	61	1.0	4	0.233	62	57	101	44
BC2916	74	1.6	9	0.161	78	47	101	54
BC3016	71	3.3	17	0.207	88	44	101	57
BC donor[2]	105	11.2	30	0.363	111	35	101	66
CB2624	67	3.0	23	0.132	99	45	97	52
CB2625	68	3.1	28	0.119	116	43	96	53
CB2627	99	2.8	19	0.146	99	44	96	53
CB2628	68	2.3	15	0.160	122	45	99	54
CB2630	95	2.0	13	0.151	93	45	96	51
CB2689	66	3.0	19	0.166	106	45	98	52
CB2690	53	3.1	16	0.197	103	45	96	51
CB2736	81	0.9	12	0.077	78	45	101	55
CB2740	112	5.1	17	0.293	99	45	98	53
CB2741	129	4.0	15	0.270	101	39	97	58
CB2857	140	2.1	10	0.208	90	44	96	52
CB2940	34	7.6	21	0.350	90	44	98	53
CB2941	140	2.3	11	0.209	85	43	96	52

Appendix B Table 4 Contd.

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest Index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
CB donor[2]	135	10.5	31	0.361	118	35	100	65
EPD2639	91	0.7	5	0.164	37	61	93	33
EPD2684	86	2.4	15	0.186	96	36	99	63
EPD2712	30	2.2	14	0.154	88	46	102	57
EPD2713	72	5.5	22	0.254	88	49	103	54
EPD2716	60	0.6	17	0.038	82	59	104	46
EPD2842	42	1.3	18	0.072	95	45	100	56
EPD2932	105	1.6	10	0.166	85	41	99	58
EPD2933	65	4.0	22	0.188	89	46	100	55
EPD2935	70	2.2	9	0.258	87	46	101	56
EPD2975	161	2.4	9	0.260	84	36	99	63
EPD2978	109	5.0	15	0.339	96	46	97	51
EPD2985	59	0.4	4	0.140	38	60	95	35
EPD2987	115	3.5	14	0.261	87	39	100	61
EPD2988	124	3.5	11	0.337	105	46	96	50
EPD2989	104	3.1	13	0.245	99	45	97	51
Echo[2]	144	5.8	16	0.374	107	35	96	61
LSD (0.05)[3]	28	1.8	6	0.060	12	3	2	3
LSD (0.05)[4]	23	1.5	5	0.049	10	3	2	3

[1] Not included in the analysis due to low number of plants/plot
[2] Average of three plots/replication
[3] LSD for comparing DH with DH
[4] LSD for comparing DP with DH

Appendix B Table 5 Pod length, seeds/pod, hundred seed weight, branches/plant, pods/plant, leaf color index and lodging score of 43 *B. rapa* doubled haploid lines, Saskatoon, 1993

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	No. of branches /plant	No. of pods /plant	Leaf color index	Lodging score
BC2618[1]	-	-	-	-	-	3	1
BC2950[1]	-	-	-	-	-	3	1
BC2573	5	9	244	27	445	3	1
BC2576	4	9	246	23	279	2	1
BC2588	3	10	226	10	121	2	1
BC2648	5	18	257	37	389	3	1
BC2660	5	8	198	32	607	3	1
BC2668	5	10	221	33	498	3	2
BC2678	5	13	239	22	265	2	1
BC2725	5	9	234	18	321	3	2
BC2774	5	8	254	20	322	3	2
BC2791	5	8	310	30	724	3	1
BC2889	4	7	265	12	164	2	1
BC2916	5	10	226	19	241	3	1
BC3016	6	10	272	20	345	3	1
BC donor[2]	7	23	267	44	763	3	2
CB2624	5	9	190	16	367	3	3
CB2625	5	10	192	22	356	3	4
CB2627	5	10	190	21	297	3	4
CB2628	5	7	195	22	402	3	5
CB2630	5	9	210	18	342	3	4
CB2689	5	8	188	26	427	3	4
CB2690	5	9	197	25	514	3	4
CB2736	4	10	227	50	385	3	2
CB2740	5	15	188	20	339	3	4
CB2741	5	15	219	24	312	3	4
CB2857	6	12	170	20	225	3	3
CB2940	7	16	167	23	195	3	3
CB2941	6	16	168	12	124	3	4

Appendix B Table 5 Contd.

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	No. of branches /plant	No. of pods /plant	Leaf color index	Lodging score
CB donor[2]	6	20	250	30	570	3	4
EPD2639	3	8	220	12	19	1	1
EPD2684	5	7	333	23	343	3	2
EPD2712	5	8	247	51	434	3	1
EPD2713	4	11	231	33	586	3	1
EPD2716	3	4	254	55	342	2	1
EPD2842	4	6	170	43	780	3	2
EPD2932	4	9	311	14	262	3	2
EPD2933	5	12	247	27	415	3	2
EPD2935	4	9	205	14	254	2	1
EPD2975	4	16	204	12	176	3	2
EPD2978	3	18	230	28	329	3	1
EPD2985	3	7	149	13	56	1	1
EPD2987	5	16	247	25	319	3	2
EPD2988	4	15	226	18	230	3	2
EPD2989	4	16	221	17	246	3	1
Echo[2]	5	22	244	22	267	3	3
LSD(0.05)[3]	0.7	3	20	13	232	-	-
LSD(0.05)[4]	0.6	3	16	11	190	-	-

[1] Not included in the analysis due to low number of plants/plot
[2] Average of three plots/replication
[3] LSD for comparing DH with DH
[4] LSD for comparing DP with DH

Appendix C. Performance of *B. rapa* doubled haploid (DH) lines in field tests, Saskatoon, 1994

Appendix C Table 1 Plant height and dry weight of a five plant sample from 131 *B. rapa* doubled haploid lines and their donor populations at the rosette, flowering and podding stages, Saskatoon, 1994

Line and population	Rosette		Flowering		Podding	
	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)
BC-42	9	5	73	30	80	58
BC-111	11	4	44	17	70	40
BC-276	10	4	50	28	60	37
BC2459	12	5	79	43	80	67
BC2507	11	5	68	30	78	57
BC2525	10	4	61	31	60	45
BC2576	11	4	60	15	68	19
BC2588	7	4	41	9	38	10
BC2595	7	4	33	6	32	6
BC2647	10	4	63	26	65	34
BC2648	9	5	55	38	59	45
BC2660	10	5	54	51	60	55
BC2665	11	5	68	39	69	43
BC2668	12	4	74	40	78	50
BC2678	8	4	44	13	46	20
BC2679	7	4	42	7	39	9
BC2705	10	6	59	51	60	76
BC2725	11	5	57	27	73	43
BC2754	10	6	56	46	66	67
BC2774	10	4	51	24	67	39
BC2791	12	6	74	53	79	72
BC2850	12	7	63	81	79	116
BC2886	11	6	64	64	68	76
BC2889	8	4	43	14	46	14
BC2913	13	5	74	36	89	47
BC2916	11	5	67	39	76	51
BC2927	10	4	40	25	69	31
BC2953	11	5	63	42	70	50
BC2960	7	4	22	10	41	13
BC2962	3	4	18	3	10	2
BC2965	12	6	78	56	80	72
BC3011	11	5	70	35	79	51
BC3015Y	13	7	65	96	90	130

Appendix C Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)
BC3015G	12	6	56	67	85	77
BC3015B	12	6	58	65	78	81
BC3016	12	5	51	44	78	59
BC3028	12	5	72	40	79	45
BC3034	8	4	45	18	50	23
BC donor[1]	10	5	51	32	89	103
CB-1	12	5	76	58	90	73
CB-13	7	4	44	7	58	8
CB-15	8	3	34	8	40	8
CB-42	8	5	78	70	91	72
CB-56	6	4	31	2	40	4
CB2524	14	5	76	37	96	52
CB2624	13	5	78	45	99	59
CB2625	13	6	73	27	90	63
CB2627	13	5	75	38	89	53
CB2628	13	5	83	38	99	49
CB2630	13	5	80	42	95	58
CB2690	13	6	76	61	100	95
CB2740	13	5	75	47	98	51
CB2741	12	5	77	30	90	46
CB2857	12	5	75	37	90	36
CB2940	13	6	71	46	96	83
CB2941	10	6	72	40	74	41
CB donor[1]	17	6	67	42	104	107
EPD-1	10	5	54	41	65	43
EPD-2	11	6	77	54	83	66
EPD-3	11	6	63	45	80	66
EPD-5	11	6	70	54	86	66

Appendix C Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)
EPD-6	10	5	68	51	79	53
EPD-7	12	5	63	48	87	61
EPD-8	12	5	81	54	87	53
EPD-9	12	6	51	49	87	81
EPD2716	10	6	56	34	70	40
EPD2684	12	5	50	31	88	31
EPD2842	11	5	72	45	85	53
EPD2932	11	4	69	22	86	32
EPD2933	11	5	67	40	85	47
EPD2935	10	4	52	15	70	19
EPD2975	11	5	61	26	80	42
EPD2978	10	4	62	30	70	42
EPD2985	4	4	21	3	30	6
EPD2987	10	5	64	29	78	37
EPD2988	10	5	67	34	77	53
EPD2989	11	5	66	26	85	34
EPD donor[1]	13	5	57	24	89	91
CBR-2	11	5	49	23	79	48
CBR-11	12	5	74	37	90	56
CBR-13	10	6	50	48	70	57
CBR-14	8	5	52	35	58	41
CBR-25	12	6	71	39	89	63
CBR-26	12	4	79	30	88	33
CBR-29	10	5	46	33	69	41
CBR-30	13	6	72	44	98	49
CBR-33	9	4	63	33	80	35
CBR-60	10	5	41	37	72	44
CBR-61	6	4	29	3	36	2
CBR-71	10	5	68	40	74	47
CBR-81	0	0	0	0	0	0
CBR-83	6	4	30	31	39	33
CBR-84	12	5	75	42	87	48

Appendix C Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)
CBR-85A	9	5	52	38	66	46
CBR-99	13	6	78	50	96	80
CBR-103	11	5	48	31	89	58
CBR-106	9	4	57	28	66	30
CBR-156	11	4	70	33	86	38
CBR-169	11	4	43	20	80	305
CBR-204	11	5	76	41	88	57
CBR 210	9	5	58	33	69	44
CBR-249	9	4	56	24	68	28
CBR-263	10	5	70	46	78	82
CBR-295	6	4	32	6	47	10
CBR-406	8	5	42	49	60	38
CBR-452	13	5	74	36	100	52
CBR-462	10	5	60	50	79	48
CBR-464	12	4	71	31	90	37
CBR-465	12	6	75	46	90	67
CBR-466	12	5	75	48	90	49
CBR-490	10	4	55	32	72	34
CBR-494	9	4	57	22	66	28
CBR-507	11	4	65	21	80	30
CBR-519	9	4	45	15	69	31
CBR-581	9	6	54	74	70	89
CBR-591	13	5	83	38	95	43
CBR-592	11	5	64	37	84	52
CBR-597	10	5	40	21	70	49
CBR-623	8	4	46	17	60	37
CBR-631	8	4	42	16	68	35
CBR-637	10	6	62	47	77	72
CBR-643	11	5	57	38	80	58
CBR-675	8	4	40	23	60	31
CBR donor[1]	12	6	57	27	88	90

Appendix C Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)
CRS-1	13	6	69	59	96	80
CRS-2	13	6	66	67	97	97
CRS-6	13	6	78	65	97	93
CRS-7	13	6	85	68	100	87
CRS-10	13	7	79	68	100	100
LSD (0.05)[2]	3	1	14	16	9	11
LSD (0.05)[3]	3	1	12	13	7	9

[1] Average of three plots/replication
[2] LSD for comparing DH with DH
[3] LSD for comparing DP with DH

Appendix C Table 2 Plants/plot, seed and biological yield/plot, harvest index, plant height, days to flower and mature and pod filling period of 131 *B. rapa* doubled haploid lines at maturity, Saskatoon, 1994

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
BC-42	47	55.2	648	0.084	96	37	96	60
BC-111	35	78.6	342	0.236	85	33	77	44
BC-276	32	45.9	290	0.157	74	34	78	44
BC2459	39	73.2	544	0.130	108	38	86	48
BC2507	44	39.8	570	0.070	100	39	76	37
BC2525	29	22.8	258	0.088	77	38	76	39
BC2576	37	14.7	214	0.067	86	43	80	37
BC2588	26	10.4	82	0.112	55	39	80	41
BC2595	23	3.0	55	0.057	49	39	77	38
BC2618	3	2.5	52	0.038	73	39	83	44
BC2647	27	18.0	236	0.076	81	37	81	44
BC2648	30	40.7	331	0.124	75	40	93	54
BC2660	20	27.7	290	0.095	78	35	81	46
BC2665	38	80.6	492	0.165	86	35	83	48
BC2668	8	20.3	218	0.093	94	36	76	40
BC2678	28	8.9	132	0.062	61	39	76	37
BC2679	34	5.6	101	0.045	56	40	80	40
BC2705	21	14.9	375	0.039	86	39	77	38
BC2723	4	14.1	139	0.101	87	39	77	38
BC2725	27	35.6	293	0.119	89	35	75	40
BC2754	32	36.1	495	0.071	82	38	88	49
BC2774	40	52.1	332	0.158	84	34	81	47
BC2791	25	72.5	424	0.172	96	37	75	38
BC2850	20	83.0	625	0.134	96	36	93	57
BC2886	13	41.0	230	0.181	86	38	74	35
BC2889	17	5.7	87	0.048	62	40	81	41
BC2913	40	63.6	458	0.142	105	39	83	44
BC2916	23	17.6	299	0.060	90	39	90	51
BC2927	47	25.2	350	0.070	88	35	76	41
BC2953	33	54.3	458	0.119	89	34	81	47
BC2960	18	5.0	72	0.063	59	41	81	40
BC2962	15	0.0	6	0.003	27	39	75	36
BC2965	32	54.9	549	0.099	100	38	93	56
BC3011	28	29.7	373	0.077	95	38	84	46
BC3015Y	28	185.9	1309	0.156	107	32	86	54

Appendix C Table 2 Contd.

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
BC3015G	47	181.9	834	0.220	103	32	86	54
BC3015B	36	120.5	599	0.203	93	32	86	54
BC3016	27	38.3	359	0.106	94	38	81	43
BC3022	5	0.0	16	0.000	40	40	81	41
BC3028	36	46.4	409	0.114	95	37	82	45
BC3034	40	25.2	261	0.098	68	39	77	37
BC donor[1]	24	199.1	652	0.325	95	34	85	51
CB-1	26	16.4	437	0.038	98	41	98	57
CB-13	42	10.5	83	0.129	64	42	76	34
CB-15	30	11.0	84	0.132	47	44	75	32
CB-42	40	61.5	658	0.095	98	38	96	58
CB-56	30	1.8	23	0.079	47	42	79	38
CB2524	43	70.4	523	0.135	100	39	96	57
CB2624	20	29.9	276	0.106	104	38	78	40
CB2625	17	23.0	267	0.081	97	38	79	41
CB2627	22	16.2	233	0.068	95	37	79	42
CB2628	25	24.8	297	0.081	105	39	76	37
CB2630	19	23.1	256	0.089	101	37	81	44
CB2690	17	38.7	405	0.094	108	38	80	41
CB2740	18	28.2	254	0.108	104	38	79	41
CB2741	29	56.9	318	0.191	96	35	76	41
CB2857	32	44.4	283	0.160	95	38	77	39
CB2940	24	89.9	451	0.198	102	39	78	39
CB2941	28	34.9	281	0.125	80	38	76	38
CB donor[1]	30	160.1	824	0.196	111	34	94	60
EPD-1	33	42.0	344	0.127	72	39	81	42
EPD-2	24	29.6	368	0.079	90	38	79	41
EPD-3	27	37.3	409	0.093	88	38	79	41
EPD-5	32	37.1	498	0.074	92	38	76	38

Appendix C Table 2 Contd.

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
EPD-6	29	11.6	361	0.033	85	39	81	43
EPD-7	27	30.6	377	0.073	91	39	81	42
EPD-8	34	47.4	435	0.116	92	37	85	48
EPD-9	35	54.5	642	0.087	94	36	81	45
EPD2716	12	1.9	116	0.013	79	47	94	47
EPD2684	26	18.3	211	0.086	95	34	82	48
EPD2842	27	21.0	318	0.065	92	35	75	40
EPD2932	41	54.8	335	0.162	92	35	80	45
EPD2933	23	45.9	322	0.143	92	37	83	46
EPD2935	24	12.1	129	0.092	76	41	78	37
EPD2975	47	108.0	512	0.211	88	35	78	43
EPD2978	32	67.2	319	0.210	79	39	79	40
EPD2985	21	0.2	28	0.006	35	46	75	30
EPD2987	34	79.8	329	0.243	84	35	82	47
EPD2988	36	107.2	449	0.244	80	36	78	42
EPD2989	39	55.0	340	0.161	91	38	77	39
EPD donor[1]	31	155.3	634	0.257	96	32	84	52
CBR-2	31	26.7	385	0.069	86	34	86	52
CBR-11	25	27.0	346	0.078	97	39	86	47
CBR-13	25	68.1	388	0.175	79	35	83	48
CBR-14	24	25.8	255	0.111	63	38	94	56
CBR-25	26	19.8	376	0.053	95	37	81	44
CBR-26	35	16.7	312	0.052	94	38	86	48
CBR-29	30	32.9	308	0.106	76	38	75	37
CBR-30	23	16.3	360	0.044	102	38	85	47
CBR-33	29	15.2	259	0.058	86	39	83	44
CBR-60	48	90.1	504	0.179	78	33	83	49
CBR-61	9	0.0	3	0.000	40	42	75	33
CBR-71	34	48.4	399	0.124	80	38	81	43
CBR-81	6	1.6	31	0.288	52	39	82	43
CBR-83	14	4.0	80	0.359	44	49	94	46
CBR-84	33	17.7	383	0.044	91	35	92	47
CBR-85	42	51.1	336	0.151	65	39	78	39

Appendix C Table 2 Contd.

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
CBR-85A	5	6.1	56	0.093	63	40	80	40
CBR-99	37	66.8	677	0.098	102	37	97	60
CBR-103	51	133.9	670	0.200	95	33	76	44
CBR-106	29	36.1	251	0.143	71	37	85	49
CBR-156	28	25.7	271	0.096	91	39	80	41
CBR-169	40	61.1	360	0.169	89	32	81	49
CBR-204	39	125.8	513	0.245	93	36	82	46
CBR 210	37	117.1	406	0.274	77	35	81	46
CBR-249	39	36.5	271	0.133	74	37	77	40
CBR-263	33	24.9	492	0.049	82	39	94	55
CBR-295	11	0.9	31	0.028	52	43	85	42
CBR-406	30	87.1	380	0.252	68	33	78	46
CBR-452	35	70.3	412	0.170	108	37	81	44
CBR-455	7	2.2	50	0.116	65	43	75	33
CBR-462	44	63.6	550	0.115	86	34	75	41
CBR-464	46	30.1	421	0.070	99	39	75	36
CBR-465	41	72.9	647	0.113	97	38	75	37
CBR-466	42	70.6	516	0.138	98	37	78	41
CBR-490	23	40.4	209	0.194	80	37	76	39
CBR-494	26	26.2	183	0.140	70	35	75	40
CBR-507	50	47.3	372	0.127	86	38	96	58
CBR-519	43	62.7	331	0.190	75	33	75	42
CBR-581	19	82.0	400	0.206	79	35	91	56
CBR-591	65	86.1	672	0.133	101	36	94	58
CBR-592	42	146.7	541	0.270	90	36	95	60
CBR-597	41	141.8	530	0.270	78	35	77	42
CBR-623	47	40.1	437	0.092	67	32	82	49
CBR-631	26	39.2	210	0.185	73	36	80	45
CBR-637	29	6.8	475	0.024	82	37	95	58
CBR-643	47	163.9	620	0.260	89	33	80	47
CBR-675	30	29.1	242	0.120	69	34	75	41
CBR-705	4	2.5	47	0.040	51	43	81	38
CBR donor[1]	40	250.0	891	0.280	95	32	87	55

Appendix C Table 2 Contd.

Line and population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod filling period (days)
CRS-1	30	84.9	539	0.160	103	39	93	53
CRS-2	25	48.3	565	0.090	103	39	94	55
CRS-6	30	77.2	692	0.110	103	38	94	57
CRS-7	27	42.2	585	0.072	108	38	94	56
CRS-10	22	56.2	606	0.090	107	39	98	59
LSD (0.05)[2]	7	13	71	0.030	12	2	1	3
LSD (0.05)[3]	6	11	58	0.030	10	2	1	3

[1] Average of three plots/replication
[2] LSD for comparing DH with DH
[3] LSD for comparing DP with DH

Appendix C Table 3 Pod length, seeds/pod, 100 seed weight, leaf color index, plant spread, branching habit, pod set and podding habit of 131 *B. rapa* doubled haploid lines, Saskatoon, 1994

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	Leaf color index	Plant spread [1]	Branch habit [2]	Pod set [3]	Pod habit [4]
BC-42	5	13	288	3	1	N	D	N
BC-111	5	13	295	3	1	N	D	N
BC-276	5	13	194	3	1	N	D	N
BC2459	5	10	274	3	2	N	D	N
BC2507	5	8	162	3	1	A	D	N
BC2525	4	8	276	3	1	A	D	N
BC2576	4	12	247	2	1	A	S	A
BC2588	3	6	178	1	1	N	S	N
BC2595	3	5	205	1	1	A	S	N
BC2618	4	5	239	3	1	N	S	N
BC2647	4	6	280	3	1	N	S	A
BC2648	5	18	286	3	1	N	D	N
BC2660	4	6	198	3	1	N	D	N
BC2665	6	9	244	3	2	N	D	N
BC2668	5	10	221	3	1	A	D	A
BC2678	3	8	211	2	1	N	D	N
BC2679	3	6	111	1	1	N	S	N
BC2705	4	5	155	2	1	N	S	N
BC2723	5	11	226	3	1	N	D	N
BC2725	4	8	209	3	1	N	D	N
BC2754	5	8	259	3	1	A	D	N
BC2774	4	9	210	3	1	N	D	N
BC2791	5	19	191	3	1	A	D	N
BC2850	5	17	259	3	3	N	D	N
BC2886	5	10	169	3	1	N	S	N
BC2889	4	8	260	1	1	N	S	N
BC2913	5	14	191	3	1	N	S	N
BC2916	6	4	208	3	1	N	S	N
BC2927	4	9	208	3	1	N	S	N
BC2953	5	11	169	3	1	N	D	N
BC2960	3	4	233	1	1	N	S	N
BC2962	2	4	-	1	1	N	S	N
BC2965	5	10	213	3	1	A	D	A
BC3011	4	5	238	3	1	A	S	A
BC3015Y	7	26	297	4	3	N	D	N

Appendix C Table 3 Contd.

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	Leaf color index	Plant spread	Branch habit	Pod set	Pod habit
BC3015G	7	23	243	4	3	N	D	N
BC3015B	6	22	204	4	3	N	D	N
BC3016	6	8	257	3	2	N	S	N
BC3022	2	4	-	1	1	A	S	N
BC3028	5	10	189	3	2	N	S	N
BC3034	4	10	275	3	1	N	S	N
BC donor[5]	6	23	219	4	2	N	D	N
CB-1	4	7	261	3	1	N	D	N
CB-13	4	14	243	1	1	N	S	N
CB-15	3	13	263	1	1	N	S	N
CB-42	4	8	247	3	2	N	S	N
CB-56	3	4	244	1	1	N	S	N
CB2524	5	11	194	3	2	N	D	N
CB2624	6	12	172	3	1	A	D	N
CB2625	5	8	193	3	1	A	D	N
CB2627	6	12	173	3	1	A	D	N
CB2628	5	9	186	3	1	A	D	N
CB2630	6	8	179	3	1	A	D	N
CB2690	5	8	178	3	1	A	D	N
CB2740	6	16	155	3	1	A	D	N
CB2741	5	13	174	3	1	A	D	N
CB2857	6	12	146	3	1	A	D	N
CB2940	8	23	172	3	1	A	S	A
CB2941	6	15	148	3	1	A	D	A
CB donor[5]	6	21	202	4	3	N	D	N
EPD-1	4	11	218	3	1	N	D	N
EPD-2	4	11	219	3	1	N	D	N
EPD-3	4	10	231	3	1	A	D	N
EPD-5	4	8	188	3	1	A	D	N

Appendix C Table 3 Contd.

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	Leaf color index	Plant spread	Branch habit	Pod set	Pod habit
EPD-6	5	8	202	3	1	N	D	N
EPD-7	5	11	192	3	1	N	D	N
EPD-8	4	15	213	3	1	A	D	N
EPD-9	4	9	202	3	1	N	D	N
EPD2716	3	4	169	2	1	A	D	N
EPD2684	5	6	272	3	1	N	S	N
EPD2842	4	5	182	3	1	A	D	N
EPD2932	4	11	281	3	1	N	S	N
EPD2933	5	14	240	3	2	N	D	N
EPD2935	4	9	235	2	1	A	D	N
EPD2975	5	13	219	3	2	N	D	N
EPD2978	4	23	246	3	1	A	D	N
EPD2985	3	7	-	1	1	N	S	N
EPD2987	5	16	249	3	1	N	D	N
EPD2988	5	17	209	3	1	N	D	N
EPD2989	4	18	211	3	1	A	D	N
EPD donor[5]	6	21	197	4	2	N	D	N
CBR-2	5	8	250	3	1	N	D	N
CBR-11	5	10	294	3	1	N	D	N
CBR-13	5	16	202	3	1	N	S	N
CBR-14	5	14	245	3	1	A	D	A
CBR-25	5	9	254	3	1	N	D	N
CBR-26	6	9	290	3	1	N	S	N
CBR-29	4	9	229	3	1	N	D	N
CBR-30	5	8	250	3	1	N	D	A
CBR-33	4	6	240	3	2	N	D	N
CBR-60	5	19	209	3	1	N	D	N
CBR-61	-	-	-	1	1	N	S	N
CBR-71	5	13	283	3	2	N	D	N
CBR-81	5	8	184	1	1	N	S	N
CBR-83	4	11	197	1	1	N	S	N
CBR-84	5	6	163	3	1	N	D	A
CBR-85	5	13	290	2	1	N	S	N

Appendix C Table 3 Contd.

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	Leaf color index	Plant spread	Branch habit	Pod set	Pod habit
CBR-85A	4	11	274	2	1	N	D	N
CBR-99	5	10	340	3	2	N	D	N
CBR-103	5	10	243	3	2	A	D	N
CBR-106	5	9	286	3	1	N	D	N
CBR-156	4	7	192	3	1	N	D	N
CBR-169	5	15	199	3	2	N	D	N
CBR-204	5	17	223	3	1	N	S	N
CBR 210	5	18	162	3	1	N	S	N
CBR-249	4	12	209	3	1	N	S	N
CBR-263	4	7	224	3	1	A	D	N
CBR-295	3	5	186	1	1	N	S	N
CBR-406	5	15	230	3	1	N	D	A
CBR-452	4	13	307	3	1	N	S	N
CBR-455	5	18	285	2	1	A	S	N
CBR-462	4	9	219	3	2	N	D	N
CBR-464	4	15	196	3	1	N	S	N
CBR-465	4	16	255	3	2	N	D	N
CBR-466	4	8	230	3	2	N	D	N
CBR-490	5	13	213	3	1	A	D	N
CBR-494	5	9	195	3	2	N	D	N
CBR-507	4	10	273	3	1	N	D	N
CBR-519	4	10	226	3	1	N	D	A
CBR-581	5	17	241	3	1	N	D	N
CBR-591	6	21	249	3	2	N	D	N
CBR-592	6	16	248	3	2	A	D	N
CBR-597	4	22	137	3	2	N	D	N
CBR-623	4	8	240	3	2	N	D	A
CBR-631	4	12	189	3	1	N	D	A
CBR-637	4	7	244	3	1	A	D	A
CBR-643	5	22	149	3	2	N	D	N
CBR-675	5	11	223	3	1	N	S	N
CBR-705	4	4	208	1	1	N	D	N
CBR donor[5]	7	26	213	4	2	N	D	N

Appendix C Table 3 Contd.

Line and population	Pod length (cm)	No. of seeds/ pod	Hundred seed wt. (mg)	Leaf color index	Plant spread	Branch habit	Pod set	Pod habit
CRS-1	5	14	245	3	1	A	D	N
CRS-2	4	11	235	3	1	A	D	A
CRS-6	5	14	207	3	1	A	D	N
CRS-7	4	14	258	3	1	A	D	N
CRS-10	4	12	267	3	1	A	D	N
LSD (0.05)[6]	0.5	3	27	-	-	-	-	-
LSD (0.05)[7]	0.4	3	22	-	-	-	-	-

[1] Plant spread (1=narrow, 2=medium bushy, 3=bushy and spreading)
[2] Branch habit (N=normal, ≥ 45 ^{0} angle with the main axis, A=appressed, angle < 45^0 with the main axis)
[3] Pod set (D=dense, S=sparse)
[4] Pod habit (N=normal, ≥ 45 ^{0} angle with the raceme, A=appressed, angle < 45^0 with the raceme)
[5] Average of three plots/replication
[6] LSD for comparing DH vs. DH
[7] LSD for comparing DP vs. DH

Appendix D. Performance of *B. rapa* doubled haploid (DH) lines in field tests, Saskatoon, 1995

Appendix D Table 1 Plant dry weight and height of 115 *B. rapa* doubled haploid lines and donor populations from three plant samples /plot at the rosette, flowering and podding stages, Saskatoon, 1995

Line and population	Rosette		Flowering		Podding	
	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)
BC13	1	7	16	45	16	65
BC29	1	7	15	44	21	59
BC43	2	8	28	77	38	80
BC69	2	6	10	48	18	57
BC84	3	9	40	60	50	65
BC111	3	10	40	54	50	66
BC169	2	6	20	60	30	62
BC204	2	6	20	65	29	69
BC249	2	7	19	45	30	60
BC276	2	8	30	44	37	63
BC278	2	8	26	55	50	70
BC295	1	5	12	35	20	44
BC946	1	10	9	45	18	60
BC2459	2	9	30	56	40	65
BC2507	2	8	20	54	30	65
BC2576	1	7	13	50	18	56
BC2588	1	5	2	33	4	40
BC2595A	1	9	3	25	7	29
BC2595	1	4	4	30	7	38
BC2660	1	9	9	49	17	53
BC2665	1	10	14	62	20	67
BC2668	3	9	32	56	40	65
BC2677	2	7	20	60	26	70
BC2678	1	5	17	35	20	41
BC2679	1	6	7	37	12	45
BC2705	1	10	15	60	25	64
BC2723	2	8	22	60	37	62
BC2725	1	8	18	48	22	55
BC2774	2	7	21	55	30	59
BC2791	1	8	18	55	26	68
BC2886	2	11	20	70	30	80
BC2889	1	5	4	30	10	35
BC2913	1	8	30	70	40	80
BC2916	2	7	15	53	19	55
BC2927	1	10	10	60	20	65

Appendix D Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)
BC2944	1	4	15	30	28	34
BC2953	2	7	20	60	30	63
BC2960	1	6	5	47	12	50
BC2956	2	9	30	60	46	65
BC2965	2	13	20	61	30	69
BC2965A	2	11	22	67	35	70
BC3011	1	7	4	62	10	66
BC3015Y	5	20	64	76	90	84
BC3015G	4	21	53	75	80	83
BC3015B	3	15	38	74	50	80
BC3016	1	10	10	64	20	70
BC3034	1	8	10	44	20	52
BC donor[1]	2	10	17	41	100	80
CB13	1	5	3	36	5	40
CB15	1	6	5	32	7	35
CB42	4	6	36	60	50	68
CB56	1	5	16	25	18	30
CB77	3	13	20	65	25	70
CB2524	1	13	11	62	21	65
CB2625	1	11	10	65	20	70
CB2627	3	15	30	75	40	78
CB2630	3	14	25	66	31	70
CB2690	3	6	30	65	40	70
CB2740	1	15	10	68	25	73
CB2741	3	10	34	60	40	67
CB2857	3	8	30	57	38	60
CB2940	2	14	20	60	31	65
CB2941	2	13	20	55	30	60
CB donor[1]	3	15	26	70	103	88

Appendix D Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)
EPD1	4	10	70	45	90	50
EPD7	2	10	30	75	40	80
EPD9	2	14	31	68	42	70
EPD10	2	8	26	70	30	75
EPD2639	1	6	6	25	10	30
EPD2713	4	10	70	60	90	58
EPD2684	2	9	30	65	40	70
EPD2842	2	10	29	63	37	66
EPD2932	2	10	19	65	20	70
EPD2933	1	10	10	66	20	72
EPD2935	1	9	9	54	12	60
EPD2965	2	10	20	69	30	75
EPD2975	2	6	28	60	39	65
EPD2978	1	8	13	45	20	50
EPD2987	2	6	22	45	35	50
EPD2988	2	10	20	65	30	70
EPD2989	1	8	17	60	25	68
EPD2985	1	5	4	18	5	22
EPD donor[1]	2	11	21	56	86	78
CBR2	3	14	30	70	40	77
CBR11	2	10	20	65	30	70
CBR13	2	6	18	40	21	42
CBR14	2	11	20	75	40	80
CBR26	2	10	21	65	30	70
CBR33	2	8	20	60	30	65
CBR60	3	6	26	57	35	61
CBR63	1	7	10	46	20	50
CBR68	1	8	6	56	10	60
CBR69	5	7	75	59	90	61
CBR85	1	6	4	42	8	45

Appendix D Table 1 Contd.

Line and population	Rosette		Flowering		Podding	
	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)	Plant wt. (g)	Plant ht. (cm)
CBR99	5	9	45	57	60	60
CBR106	1	8	12	53	25	60
CBR210	4	10	40	66	50	70
CBR452	4	9	40	52	50	59
CBR455	3	7	30	47	40	55
CBR462	3	8	31	45	40	50
CBR464	3	13	31	75	40	80
CBR465	3	8	30	60	40	65
CBR466	6	8	70	70	80	75
CBR490	2	8	20	51	30	58
CBR492	2	7	15	47	25	50
CBR494	1	6	2	36	5	40
CBR507	1	5	10	60	20	64
CBR519	1	11	4	54	10	57
CBR538	1	7	10	46	20	50
CBR581	3	8	50	55	56	60
CBR591	2	10	20	64	30	70
CBR592	3	15	30	60	40	60
CBR597	3	10	26	48	35	53
CBR643	1	8	6	50	10	55
CBR705	2	7	36	46	40	50
CBR donor[1]	2	12	23	61	93	84
LSD (0.05)[2]	1	2	7	11	6	6
LSD (0.05)[3]	1	2	6	9	5	5

[1] Average of three plots/replication
[2] LSD for comparing DH vs. DH
[3] LSD for comparing DP vs. DH

Appendix D Table 2 Plants/plot, seed and biological yield/plot, harvest index, plant height, days to flower and mature, pod fill period and leaf color index of 115 *B. rapa* doubled haploid lines at maturity, Saskatoon, 1995

Line and population	Plants/ plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod fill period (days)	Leaf color index
BC13	6	10.9	98	0.108	72	41	104	63	2
BC29	10	4.7	135	0.034	63	39	103	64	2
BC43	15	56.9	195	0.277	83	36	105	69	3
BC69	12	4.1	57	0.069	59	39	100	61	2
BC84	17	21.7	298	0.071	66	37	105	68	3
BC111	18	50.4	420	0.110	67	36	104	68	3
BC169	29	75.8	372	0.205	66	37	103	66	3
BC204	24	57.6	233	0.247	70	38	105	67	3
BC249	17	32.6	215	0.155	60	37	108	71	3
BC276	25	59.6	309	0.193	67	36	101	65	3
BC278	7	33.8	219	0.153	73	36	104	68	3
BC295	3	0.0	26	0.022	45	44	104	60	1
BC946	16	5.4	73	0.070	64	39	104	65	1
BC2459	10	36.3	195	0.203	79	37	106	69	3
BC2507	30	43.2	321	0.153	66	38	105	67	3
BC2576	11	4.8	56	0.117	60	48	101	53	1
BC2588	20	8.4	43	0.179	58	48	102	54	1
BC2595A	12	3.3	41	0.070	30	45	99	54	2
BC2595	18	2.1	43	0.050	39	42	98	56	2
BC2660	18	20.3	152	0.136	61	37	102	65	3
BC2665	27	31.0	205	0.150	69	38	104	66	3
BC2668	13	35.7	178	0.217	66	37	101	64	3
BC2677	24	47.5	292	0.174	75	40	102	62	3
BC2678	23	9.7	173	0.057	44	39	98	59	2
BC2679	22	8.8	147	0.057	47	40	103	63	2
BC2705	11	6.6	145	0.047	67	38	105	67	2
BC2723	19	28.6	239	0.129	72	38	101	63	3
BC2725	18	29.5	217	0.135	62	35	103	68	3
BC2774	16	25.2	194	0.131	59	37	101	64	3
BC2791	19	26.5	229	0.117	74	34	100	66	3
BC2886	6	10.0	105	0.097	88	39	102	63	3
BC2889	5	0.0	16	0.023	42	56	100	44	1
BC2913	30	73.4	499	0.146	82	32	104	72	3
BC2916	10	6.1	76	0.085	70	40	103	63	3
BC2927	24	22.2	283	0.082	70	39	101	62	3

Appendix D Table 2 Contd.

Line and population	Plants/ plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod fill period (days)	Leaf color index
BC2944	5	5.2	155	0.034	39	55	100	45	2
BC2953	28	77.7	326	0.308	69	35	104	69	3
BC2960	11	1.5	38	0.032	53	59	98	39	1
BC2956	10	41.5	225	0.183	71	35	103	68	3
BC2965	27	38.7	388	0.100	74	32	103	71	3
BC2965A	24	41.4	411	0.101	76	37	106	69	3
BC3011	24	15.5	139	0.112	78	37	104	67	3
BC3015Y	22	188.3	696	0.280	89	32	109	77	4
BC3015G	29	151.4	769	0.197	87	39	109	70	4
BC3015B	27	111.0	515	0.217	82	32	105	73	4
BC3016	11	12.2	114	0.109	73	41	103	62	3
BC3034	22	44.6	228	0.191	54	40	99	59	3
BC donor [1]	11	172.0	589	0.293	84	36	104	68	4
CB13	18	7.9	45	0.157	46	43	100	57	2
CB15	15	2.5	34	0.074	39	40	99	59	2
CB42	23	74.6	536	0.140	69	35	106	71	3
CB56	5	2.1	30	0.071	31	40	99	59	2
CB77	6	2.9	78	0.042	75	38	110	72	3
CB2524	29	45.6	277	0.158	69	35	104	69	3
CB2625	20	24.9	200	0.123	73	36	102	66	3
CB2627	22	33.9	283	0.126	81	34	102	68	3
CB2630	14	20.8	204	0.099	73	38	102	64	3
CB2690	14	22.0	293	0.075	74	35	102	67	3
CB2740	19	28.5	175	0.160	77	37	101	64	3
CB2741	22	76.6	344	0.220	69	32	101	69	3
CB2857	22	45.0	353	0.132	65	36	101	65	3
CB2940	11	53.4	194	0.271	70	36	98	62	3
CB2941	19	49.8	190	0.259	63	32	99	67	3
CB donor [1]	22	210.8	821	0.260	93	30	104	74	4

Appendix D Table 2 Contd.

Line and population	Plants/ plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod fill period (days)	Leaf color index
EPD1	9	46.1	376	0.124	53	38	106	68	3
EPD7	27	42.3	356	0.101	82	39	102	63	3
EPD9	15	25.5	363	0.069	72	36	103	67	3
EPD10	21	10.7	302	0.038	77	36	100	64	3
EPD2639	4	1.9	19	0.087	33	56	99	43	1
EPD2713	7	33.7	272	0.119	61	35	105	70	3
EPD2684	14	22.6	240	0.095	74	35	103	68	3
EPD2842	20	19.6	233	0.085	68	33	101	68	3
EPD2932	26	26.9	200	0.143	72	32	102	70	3
EPD2933	13	14.5	131	0.106	75	40	104	64	3
EPD2935	9	6.1	31	0.210	62	40	97	57	2
EPD2965	10	21.0	159	0.137	77	39	105	66	2
EPD2975	30	94.2	367	0.256	75	37	100	63	3
EPD2978	19	24.1	142	0.186	52	40	99	59	3
EPD2987	25	52.1	288	0.187	58	38	100	62	3
EPD2988	33	77.2	348	0.229	76	35	97	62	3
EPD2989	16	26.9	126	0.214	71	38	99	61	3
EPD2985	9	0.0	12	0.000	23	56	96	40	1
EPD donor[1]	26	270.5	779	0.347	84	25	104	79	4
CBR2	22	22.6	351	0.064	78	37	105	68	3
CBR11	26	35.0	337	0.101	93	37	102	65	3
CBR13	9	7.3	86	0.078	71	37	105	68	3
CBR14	4	4.6	69	0.064	45	51	101	50	3
CBR26	25	20.6	288	0.068	83	37	101	64	3
CBR33	15	17.1	193	0.094	73	36	103	67	3
CBR60	23	46.5	332	0.138	69	33	108	75	3
CBR61	2	0.0	0	0.000	45	50	96	46	1
CBR63	11	3.1	107	0.030	64	40	96	56	2
CBR68	9	1.0	30	0.035	54	40	96	56	1
CBR69	13	104.5	456	0.229	69	38	106	68	3
CBR83	1	0.0	0	0.000	45	50	98	48	2
CBR85	14	6.0	37	0.179	59	40	71	31	2
CBR85A	6	0.0	16	0.000	51	45	99	54	1

Appendix D Table 2 Contd.

Line and population	Plants/ plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature	Pod fill period (days)	Leaf color index
CBR99	17	29.9	420	0.067	81	38	105	67	3
CBR106	21	30.4	193	0.143	66	40	101	61	3
CBR210	18	107.1	348	0.303	68	34	105	71	3
CBR452	21	81.9	426	0.188	79	33	107	74	3
CBR455	1	3.3	21	0.054	61	40	96	56	1
CBR462	15	30.3	281	0.103	56	36	104	68	3
CBR464	20	41.4	297	0.137	84	39	106	67	3
CBR465	27	38.6	374	0.100	67	36	99	63	3
CBR466	21	145.5	588	0.243	78	29	103	74	3
CBR490	9	15.2	102	0.107	61	41	101	60	3
CBR492	23	30.3	221	0.142	55	33	100	67	3
CBR494	9	3.7	19	0.216	42	37	99	62	3
CBR507	24	5.5	261	0.021	72	38	105	67	3
CBR519	26	35.6	146	0.234	60	36	100	64	3
CBR538	11	6.6	83	0.082	63	40	100	60	2
CBR581	6	18.3	184	0.097	68	39	100	61	3
CBR591	27	129.7	583	0.223	84	39	105	66	3
CBR592	21	61.1	327	0.194	68	34	106	72	3
CBR597	22	125.1	306	0.400	58	33	103	70	3
CBR643	18	114.3	323	0.333	63	34	103	69	3
CBR705	4	8.7	73	0.112	63	40	100	60	2
CBR donor[1]	27	293.8	875	0.333	87	28	105	77	4
LSD (0.05)[2]	4	12	48	0.09	13	7	4	8	-
LSD (0.05)[3]	3	10	39	0.07	11	6	3	7	-

[1] Average of three plots/replication
[2] LSD for comparing DH with DH
[3] LSD for comparing DP with DH

Appendix E. Performance of single cross hybrids produced by crossing *B. rapa* doubled haploid (DH) lines, Saskatoon, 1994

Appendix E Table 1 Plants/plot, seed and biological yield/plot, harvest index, plant height, days to flower and mature of *B. rapa* doubled haploid (DH) single cross hybrids, donor populations, DH parental lines and the cultivar Tobin, Saskatoon, 1994

Cross, DH or donor population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature
BC2573 x EPD2932	40	90.8	347	0.259	88	35	92
BC2573 x EPD2975	28	119.8	387	0.309	85	30	90
BC2573 x EPD2987	57	171.5	554	0.309	98	31	89
BC2666 x EPD2975	65	218.8	668	0.326	99	30	89
BC2668 x EPD2987	38	94.0	441	0.209	98	32	90
BC2668 x EPD2988	78	202.8	607	0.331	99	29	89
BC2668 x EPD2989	62	132.8	508	0.263	101	30	89
BC2791 x EPD2932	39	116.3	454	0.258	95	36	91
BC2791 x EPD2975	46	183.4	658	0.278	102	33	91
BC2791 x EPD2988	44	150.9	553	0.272	100	34	90
BC2791 x EPD2989	35	154.0	600	0.254	106	35	91
CB2625 x EPD2932	48	77.9	393	0.198	99	35	91
CB2625 x EPD2975	47	153.7	667	0.230	104	34	89
CB2625 x EPD2987	37	98.2	532	0.172	105	33	92
CB2625 x EPD2988	60	196.0	659	0.284	106	33	92
CB2625 x EPD2989	48	165.2	617	0.269	111	34	91
CB2736 x EPD2975	57	173.6	610	0.281	97	33	91
CB2736 x EPD2988	32	152.2	635	0.239	103	34	92
CB2736 x EPD2989	56	146.3	575	0.257	92	34	91
CB2740 x EPD2932	55	105.5	519	0.207	102	34	91
CB2740 x EPD2975	67	156.4	562	0.282	100	31	89
CB2740 x EPD2987	67	173.0	646	0.269	104	32	89
CB2740 x EPD2988	54	160.8	640	0.253	103	34	90
CB2740 x EPD2989	55	168.2	625	0.270	102	32	88
CB2741 x EPD2932	45	139.2	577	0.242	99	32	91
CB2741 x EPD2975	55	172.1	614	0.286	102	29	89
CB2741 x EPD2987	58	155.4	582	0.259	102	29	89
CB2741 x EPD2988	55	131.2	477	0.272	99	30	89
CB2741 x EPD2989	59	180.7	707	0.257	97	29	89
CB2857 x EPD2932	42	129.8	530	0.247	100	33	91
CB2857 x EPD2975	70	200.3	601	0.333	104	33	89
CB2857 x EPD2987	63	172.0	677	0.255	105	34	88
CB2857 x EPD2988	60	185.3	610	0.305	103	33	90
CB2857 x EPD2989	54	166.9	585	0.289	94	33	88

Appendix E Table 1 Contd.

Cross, DH or donor population	No. of plants /plot	Seed yield (g)	Biological yield (g)	Harvest index	Plant height (cm)	Days to flower	Days to mature
CB2940 x EPD2932	60	178.9	723	0.248	104	33	92
CB2940 x EPD2975	57	194.4	643	0.300	105	30	90
CB2940 x EPD2987	52	196.4	707	0.279	100	32	90
CB2940 x EPD2988	36	162.8	551	0.292	98	31	90
CB2940 x EPD2989	55	170.4	637	0.270	99	32	89
CB2941 x EPD2932	74	165.3	589	0.283	98	34	91
CB2941 x EPD2975	62	187.7	713	0.263	105	34	90
CB2941 x EPD2987	58	200.6	610	0.328	105	29	88
CB2941 x EPD2988	57	139.9	538	0.260	102	34	89
CB2941 x EPD2989	60	177.4	636	0.280	105	31	88
CB2740 x CB2736	16	49.3	315	0.158	103	37	91
BC86-18	18	77.6	363	0.219	93	33	93
CompB	25	137.2	622	0.221	107	41	94
E/P/D	53	153.8	561	0.275	104	30	91
Tobin	51	168.1	663	0.252	98	29	91
LSD(0.05)	12	49	114	0.122	-	2	3
BC2573	-	-	-	-	-	-	-
BC2668	-	-	-	-	-	-	-
BC2791	-	-	-	-	-	-	-
CB2625	-	-	-	-	-	-	-
CB2736	-	-	-	-	-	-	-
CB2740	-	-	-	-	-	-	-
CB2741	-	-	-	-	-	-	-
CB2857	-	-	-	-	-	-	-
CB2940	-	-	-	-	-	-	-
CB2941	-	-	-	-	-	-	-
EPD2932	50	44.6	258	0.183	83	33	91
EPD2975	57	69.6	330	0.212	78	32	89
EPD2987	36	64.1	254	0.254	81	35	92
EPD2988	42	63.3	225	0.284	73	33	88
EPD2989	44	43.2	232	0.187	91	36	89

- Killed by herbicide spray

Appendix E Table 2 Pod length, number of seeds/pod and hundred seed weight of *B. rapa* doubled haploid (DH) single cross hybrids, donor populations and DH parental lines and the cultivar Tobin, Saskatoon. 1994

Cross, DH or donor population	Pod length (cm)	No. of seeds /pod	Hundred seed wt. (mg)
BC2573 x EPD2932	5	16	233
BC2573 x EPD2975	6	26	211
BC2573 x EPD2987	6	26	195
BC2668 x EPD2975	6	26	184
BC2668 x EPD2987	6	22	182
BC2668 x EPD2988	6	26	187
BC2668 x EPD2989	6	22	187
BC2791 x EPD2932	6	18	258
BC2791 x EPD2975	6	27	215
BC2791 x EPD2988	6	29	225
BC2791 x EPD2989	6	24	241
CB2625 x EPD2932	7	17	240
CB2625 x EPD2975	7	26	184
CB2625 x EPD2987	6	22	191
CB2625 x EPD2988	7	26	190
CB2625 x EPD2989	6	25	188
CB2736 x EPD2975	7	27	204
CB2736 x EPD2988	7	27	208
CB2736 x EPD2989	6	28	190
CB2740 x EPD2932	6	22	211
CB2740 x EPD2975	6	26	163
CB2740 x EPD2987	6	25	178
CB2740 x EPD2988	6	31	168
CB2740 x EPD2989	6	24	170
CB2741 x EPD2932	6	21	239
CB2741 x EPD2975	7	28	176
CB2741 x EPD2987	6	29	186
CB2741 x EPD2988	7	32	172
CB2741 x EPD2989	6	29	175
CB2857 x EPD2932	6	22	199
CB2857 x EPD2975	6	28	161
CB2857 x EPD2987	6	25	183
CB2857 x EPD2988	7	27	164

Appendix E Table 2 Contd.

Cross, DH or donor population	Pod length (cm)	No. of seeds /pod	Hundred seed wt. (mg)
CB2857 x EPD2989	6	28	162
CB2940 x EPD2932	7	28	206
CB2940 x EPD2975	7	34	176
CB2940 x EPD2987	7	29	162
CB2940 x EPD2988	8	34	172
CB2940 x EPD2989	7	29	173
CB2941 x EPD2932	7	27	189
CB2941 x EPD2975	7	31	169
CB2941 x EPD2987	6	29	185
CB2941 x EPD2988	6	30	156
CB2941 x EPD2989	7	31	151
CB2740 x CB2736	6	19	196
BC8618	6	25	214
CompB	6	19	215
E/P/D	6	21	214
Tobin	7	25	206
LSD(0.05)	1.6	5	10
BC2573	-	-	-
BC2668	-	-	-
BC2791	-	-	-
CB2625	-	-	-
CB2736	-	-	-
CB2740	-	-	-
CB2741	-	-	-
CB2857	-	-	-
CB2940	-	-	-
CB2941	-	-	-
EPD2932	5	10	251
EPD2975	5	20	208
EPD2987	5	19	220
EPD2988	5	20	210
EPD2989	4	19	195

- Killed by herbicide spray