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DEVELOPMENT COMMISSION

Reduced pesticide inputs for flea beetle control in canola and mustard

I. Flea beetle resistance and growth attributes of mustard and canola species

CARP Final Report

Project # 97-95-10

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Summary

A three- year laboratory and field study was conducted on nearly 40 lines of *Sinapis alba, Brassica carinata, B. juncea, B. rapa* and *B. napus*. The objectives of the study were to evaluate the resistance and tolerance of lines to the crucifer flea beetle, *Phyllotreta cruciferae*, and identify lines with superior agronomic attributes including seedling establishment, growth rates and seed yield. Entries were selected on the bases of breeding type, morphological traits, resistance to blackleg and glucosinolate content of the seed. With the exception of hybrid entries, all lines were first grown in isolation tents in the field to standardize seed quality. After vernalization at 4°C, seedlots were sieved through graded screens to identify the most prevalent seed-size in each species. Seeds from this fraction were evaluated in the lab and in the field. Seeds measured 2.2-2.4mm in *S.alba*, 1.8-2.0mm in *B. carinata*, 1.6-1.8mm in *B. rapa* and 1.8-2.0mm in *B. napus*.

Three growth chamber experiments were conducted at 7°C to investigate the influence of low temperature on seedling emergence and seedling growth. Entries included five lines of *S. alba* and four lines of *B. carinata* (test 1), eight lines of *B. juncea* and six lines of *B. rapa* (test 2) and 13 lines of *B. napus* (test 3). Each test was replicated four times using a randomized split-plot design or randomized complete block design depending on the test.

Seedling counts 13 days after planting (DAP) varied significantly depending on the entry. Counts ranged from 3.3 seedlings/row in S-67 to 10.0 seedlings/row in AC Pennant. Counts were higher in lines of *S. alba* and *B. napus* than lines of *B. rapa, B. juncea* and *B. carinata*. Counts in the five species averaged 9.5, 9.0, 7.9, 7.7 and 6.1 seedlings/row, respectively. Counts also differed among lines within species. Experimental low glucosinolate lines had the lowest counts in *S. alba* (low GS line), *B. juncea* (J90-4253/1), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski). Conversely, high glucosinolate had the highest counts in *S. alba* (AC Pennant), *B. juncea* (AC Vulcan, common brown) and *B. rapa* (Echo). C90-1088 had the highest counts in lines of *B. carinata* whereas Hyola 417 and Profit had the highest counts in lines of *B. napus.*

Rates of cotyledon/leaf growth varied significantly among entries, ranging from 17mm^2/day in Bronowski to 80mm^2/day in AC Pennant. Growth rates were 2-3 times higher in lines of *S. alba* than in lines of the four *Brassica* species. Growth rates averaged 72mm^2/day in lines of *S. alba* compared to 26-30mm^2/day in lines of *Brassica* species. Experimental low glucosinolate lines had the lowest growth rates in *B. juncea* (J90-4253/1), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski). AC Pennant, C90-1088 and Cutlass had the highest growth rates in *S.alba*, *B. carinata* and *B. juncea*, respectively. Tobin had the highest growth rate in lines of *B. rapa* whereas ACS N14, Westar and AC H102 had the highest growth rates in lines of *B. napus.*

Dry matter accumulation 15-29 DAP ranged from 1.2mg/day in Bronowski to 4.1mg/day in AC Pennant. Dry matter accumulation was two times higher in lines of *S. alba* than in lines of the four *Brassica* species. Values averaged 3.7mg/day in *S. alba*

compared to 1.6-1.9mg/day in *Brassica* species. Experimental low glucosinolate lines had the lowest accumulation rate in *B. juncea* (J90-4253/3), *B. rapa* (8618 x DLY, composite H) and *B. napus* (Bronowski). ACS C5 and Tobin had the highest dry matter accumulation in lines of *B. rapa* whereas ACS N14 and Westar had the highest accumulation rates in lines of *B. napus*.

Three growth chamber experiments were conducted at 12°C to determine the influence of moderate temperature on emergence and seedling growth. The experimental design and entries were identical to previous tests. Seedling counts 7 DAP ranged from 6.9 seedlings/row in Cresor to 9.8 seedlings/row in Ochre, ACS C5, Argentine and DH 12063. Seedling counts in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus* averaged 9.4, 7.8, 9.1, 9.3 and 8.8 seedlings/row, respectively. Experimental low glucosinolate lines had the lowest counts in *S. alba* (low GS line) and *B. rapa* (8618 x DLY). Ochre, C90-1088 and AC Vulcan had the highest seedling counts in *S. alba, B. carinata,* and *B. juncea*, respectively. ACS C5 had the highest counts in lines of *B. rapa* whereas Argentine and DH 12063 had the highest counts in lines of *B. napus*.

Rates of cotyledon/leaf growth 11-18DAP ranged from 58mm^2/day in Bronowski to 390mm^2/day in AC Pennant and Ochre. Growth rates were 2-3 times higher in lines of *S. alba* than in lines of *Brassica* species. Growth rates averaged 327mm^2/day in *S. alba,* 176mm^2/day in *B. carinata*, 156mm^2/day in *B. juncea*, 168mm^2/day in *B. rapa* and 89mm^2/day in *B. napus*. Experimental low glucosinolate lines had the lowest growth rates in lines of *B. rapa* (8618 x DLY) and *B. napus* (Bronowski). Ochre, Dodolla and Zeho had the highest growth rate in *S. alba*, *B. carinata* and *B. juncea*, respectively. ACS C5 and Echo had the highest growth rate in lines of *B. rapa* whereas Westar, Argentine and Midas had the highest growth rate in lines of *B. napus.*

Dry matter accumulation 11-18DAP ranged from 2.5mg/day in Bronowski to 12.0mg/day in Ochre. Dry matter accumulation varied among species, averaging 10.1mg/day in *S. alba*, 6.4mg/day in *B. carinata*, 4.4mg/day in *B. juncea*, 4.6mg/day in *B. rapa* and 3.4mg/day in *B. napus.* Experimental low glucosinolate lines had the lowest rate of dry matter accumulation in *B. rapa* (8618 x DLY) and *B. napus* (Bronowski). Ochre, Dodolla and Zem-87 had the highest dry matter in *S. alba, B. carinata* and *B. juncea*, respectively. ACS C5 and Echo had the highest values in lines of *B. rapa* whereas Midas, Westar, *Topas* and Argentine had the highest values in lines of *B. napus.*

Field tests were conducted on the 40 lines in 1995, 1996 and 1997. The experimental design and entries were identical to previous tests. Medium-sized seeds of each entry were planted without chemical protectants in six-row plots at 200 seeds per 6.0m row.

Flea beetle damage and agronomic attributes of each species varied significantly from year to year. Flea beetle damage was, on average, 10-30% lower in 1995 than in 1996 or 1997. Dry conditions during May and early June limited seedling establishment in 1995 whereas moderate to very high flea beetle damage reduced seedling growth in 1996 and 1997.

Flea beetle damage to the cotyledons 22 days after seedling (DAS) ranged from 22% in Ochre to 77% in 8618 x DLY. Damage differed among species, averaging 28% in *S. alba*, 37% in *B. carinata*, 65% in *B. juncea*, 69% in *B. rapa* and 50% in *B. napus.* Results indicated that lines of *S. alba* and *B. carinata* had the highest resistance to flea beetles whereas lines of *B. juncea* and *B. rapa* had the lowest resistance to flea beetles. Lines of *S. alba* with high concentrations of hydroxybenzyl glucosinolate in the seed had the least damage and were judged most resistant to flea beetles. Damage in experimental low glucosinolate lines of *S. alba* (low GS line), *B. juncea* (J90-4253/1, J90-4253/3), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski) was 10-15% higher than in high glucosinolate lines of *S. alba* (Ochre), *B. juncea* (Cutlass), *B. rapa* (Echo) and *B. napus* (DH 12063, Cresor). The latter lines had the highest resistance to flea beetles in the four species.

Seedling counts 23 DAS varied among entries, ranging from 23 seedlings/row in 8618 x DLY to 119 seedlings/row in Ochre. Counts differed among species, averaging 100 seedlings/row in *S. alba*, 60 seedlings/row in *B. carinata*, 55 seedlings/row in *B. juncea*, 42 seedlings/row in *B. rapa* and 65 seedlings/row in *B. napus*. Results indicated that lines of *S. alba* were the most tolerant to flea beetle damage whereas lines of *B. juncea* and *B. rapa* were the least tolerant to damage. Experimental low glucosinolate lines of *S. alba* (low GS line), *B. juncea* (J90-4253/1, J90-4253/3), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski) had the lowest counts and were judged least tolerant to flea beetle damage. Conversely, high glucosinolate lines of *S. alba* (Ochre), *B. juncea* (AC Vulcan, Cutlass), *B. rapa* (Echo) and *B. napus* (Midas, Argentine) had the highest seedling counts and were judged most tolerant to flea beetle damage.

Rates of cotyledon/leaf growth 14-21 DAS ranged from 15mm^2/day in 8618 x DLY to 155mm^2/day in Ochre. Growth rates were 3-10 times higher in lines of *S. alba* than in lines of *Brassica* species. Growth rates averaged 111mm^2/day in *S. alba*, 24mm^2/day in *B. carinata*, 33mm^2/day in *B. juncea*, 28mm^2/day in *B. rapa* and 12mm^2/day in *B. napus.* Experimental low glucosinolate lines had the lowest growth rates in *S. alba* (low GS line), *B. juncea* (J90-4253/1, J90-4253/3), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski, Hyola 417). Ochre, Dodolla and Cutlass had the highest growth rates in lines of *S. alba, B. carinata* and *B. juncea*, respectively. Tobin and Echo had the highest growth rates in lines of *B. rapa* whereas Argentine, Cyclone and Topas had the highest growth rates in lines of *B. napus*.

Dry matter content varied significantly among lines 14, 21, 28 and 35 DAS. Lines of *S. alba* had the highest dry matter content on each sampling date. Dry matter also differed among lines within each species. Experimental low glucosinolate lines had the lowest values in *S. alba* (low GS line), *B. juncea* (J90-4253/1), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski). Ochre, Dodolla and Cutlass had the highest dry matter content in *S. alba, B. carinata* and *B. juncea* on each sampling date. Echo and Tobin had the highest values in lines of *B. rapa*. In *B. napus*, Argentine and Hyola 417 had the highest values 14 DAS; Argentine and Topas the highest values 21 DAS. Argentine and AC H102 the highest values 28 DAS; and AC H102 and Topas the highest values 35 DAS.

Seed yields differed among entries ranging from 37g/m^2 in 8618 x DLY to 282g/m^2 in Dodolla. Seed yields differed among species averaging 201g/m^2 in *S. alba*, 252g/m^2 in *B. carinata*, 195g/m^2 in *B. juncea*, 89g/m^2 in *B. rapa* and 194g/m^2 in *B. napus*. Experimental low glucosinolate lines had the lowest seed yield in lines of *S. alba* (low GS line), *B. juncea* (J90-4253/1, J90-4253/3), *B. napa* (8618 x DLY, composite H) and *B. napus* (Bronowski). AC Pennant, Dodolla and J2741 has the highest seed yield in *S. alba*, *B. carinata* and *B. juncea*, respectively. Echo had the highest seed yield in lines of *B. rapa* whereas Cyclone, Topas and Argentine had the highest seed yields in lines of *B. napus*. With the exception of J2741, lines with the highest establishment, growth rate and dry matter content usually had the highest seed yield.

Harvest seed weights varied among entries, ranging from 2.17g in composite H to 6.67g in Sabre. Harvest seed weights differed among species, averaging 6.22g in *S. alba*, 3.99g in *B. carinata*, 2.78g in *B. juncea*, 2.33g in *B. rapa* and 3.53g in *B. napus*. Weights also differed among lines within species. Low glucosinolate lines had the lowest seed weights in *B. juncea* (J90-4253/1, J90-4253/3), *B. rapa* (composite H) and *B. napus* (Bronowski). Sabre, C90-1215 and J2741 had the highest seed weights in *S. alba, B. carinata* and *B. juncea*, respectively. ACS C5 had the highest seed weight in lines of *B. rapa* whereas DH 122063 had the highest seed weight in lines of *B. napus.*

Introduction

The crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), is a serious pest of canola and mustard in western Canada (Anonymous 1997). After overwintering in non-crop areas (Burgess and Spurr 1984), adults migrate into commercial fields and feed on the cotyledons, true leaves and stems of young seedlings. Feeding damage results in seedling mortality, reduced seedling growth, delayed crop development, uneven maturity and lower seed yields or grade (Putnam 1977, Lamb 1984). Crop rotation and biological agents provide limited regulation of flea beetle populations so producers are dependant on several methods of chemical control (Anonymous 1997). Most seed (>90% acreage) is treated with a lindane-based seed dressing and either planted with a granular insecticide (10-20% acreage) or sprayed with an insecticide (9-14% acreage). However, these treatments are costly economically and may pose a hazard to the applicator or non-target species. Clearly, alternate management tactics that reduce reliance on chemical control would be beneficial economically and environmentally.

Host plant resistance has been proposed as an alternative to chemical control of flea beetles (Lamb 1989). Studies have shown that lines of *Sinapis alba, Brassica carinata, B. juncea, B. rapa* and *B. napus* differ in their attractiveness or palatability to flea beetles, tolerance to flea beetle damage and growth attributes (Putnam 1977, Lamb 1988, Bodnaryk 1991, Bodnaryk and Lamb 1991, Palaniswamy *et al.* 1992, 1997, Brandt and Lamb 1994). The objectives of this study were to evaluate the resistance and tolerance of mustard, rapeseed and canola lines to flea beetles and identify lines with superior growth attributes including seedling emergence, growth rate and seed yield. Growth chamber experiments were also conducted to determine the influence of temperature on emergence and seedling growth.

Materials and Methods

Laboratory and field tests were conducted on nearly 40 lines of *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*. Lines were selected on the bases of breeding type, morphological traits, resistance to blackleg and glucosinolate content of the seed. With the exception of hybrid entries, lines were grown in isolation tests in the field in 1994 to standardize seed quality. Seed was harvested, cleaned and vernalized at 4°C for six weeks. Thousand-seed weights were determined from three 100-seed subsamples. Seedlots were sieved through graded screens of 0.2 mm increments to evaluate seed-size distributions and identify the most prevalent seed-size fraction in each species (Tables 1 and 2). Seeds from this fraction were evaluated in the lab and in the field. The glucosinolate content of the seed was determined by gas chromatography using the modified procedure of Raney and Rakow (1995). Allyl isothiocyanate and benzyl glucosinolate were used as standards for *Sinapis* and *Brassica* species, respectively.

Laboratory experiments

Growth chamber experiments were conducted to determine the influence of temperature on seedling emergence and seedling growth. Each experiment was replicated four times. Test 1 and test 2 employed a randomized split-plot design with species as main plots and lines as subplots. Test 1 included five lines of *S. alba* and four lines of *B. carinata* whereas test 2 included eight lines of *B. juncea* and six lines of *B. rapa.* Test 3 employed a randomized complete block design and included 13 lines of *B. napus.* In each test, seeds were planted in wooden flats containing a potting mix at 10 seeds per row and 1.0 cm planting depth. In the first series of experiments, flats were placed in a growth chamber at 7°C and 16L/8D photoperiod. Flats were rotated daily to minimize environmental differences within the chamber on emergence. Seedling emergence was assessed 10-15 days after planting (DAP). Four seedlings were harvested from each row 15 DAP and 29 DAP. Seedlings were cleaned and dissected. The surface area of the cotyledons and true leaves was measured with a computer-based imaging system (Decagon Devices Inc.). After imaging, cotyledons, leaves and stems were dried at 60°C for 5 days and weighed. Rates of cotyledon/leaf growth and dry matter content were calculated from areas and dry weights on the two sampling dates. The second series of experiments were conducted at 12°C and 16L/8D photoperiod. Emergence was assessed 4-7 DAP. Seedlings were harvested 11 and 18 DAP and evaluated using the same methods as the previous experiment.

Field tests

Field tests were conducted in 1995, 1996 and 1997 at the AAFC Research Farm at Saskatoon. Plots were treated with Treflan® in early May at the recommended rate. Fertilizer was broadcast and incorporated at different rates depending on soil tests and blend or formulation of fertilizer. Fertilizer was applied at 112 kg/ha in 1995 (16-20-0-14 formulation), 225 kg/ha in 1996 (14-36-0-8 blend) and 210 kg/ha in 1997 (16-37-0-10 blend). Fertilizer was also applied in-furrow during seeding at 45 kg/ha in 1995 (11-51-0-2 formulation) and 28 kg/ha in 1996 (16-20-0-14 formulation).

Seedlots of *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus* were sieved to obtain samples of medium-sized seed. Seeds measured 2.2-2.4 mm in *S. alba,* 1.8-2.0 mm in *B. carinata,* 1.6-1.8 mm in *B. juncea,* 1.6-1.8 mm in *B. rapa* and 1.8-2.0 mm in *B. napus*. Each test was replicated four times using the same experimental design as the growth chamber experiments. Test 1 included five lines of *S. alba* and four lines of *B. carinata*. Test 2 included eight lines of *B. juncea* and six lines of *B. rapa*. Test 3 included 13 lines of *B. napus*. Sized seeds of each line were planted without chemical protectants in six-row plots at 200 seeds per 6.0 m row and 0.30 m row-spacing. Depending on moisture conditions, seeds were planted at 1.5-2.5 cm on depths with a double-disc drill on May 16 in 1995, May 28 in 1996 and May 16 in 1997.

Flea beetle damage to 20 cotyledons in each subplot was assessed visually 15 and 22 days after seeding (DAS) using a 10-point rating system (after Palaniswamy *et al.* 1992). Ratings corresponded to the percentage of cotyledon surface eaten by flea beetles. Seedlings along the centre rows of each subplot were counted 16 and 23 DAS. To assess plant growth, 10 plants were collected from the outer rows of each subplot 14, 21, 28 and 35 DAS. Samples were transported on crushed ice to the lab, cleaned, weighed and dissected. Surface areas of the cotyledons and true leaves were measured with a computer-based imaging system 14 and 21 DAS. After imaging, cotyledons, leaves and stems were dried at 60°C for 5-7 days and weighed to determine dry matter content. The four centre rows of each subplot were harvested at maturity with a small-plot combine to determine seed yield. Three 100-seed subsamples were weighed to determine 1000-seed weight.

Laboratory and field data were analyzed using the General Linear Model Procedure (SAS Institute Inc. 1989). Laboratory experiments were analyzed as a split-plot design or randomized complete block design. Lines of each species were also analyzed separately. Field data were analyzed as a split-split-plot design with years as main plots, species as subplots and lines as subsubplots. Lines from each species were also analyzed separately. The LSD test was used to compare means from years and means from lines. Year by species and year by line interactions were also assessed.

Results

Glucosinolates (GS) in seeds of *Sinapis* and *Brassica* species differed quantitatively and qualitatively (Fig. 1). Concentration of GS in lines of *S. alba* ranged from 27 μmoles/g in the low GS line to 165 μmoles/g in Sabre. Hydroxbenzyl GS or sinalbin was the predominant GS in lines of *S. alba*. Concentrations of sinalbin ranged from 12 μmoles/g in the low GS line to 158 μmoles/g in Sabre. Total GS in lines of *B. carinata* ranged from 74 μmoles/g in C90-1215 to 99 μmoles/g in S-67. Allyl GS or sinigrin was the predominant GS in lines of *B. carinata*. Concentrations of sinigrin ranged from 67 μmoles/g in C90-1215 to 90 μmoles/g in S-67 and C90-1088. Total GS in lines of *B. juncea* ranged from 11

μmoles/g in J90-4253/1 to 121 μmoles/g in Cutlass. Concentrations of sinigrin, the predominant GS, ranged from 1 μmole/g in J90-4253/1 to 116 μmoles/g in AC Vulcan. Total GS in lines of *B. rapa* ranged from 2 μmoles/g in 8618 x DLY to 67 μmoles/g in Echo. The major GS in Echo were butenyl GS (22 μmoles/g) and pentenyl GS (20 μmoles/g). Total GS in lines of *B. napus* ranged from 7 μmoles/g in Bronowski to 98 μmoles/g in Argentine. The major GS in Argentine were hydroxylbutenyl GS (57 μmoles/g) and butenyl GS (22 μmoles/g).

Laboratory experiments

In experiments conducted at 7°C, seedling counts varied significantly among species and lines within species (Fig. 2). In test 1, counts were higher (F=111.1, p=0.002) in *S. alba* than in *B. carinata*. Counts averaged 9.5 seedlings/row and 6.1 seedlings/row, respectively. Counts in *S. alba* ranged from 9.3 seedlings/row in the low GS lines to 10.0 seedlings/row in AC Pennant. Counts in *B. carinata* ranged from 3.3 seedlings/row in S-67 to 7.3 seedlings/row in C90-1088. In test 2, seedling counts were similar (F=0.18, p=0.70) in lines of *B. juncea* and *B. rapa*, averaging 7.7 seedlings/row and 7.9 seedlings/row, respectively. Counts in *B. juncea* ranged from 6.3 seedlings/row in C90-4253/1 to 9.0 seedlings/row in common brown and AC Vulcan. Counts in *B. rapa* ranged from 6.0 seedlings/row in 8618 x DLY to 9.8 seedlings/row in Echo. Counts averaged 9.0 seedlings/row in lines of *B. napus*. Counts ranged from 6.3 seedlings/row in Bronowski to 9.8 seedlings/row in Hyola 417.

Rates of cotyledon/leaf growth at 7°C varied among species and lines within species (Fig. 3). In test 1, growth rates were higher (F=39.3, p=0.008) in lines of *S. alba* than in lines of *B. carinata*. Growth rates averaged 71.7 mm^2/day and 28.5 mm^2/day, respectively. Growth rates in *S. alba* ranged from 58 mm^2/day in Sabre to 80 mm^2/day in AC Pennant. Growth rates in *B. carinata* ranged from 24 mm^2/day in S-67 to 31 mm^2/day in C90-1088. In test 2, rates of cotyledon/leaf growth were similar (F=0.02, p=0.90) in *B. juncea* and *B. rapa*, averaging 30 mm^2/day and 29 mm^2/day, respectively. Growth rates in *B. juncea* ranged from 27 mm^2/day in C90-4253/1 to 34 mm^2/day in Cutlass whereas growth rates in *B. rapa* ranged from 21 mm^2/day in 8618 x DLY to 36 mm^2/day in Tobin. Rates of cotyledon/leaf growth averaged 26 mm^2/day in lines of *B. napus*. Growth rates ranged from 17 mm^2/day in Bronowski to 34 mm^2/day in ACS N14.

Rates of dry matter accumulation at 7°C varied among entries (Fig. 4). In test 1, growth rates were higher (F=32.7, p=0.01 in *S. alba* than in *B. carinata*. Dry matter accumulation averaged 3.7 mg/day in *S. alba* and 1.9 mg/day in *B. carinata*. Growth rates in *S. alba* ranged from 3.1 mg/day in Sabre to 4.1 mg/day in AC Pennant. Growth rates in *B. carinata* ranged from 1.6 mg/day in Dodolla to 2.0 mg/day in C90-1215. In test 2, rates of dry matter accumulation were similar (F=0.03, p=0.87) in *B. juncea* and *B. rapa,* averaging 1.7 mg/day and 1.6 mg/day, respectively. Values in *B. juncea* ranged from 1.5 mg/day in J90-4253/3 to 1.9 mg/day in Cutlass. Values in *B. rapa* ranged from 1.1 mg/day in Composite H to 2.0 mg/day in ACS C5. Rates of dry matter accumulation averaged 1.9

mg/day in lines of *B. napus*. Rates ranged from 1.2 mg/day in Bronowski to 2.4 mg/day in ACS N14 and Westar.

In experiments conducted at 12°C, seedling counts varied significantly among entries (Fig. 5). In test 1, counts were higher (F=16.0, p=0.03) in *S. alba* than in *B. carinata*, averaging 9.4 seedlings/row and 7.8 seedlings/row, respectively. Counts in *S. alba* ranged from 9.3 seedlings/row in Sabre and low GS line to 9.8 seedlings/row in Ochre. Counts in *B. carinata* ranged from 7.1 seedlings/row in S-67 to 8.8 seedlings/row in C90-1088. In test 2, seedling counts were similar (F=0.18, p=0.70) in *B. juncea* and *B. rapa*, averaging 9.1 seedlings/row and 9.3 seedlings/row, respectively. Counts in *B. juncea* ranged from 8.1 seedlings/row in J2741 to 9.6 seedlings/row in AC Vulcan. Counts in *B. rapa* ranged from 8.9 seedlings/row in 8618 x DLY to 9.8 seedlings/row in ACS C5. Counts averaged 8.8 seedlings/row in *B. napus*. Counts ranged from 6.9 seedlings/row in Cresor to 9.8 seedlings/row in DH 12063 and Argentine.

Rates of cotyledon/leaf growth at 12°C varied among entries (Fig. 6). In test 1, growth rates were higher (F=1066.2, p=0.0001) in *S. alba* than *B. carinata*, averaging 327 mm^2/day and 176 mm^2/day, respectively. Growth rates in *S. alba* ranged from 234 mm^2/day in Sabre to 390 mm^2/day in AC Pennant and Ochre. Rates in *B. carinata* ranged from 146 mm^2/day in S-67 to 214 mm^2/day in Dodolla. Rates of cotyledon/leaf growth in test 2 were similar (F=0.29, p=0.63) in *B. juncea* and *B. rapa*, averaging 156 mm^2/day and 168 mm^2/day, respectively. Growth rates in *B. juncea* ranged from 131 mm^2/day in AC Vulcan to 178 mm^2/day in Zeho. Growth rates in *B. rapa* ranged from 122 mm^2/day to 8618 x DLY to 196 mm^2/day in ACS C5. Rates of cotyledon/leaf growth averaged 89 mm^2/day in lines of *B. napus*. Rates ranged from 58 mm^2/day in Bronowski to 115 mm^2/day in Midas.

Rates of dry matter accumulation at 12°C varied among entries (Fig. 7). In test 1, dry matter accumulation was higher (F=117.1, p=0.002) in *S. alba* than in *B. carinata*, averaging 10.1 mg/day and 6.4 mg/day, respectively. Dry matter accumulation in *S. alba* ranged from 7.2 mg/day in Sabre to 12.0 mg/day in Ochre. Accumulation rates in *B. carinata* ranged from 5.4 mg/day in S-67 to 7.7 mg/day in Dodolla. Rates of dry matter accumulation in test 2 were similar (F=0.13, p=0.74) in *B. juncea* and *B. rapa*, averaging 4.4 mg/day and 4.6 mg/day, respectively. Growth rates in *B. juncea* ranged from 3.7 mg/day in J2741 to 5.0 mg/day in Zeho and Zem 87. Growth rates in *B. rapa* ranged from 3.6 mg/day in 8618 x DLY to 5.3 mg/day in Echo and AC5 C5. Dry matter accumulation averaged 3.4 mg/day in lines of *B. napus*. Accumulation rates ranged from 2.5 mg/day in Bronowski to 4.1 mg/day in Midas.

Field Tests

Flea beetle damage and agronomic attributes of *S. alba* varied significantly from year to year (Table 3). Flea beetle damage 22 DAS averaged 16% in 1995, 27% in 1996 and 42% in 1997. Seedling counts 16 and 23 DAS were lower in 1995 than in 1996 and 1997. Seedling counts 16 and 23 DAS were lower in 1995 than in 1996 and 1997.

Seedling establishment averaged 29% in 1995, 59% in 1996 and 62% in 1997. Rates of cotyledon/leaf growth and dry matter content on most sampling dates were higher in 1995 and 1996 than in 1997. Seed yields were also higher in 1995 and 1996 than in 1997, averaging 213, 224 and 167 m^2**,** respectively. Harvest seed weights ranged from 5.90 g in 1996 to 6.73 g in 1995.

Flea beetle damage and agronomic attributes of *B. carinata* varied significantly from year to year (Table 3). Flea beetle damage 22 DAS averaged 19% in 1995, 39% in 1996 and 54% in 1997. Seedling counts 16 and 23 DAS were lower in 1995 than in 1996 or 1997. Establishment averaged 21% in 1995, 33% in 1996 and 37% in 1997. Rates of cotyledon/leaf growth and dry matter content on all sampling dates were higher in 1995 than in 1996 and 1997. Seed yields were higher in 1995 and 1996 than in 1997, averaging 290, 260 and 199 g^2/m, respectively. Harvest seed weights ranged from 3.48 g in 1996 to 4.37 g in 1995.

Flea beetle damage and agronomic attributes of *B. juncea* differed from year to year (Table 4). Flea beetle damage 22 DAS was higher in 1996 and 1997 than in 1995, averaging 77%, 71% and 46%, respectively. Seedling counts were lower in 1995 than in 1996 or 1997. Establishment averaged 20% in 1995, 30% in 1996 and 31% in 1997. Rates of cotyledon/leaf growth and dry matter content on all sampling dates were higher in 1995 than in 1996 and 1997. Seed yields were higher in 1995 than in 1996 or 1997 averaging 224, 179 and 182 g^2/m, respectively. Harvest seed weights ranged from 2.68 g in 1996 to 2.96 g in 1995.

Flea beetle damage and agronomic attributes of *B. rapa* varied significantly depending on the year (Table 4). Flea beetle damage 22 DAS was lower in 1995 than in 1996 or 1997, averaging 45%, 79% and 61%, respectively. Seedling counts 23 DAS were lowest in 1996 and highest in 1997. Establishment averaged 21% in 1995, 18% in 1996 and 24% in 1997. Rates of cotyledon/leaf growth and dry matter content on all sampling dates were higher in 1995 than in 1996 or 1997. Seed yields ranged from 50 g^2/m in 1996 to 119 g^2/m in 1997; harvest seed weights ranged from 2.16 g in 1996 to 2.60 g in 1995.

Flea beetle damage and agronomic attributes of *B. napus* varied from year to year (Table 4). Damage 22 DAS averaged 31% in 1995, 45% in 1996 and 73% in 1997. Seedling counts 16 and 23 DAS were lower in 1995 than in 1996 or 1997. Establishment averaged 25% in 1995, 37% in 1996 and 35% in 1997. Rates of cotyledon/leaf growth and dry matter content on all sampling dates were higher in 1995 than in 1996 or 1997. Seed yield was higher in 1995 than in 1996 or 1997, averaging 237, 180 and 166 g/m^2 respectively. Harvest seed weights ranged from 3.13 g in 1996 to 3.85 g in 1995.

Flea beetle damage 15 DAS varied significantly among lines of *S. alba* and four *Brassica* species (Fig. 8). In test 1, damage was lower (F=27.1, p=0.005) in *S. alba* than *B. carinata*, averaging 16% and 20%, respectively. Damage in lines of *S. alba* ranged from 12% in AC Pennant and Sabre to 28% in the low GS line. Damage in lines of *B. carinata* ranged from 18% in S-67 to 23% in C90-1215. Damage in test 2 was lower (F=34.3, p=0.0002) in *B. juncea* than *B. rapa*, averaging 25% and 35%, respectively. Damage in *B. juncea* ranged from 21% in Cutlass and Zeho to 35% in J90-4253/3. Damage in *B. rapa* ranged from 30% in Tobin to 44% in 8618 x DLY. Damage averaged 31% in lines of *B. napus*. Damage ranged from 27% in DH 12063 to 34% in Hyola 417.

Flea beetle damage 22 DAS ranged from 22% to 77% depending on the entry (Fig. 9). Damage was lower (F=29.0, p=0.0004) in *S. alba* than *B. carinata*, averaging 28% and 37% respectively. Damage in lines of *S. alba* ranged from 22% in Ochre to 43% in the low GS line. Damage in lines of *B. carinata* ranged from 35% in C90-1215 to 40% in C90-1088. Damage was lower (F=5.2, p=0.04) in *B. juncea* than *B. rapa,* averaging 65% and 69% respectively. Damage in *B. juncea* ranged from 54% in Cutlass to 71% in J90-4253/1. Damage in *B. rapa* ranged from 65% in IMP 8618 and Echo to 77% in 8618 x DLY. Damage averaged 50% in lines of *B. napus*. Damage ranged from 43% in DH 12063 to 55% in Bronowski and Hyola 417.

Seedling counts 16 DAS ranged from 35 seedlings/row to 116 seedlings/row depending on the entry (Fig. 10). Counts were higher (F=143.7, p=0.0001) in *S. alba* than *B. carinata ,* averaging 106 seedlings/row and 73 seedlings/row, respectively. Counts in lines of *S. alba* ranged from 85 seedlings/row in the low GS line to 116 seedlings/row in Ochre. Counts in lines of *B. carinata* ranged from 65 seedlings/row in S-67 to 79 seedlings/row in C90-1088. Counts were higher (F=84.6, p=0.0001) in *B. juncea* than *B. rapa,* averaging 76 seedlings/row and 62 seedlings/row, respectively. Counts in *B. juncea* ranged from 51 seedlings/row in J90-4253/3 to 102 seedlings/row in Cutlass. Counts in *B. rapa* ranged from 35 seedlings/row in 8618 x DLY to 93 seedlings/row in Echo. Counts averaged 81 seedlings/row in lines of *B. napus*. Counts ranged from 57 seedlings/row in AC H102 to 106 seedlings/row in Argentine.

Seedling counts 22 DAS ranged from 23 seedlings/row to 119 seedlings/row depending on the entry (Fig. 11). Counts were higher (F=285.1,p=0.0001) in *S. alba* than *B. carinata*, averaging 100 seedlings/row and 60 seedlings/row respectively. Seedling establishment in *S. alba* ranged from 35% in the low GS line to 59% in Ochre. Establishment in *B. carinata* ranged from 26% in S-67 to 35% in C90-1088. Seedling counts were higher (F=21.3, p=0.001) in *B. juncea* than *B. rapa,* averaging 55 seedlings/row and 42 seedlings/row, respectively. Establishment in *B. juncea* ranged from 16% in J90-4253/1 to 38% in AC Vulcan. Establishment in *B. rapa* ranged from 12% in 8618 x DLY to 31% in Echo. Seedling counts averaged 65 seedlings/row in lines of *B. napus*. Establishment ranged from 25% in AC H102 and Bronowski to 45% in Argentine.

Rates of cotyledon/leaf growth 14 to 21 DAS varied significantly among species and lines within species (Fig. 12). Growth rates were higher (F=431.2, p=0.0001) in *S. alba* than *B. carinata*, averaging 111 mm^2/day and 24 mm^2/day, respectively. Growth rates in *S. alba* ranged from 58 mm^2/day in the low GS line to 155 mm^2/day in Ochre. Growth rates in *B. carinata* ranged from 18 mm^2/day in C90-1088 to 31 mm^2/day in Dodolla. Growth rates were higher (F=9.7, p=0.01) in *B. juncea* than *B. rapa*, averaging 33 mm^2/day and 28 mm^2/day, respectively. Growth rates in *B. juncea* ranged from 24 mm^2/day in J90-4253/3 to 46 mm^2/day in Cutlass. Growth rates in *B. rapa* ranged from 15 mm^2/day in 8618 x DLY to 40 mm^2/day in Tobin. Rates of cotyledon/leaf growth averaged 12 mm^2/day in lines of *B. napus*. Growth rates ranged from 8 mm^2/day in Hyola 417 and Bronowski to 17 mm^2/day in Argentine.

Dry matter content 14 DAS ranged from 3.8 mg to 17.7 mg depending on the entry (Fig. 13). Dry matter was higher (F=594.1, p=0.0001) in *S. alba* than *B. carinata,* averaging 15.4 mg and 6.7 mg, respectively. Dry matter in *S. alba* ranged from 14 mg in the low GS line to 18 mg in Ochre. Dry matter in *B. carinata* ranged from 6.3 mg in C90-1088 to 7.3 mg in Dodolla. Dry matter was higher (F=95.9, p=0.0001) in *B. juncea* than *B. rapa.* Values in *B. juncea* ranged from 5.5 mg in J90-4253/1 to 7.3 mg in Cutlass. Values in *B. rapa* ranged from 4.1 mg in 8618 x DLY to 5.4 mg in Echo. Dry matter averaged 5.1 mg in lines of *B. napus*. Values ranged from 3.8 mg in Bronowski to 5.6 mg in Argentine and Hyola 417.

Dry matter 21 DAS ranged from 10 mg to 90 mg depending on the entry (Fig. 14). Dry matter content was higher in *S. alba* than *B. carinata*, averaging 72 mg and 20 mg, respectively. Values in *S. alba* ranged from 48 mg in the low GS line to 91 mg in AC Pennant. Values in *B. carinata* ranged from 18 mg in C90-1088 to 21 mg in Dodolla. Dry matter content was higher (F=8.5, p=0.02) in *B. juncea* than *B. rapa,* averaging 24 mg and 21 mg, respectively. Values in *B. juncea* ranged from 19 mg in J90-4253/1 to 30 mg in Cutlass. Values in *B. rapa* ranged from 14 mg in 8618 x DLY to 32 mg in Tobin. Dry matter averaged 14 mg in lines of *B. napus*. Values ranged from 10 mg in Bronowski to 17 mg in Argentine.

Dry matter 28 DAS ranged from 27 mg to 403 mg depending on the entry (Fig. 15). Values were higher (F=456.9, p=0.0001) in *S. alba* than *B. carinata*, averaging 311 mg and 65 mg, respectively. Values in *S. alba* ranged from 142 mg in the low GS line to 403 mg in Ochre. Values in *B. carinata* ranged from 50 mg in C90-1088 to 81 mg in Dodolla. Dry matter was higher (F=40.8, p=0.0001) in *B. juncea* than *B. rapa*, averaging 86 mg and 65 mg, respectively. Values in *B. juncea* ranged from 66 mg in J90-4253/1 to 108 mg in Cutlass; values in *B. rapa* ranged from 40 mg in 8618 x DLY to 81 mg in Tobin. Dry matter averaged 40 mg in lines of *B. napus*. Values ranged from 27 mg in Bronowski to 47 mg in Argentine.

Dry matter content 35 DAS ranged from 91 mg to 1811 mg depending on the entry (Fig. 16). Dry matter was higher (F=561.3, p=0.0001) in *S. alba* than *B. carinata*, averaging 1393 mg and 292 mg, respectively. Values in *S. alba* ranged from 866 mg in the low GS line to 1811 mg in Ochre; values in *B. carinata* ranged from 223 mg in C90-1088 to 355 mg in Dodolla. Dry matter was higher (F=101.9, p=0.0001) in *B. juncea* than *B. rapa*, averaging 469 mg and 287 mg, respectively. Values in *B. juncea* ranged from 285 mg in J90-4253/1 to 627 mg in Cutlass. Values in *B. rapa* ranged from 140 mg in 8618 x DLY to 416 mg in Echo. Dry matter averaged 166 mg in lines of *B. napus*. Values ranged from 91 mg in Bronowski to 194 mg in Topas and AC H102.

Seed yields ranged from 37 g/m^2 to 282 g/m^2 depending on the entry (Fig. 17). Seed yields were higher (F=462.5, p=0.0001) in *B. carinata* than *S. alba*, averaging 252 g/m^2 and 201 g/m^2, respectively. Yields in *S. alba* ranged from 162 g/m^2 in the low GS line to 231 g in AC Pennant. Yields in *B. carinata* ranged from 225 g/m^2 in C90-1088 to 282 g/m^2 in Dodolla. Yields were higher (F=273.8, p=0.0001) in *B. juncea* than *B. rapa*, averaging 195 g/m^2 and 89 g/m^2, respectively. Yields in *B. juncea* ranged from 129 g/m^2 in J90-4253/1 to 239 g/m^2 in J2741. Yields in *B. rapa* ranged from 37 g/m^2 in 8618 x DLY to 136 g/m^2 in Echo. Yields averaged 194 g/m^2 in lines of *B. napus*. Yields ranged from 117 g/m^2 in Bronowski to 232 g/m^2 in Cyclone.

Harvest seed weights ranged from 2.17 g to 6.67 g depending on the entry (Fig. 18). Seed weights were higher (F=462.5, p=0.0001) in *S. alba* than *B. carinata*, averaging 6.22 and 3.99 g, respectively. Seed weights in *S. alba* ranged from 5.93 in SVHO to 6.67 g in Sabre. Values in *B. carinata* ranged from 3.77 g in S-67 to 4.3 g in C90-1215. Seed weights were higher (F=197.2, p=0.0001) in *B. juncea* than *B. rapa*, averaging 2.78 g and 2.33 g, respectively. Seed weights in *B. juncea* ranged from 2.39 g in J90-4253/1 to 3.21 g in J2741. Weights in *B. rapa* ranged from 2.17 g in Comp H to 2.6 g in ACS C5. Seed weights averaged 3.53 g in lines of *B. napus*. Weights ranged from 2.55 g in Bronowski to 4.06 g in DH 12063.

Discussion

Temperatures are known to have a substantial effect on establishment and growth of *Brassica species* (Thomas 1994). In growth chamber experiments, seedling counts differed significantly among *Sinapis* and *Brassica species*. At 7^{0}C, seedling counts 13 DAP averaged 9.5, 6.1, 7.7, 7.9 and 9.0 seedlings/row in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*, respectively. In terms of seedling establishment, results indicated that lines of *S. alba* and *B. napus* were the most tolerant to cool temperatures whereas lines of *B. carinata* were the least tolerant to cool temperatures. When the experiment was repeated at 12^{0}C, seedling counts 7 DAP averaged 9.4, 7.8, 9.1, 9.3 and 8.8 seedlings/row in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*, respectively. Higher temperatures improved seedling counts in *B. carinata, B. juncea* and *B. rapa* but had little or no effect on seedling counts in *S. alba* and *B. napus*.

Temperatures also affected seedling growth in *Sinapis* and *Brassica* species. At 7^{0}C, rates of cotyledon/leaf growth 15-29 DAP averaged 72, 29, 30, 29 and 26 mm^2/day in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*, respectively. Growth rates were 2.4-2.8 times higher in *S. alba* than in the four *Brassica* species. Lines of *B. napus* had the lowest rate of cotyledon/leaf growth at 7^{0}C. When experiments were repeated at 12^{0}C growth rates improved 3- to 6-fold depending the species. Growth rates 11-18 DAP averaged 327, 176, 156, 168 and 89 mm^2/day in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus,* respectively. Growth rates were 1.9-3.7 times higher in *S. alba* than in *Brassica* species. Lines of *B. napus* had the lowest rate of cotyledon/leaf growth at 12^{0}C. Dry matter accumulation in *Sinapis* and *Brassica* species also varied with temperature. Dry matter accumulation in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus* averaged 3.7, 1.9, 1.7, 1.6 and 1.9 mg/day, respectively, at 7°C and 10.1, 6.4, 4.4, 4.6 and 3.4 mg/day, respectively at 12°C. Depending on the species, dry matter accumulation was 1.8-3.4 times higher at 12°C than at 7°C. At each temperature, dry matter accumulation was 1.4-2.3 times higher in *S. alba* than in *Brassica* species. *B. juncea* and *B. rapa* had the lowest dry matter accumulation at 7°C whereas *B. napus* had the lowest dry matter accumulation at 12°C.

In growth chamber experiments, seedling counts and growth rates also differed among lines within species. At 7°C and 12°C, experimental low glucosinolate lines of *S. alba* (low GS line), *B. juncea* (J90-4253/1), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski) usually had the lowest seedling counts, lowest rate of cotyledon/leaf growth and lowest rate of dry matter accumulation. These lines were judged least vigourous and least tolerant to low temperatures. Based on seedling counts, rates of cotyledon/leaf growth and dry matter accumulation at 7°C and 12°C, AC Pennant and Ochre were judged the most vigourous lines in *S. alba*, C90-1088 and Dodalla the most vigourous lines in *B. carinata* and Cutlass, Zeho and AC Vulcan the most vigourous lines in *B. juncea*. Echo, Tobin and ACSC5 were the most vigourous lines in *B. rapa* whereas Argentine, Midas, Westar, AC H102 and ACS N14 were the most vigourous lines in *B. napus*.

Antixenosis or non-perference to feeding damage has been shown to be an important factor in the resistance of *Brassica* and *Sinapis* species to flea beetles. In feeding bioassays conducted at the cotyledon stage, lines of *S. alba* and *B. carinata* had moderate to high antixenosis whereas lines of *B. juncea, B. rapa* and *B. napus* had little or no antixenosis (Bodnaryk and Lamb 1991, Palaniswamy *et al.* 1992, 1997, Brandt and Lamb 1994). In the current study, flea beetle damage to the cotyledons 22 DAS ranged from 22% to 77% depending on the entry. Damage differed among species averaging 28% in *S. alba*, 37% in *B. carinata*, 65% in *B. juncea*, 69% in *B. rapa* and 50% in *B. napus*. Results indicated that lines of *S. alba* and *B. carinata* had the highest antixenosis whereas lines of *B. juncea* and *B. rapa* had the lowest antixenosis.

Flea beetle damage also differed among lines of *Sinapis* and *Brassica* species. Damage in *S. alba* ranged from 22% in Ochre and AC Pennant to 43% in the experimental low GS line. Differences in antixenosis among lines of *S. alba* may relate to glucosinolates in the seed. Hydroxybenzyl glucosinolate or sinalbin has been shown to inhibit feeding in flea beetles at concentrations found in cotyledons of newly emerged seedlings of Ochre (Bodnaryk 1991). Concentrations of hydroxybenzyl glucosinolate were substantially lower in seeds of the experimental low GS line (5μmoles/g) than in seeds of AC Pennant (147 μmoles/g) and Ochre (156 μmoles/g). Therefore, lower antixenosis in the low GS line may be partly due to reduced concentrations of hydroxybenzyl glucosinolate in the seed and young cotyledons. Damage was less variable among lines of *B. carinata* ranging from 35% in C90-1215 to 40% in C90-1088. Concentrations of allyl isothiocyanate or sinigrin, the major glucosinolate in seeds of *B. carinata*, averaged 67μmoles/g in C90-1215 and 90 μmoles/g in C90-1088. Variation in damage was greater among lines of *B. juncea*, ranging from 54% to 70% depending on the entry. Cutlass was the most resistant line whereas

J90-4253/3 was the least resistant line. Differences in resistance appeared related to glucosinolates in the seed. Concentrations of allyl isothiocyanate or sinigrin were substantially lower in seeds of J90-4253/1 (1μmole/g) than in seeds of Cutlass (107μmoles/g). However, resistance in Cutlass was probably due to factors other than glucosinolates. Flea beetle damage was 10% lower in Cutlass than in AC Vulcan which had higher concentrations of sinigrin in the seed (116μmoles/g). Damage in lines of *B. rapa* ranged from 65% to 77%. Echo and IMP 8616 had the least damage and highest resistance whereas 8618 x DLY, an experimental double low alkenyl line, had the highest damage and least resistance. Concentrations of glucosinolate in Echo (67μmoles/g), IMP 8618 (5μmoles/g) and 8618 x DLY (<2μmoles/g) indicated that resistance in lines of *B. rapa* was not associated with glucosinolate concentrations. Damage in lines of *B. napus* ranged from 43% to 52%. DH 12063, Cresor, Topas and AC H102 had the least damage and highest antixenosis whereas Bronowski and Hyola 417 had the highest damage and lowest antixenosis. Concentrations of glucosinolates in DH 12063 (64μmoles/g), Cresor (77μmoles/g), Topas (15μmoles/g) and AC H102 (11μmoles/g) indicated that resistance in *B. napus* was not correlated with glucosinolate levels in the seed.

Seedling survival, which has been used to evaluate the susceptibility and tolerance of seedlings to flea beetle damage (Lamb 1988), varied significantly among species. Counts 23 DAS averaged 100, 60, 55, 42 and 65 seedlings/row in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*, respectively. Results indicated that seedlings of *S. alba* were the most tolerant to flea beetle damage. *B. juncea* was more tolerant to damage than *B. rapa* whereas *B. napus* was more tolerant to damage than *B. carinata*. Seedling counts also differed among lines within species. Experimental low GS lines of *S. alba* (low GS line), *B. juncea* (J90-4253/1), *B. rapa* (8618 x DLY) and *B. napus* (Bronowski) had the lowest seedling counts and were judged the least tolerant to flea beetle damage. Conversely, Ochre was the most tolerant line in *S. alba*; C90-1088 and Dodolla the most tolerant lines in *B. carinata*; and AC Vulcan and Cutlass the most tolerant lines in *B. juncea*. Echo was the most tolerant line in *B. rapa* whereas Argentine, Midas and ACS N14 were the most tolerant lines in *B. napus*.

Tolerance to feeding damage has been shown to be an important factor in the resistance of *Sinapis* and *Brassica* species to flea beetles. Evaluation of growth rates, dry matter content or seed yield indicated that lines of *S. alba* and *B. juncea* were more tolerant to flea beetles than lines of *B. rapa* and *B. napus* (Putnam 1977, Bodnaryk and Lamb 1991, Brandt and Lamb 1994). Brandt and Lamb (1994) concluded that the level of tolerance is species specific, growth-stage specific and not related to growth rates of the species. In the present study, rates of cotyledon/leaf growth 14-21 DAS averaged 111, 24, 33, 28 and 12 mm^2/day in *S. alba, B. carinata, B. juncea, B. rapa* and *B. napus*, respectively. Growth rates indicated that *S. alba* was the most vigourous and tolerant to flea beetle damage whereas *B. napus* was the least vigourous and least tolerant to flea beetle damage. Dry matter content 14, 21, 28 and 35 DAS also differed among species. On each sampling date, dry matter was highest in *S. alba* and usually lowest in *B. napus*. Values confirmed that *S. alba* was the most vigourous and tolerant to flea beetle damage whereas *B. napus* was the least vigourous and least tolerant to damage. However, seed yields were similar in *S. alba, B. juncea* and *B. napus*. Yields indicated that *B. juncea* and *B. napus* were able to compensate for damage later in development. *B. carinata* had the highest seed yield indicating that plants were also able to compensate for flea beetle damage during reproductive growth.

Growth attributes also varied among lines of *Sinapis* and *Brassica species*. Experimental low glucosinolate lines of *S. alba, B. juncea, B. rapa* and *B. napus* had the lowest rates of cotyledon/leaf growth 14-21 DAS, lowest dry matter content 14, 21, 28 and 35 DAS and lowest seed yields. Results indicated that these lines had the least vigour, lowest tolerance to flea beetles and poorest agronomic attributes. Based on growth rates, dry matter content and seed yield, Ochre and AC Pennant had the highest vigour, highest tolerance to flea beetle damage and best agronomic attributes in lines of *S. alba*. Dodolla had the highest vigour, highest flea beetle tolerance and best agronomic attributes in *B. carinata*. Cutlass and J2741 had the best attributes in *B. juncea* whereas Echo and Tobin had the best attributes in *B. rapa*. In *B. napus*, Argentine, Topas and AC H102 had the highest vigour and tolerance to flea beetle damage whereas Cyclone, Topas, AC H102 and Argentine had the highest seed yields. In each species, lines with superior seedling establishment, growth rate and tolerance to flea beetles usually had the highest seed yield.

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Table 1. Seed weights and seed-size distributions of selected lines of *Sinapis alba*, *Brassica carinata* and *B. juncea*.

		1000-seed	Percentage of seedlot by weight						
Species	Line	weight (g)	<1.4mm	1.4-1.6mm	1.6-1.8mm	1.8-2.0mm	2.0-2.2mm	2.2-2.4mm	2.4-2.6mm
S. alba	Ochre	4.90	-	0.8	3.9	51.9	14.3	24.5	4.6
	AC Pennant	5.06	-	0.8	3.3	47.1	15.2	29.6	4.0
	Sabre	5.15	0.1	0.8	2.5	38.4	13.7	37.4	7.0
	SV high oil	5.17	0.1	1.0	2.7	33.0	13.3	38.1	11.8
	Low GS	5.46	0.1	0.9	2.9	49.1	13.6	27.6	5.8
B. carinata	C90-1215	3.69	0.1	5.7	13.7	60.9	9.1	9.2	1.3
	S-67	3.81	0.3	9.3	17.0	60.0	6.8	5.5	1.1
	Dodolla	3.89	0.1	6.8	12.3	60.0	9.0	10.4	1.5
	C90-1088	3.92	0.1	5.4	16.7	66.2	6.7	4.8	0.2
B. juncea	C. brown	2.23	3.9	49.7	37.0	9.4	-	-	-
	ZEM-87-1	2.28	5.2	55.1	31.9	7.4	0.3	0.1	-
	J90-4253/1	2.34	2.4	33.3	51.8	12.4	0.1	-	-
	AC Vulcan	2.37	1.7	51.4	40.0	6.5	0.2	0.1	-
	Cutlass	2.39	2.6	48.3	36.2	12.4	0.4	0.1	-
	J90-4253/3	2.50	1.5	28.2	56.8	13.5	0.1	-	-
	J90-2741	2.62	1.9	23.2	31.8	41.2	1.3	0.6	-
	Zeho	2.78	1.6	28.4	32.3	36.0	1.2	0.6	-

Table 2. Seed weights and seed-size distributions of selected lines of B. rapa and B. napus.

		1000-seed	Percentage of seedlot by weight						
Species	Line	weight (g)	<1.4mm	1.4-1.6mm	1.6-1.8mm	1.8-2.0mm	2.0-2.2mm	2.2-2.4mm	2.4-2.6mm
B. rapa	IMP 8618	1.73	14.2	64.8	17.6	3.4	-	-	-
	Comp H	1.77	19.4	67.4	10.1	3.0	0.1	-	-
	8618 DLY	1.93	13.0	61.7	20.1	5.1	0.1	-	-
	Echo	2.05	8.3	54.3	26.4	11.0	0.1	-	-
	Tobin	2.26	7.1	48.2	31.5	12.9	0.2	0.1	-
	ACS-C5	2.37	2.4	36.3	34.5	26.0	0.6	0.1	-
B. napus	Bronowski	2.39	1.6	21.1	34.4	42.7	0.2	0.1	-
	Argentine	2.62	0.9	19.8	29.6	47.2	1.5	0.9	-
	Profit	2.70	1.2	16.8	20.8	52.4	4.3	4.4	0.1
	AC Elect	2.89	0.6	13.1	21.5	60.6	2.8	1.5	-
	Topas	2.93	0.3	8.7	18.2	66.1	4.3	2.4	-
	Westar	3.03	0.5	12.3	19.0	52.6	7.3	8.0	0.3
	Midas	3.04	0.1	9.1	21.0	63.5	4.0	2.3	-
	Cyclone	3.14	0.2	3.7	11.8	78.0	4.2	2.1	-
	DH 12063	3.56	0.1	5.8	11.4	65.9	9.7	6.8	0.3
	Cresor	3.58	0.1	5.5	15.4	59.7	8.8	9.6	0.9
	ACS N14	3.75	-	1.4	5.5	59.0	16.6	17.0	0.5
	Hyola 417	4.48	-	2.8	6.3	37.2	34.7	18.0	1.0
	AC H102	4.84	-	0.8	1.7	16.0	40.2	40.3	1.1

Table 3. Flea beetle damage and agronomic attributes of S. alba and B. carinata in 1995, 1996 and 1997.[†]

		Damage (% eaten)		Seedlings/ row		Growth rate	Dry matter content (mg)				Seed yield	Harvested seed
Species	Year	15 DAS	22 DAS	16 DAS	23 DAS	(mm^2/ day)	14 DAS	21 DAS	28 DAS	35 DAS	(g/m^2)	weight (g)
S. alba	1995	13a	16a	59.3a	57.1a	146.2b	19.4b	95.7b	463.4c	2226.7b	213.4b	6.73b
	1996	23a	27b	126.0b	117.0b	148.1b	19.1b	90.2b	278.0b	1088.7a	223.7b	5.90a
	1997	13a	42c	132.5b	124.6b	38.7a	7.8a	28.7a	192.7a	864.0a	166.6a	6.04a
	LSD	**13**	**5**	**13.0**	**11.6**	**20.3**	**2.3**	**14.8**	**57.1**	**298.4**	**21.9**	**0.45**
B. carinata	1995	16a	19a	41.1a	42.3a	40.3a	9.0c	30.7c	129.1b	632.4b	290.3b	4.37b
	1996	39b	39b	95.9c	65.4b	23.1b	7.0b	19.3b	25.2a	86.5a	265.1b	3.48a
	1997	6a	54c	80.4b	74.0b	9.7a	3.9a	11.3a	42.1a	158.0a	199.2a	4.13b
	LSD	**16**	**6**	**12.7**	**13.6**	**9.3**	**0.7**	**4.8**	**19.1**	**118.6**	**32.9**	**0.28**

[†] similar means within species followed by the same letter are not significantly different (LSD, p=0.05).

Table 4. Flea beetle damage and agronomic attributes of B. juncea, B. rapa and B. napus.[†]

		Damage (% eaten)		Seedlings/ row		Growth rate	Dry matter content (mg)				Seed yield	Harvested seed
Species	Year	15 DAS	22 DAS	16 DAS	23 DAS	(mm^2/ day)	14 DAS	21 DAS	28 DAS	35 DAS	(g/m^2)	weight (g)
B. juncea	1995	24b	46a	45.5a	41.1a	52.1c	8.7c	38.3c	172.6b	1054.7b	224.2b	2.96c
	1996	35c	77b	99.8c	60.6b	32.6b	6.8b	22.1b	36.8a	154.9a	178.9a	2.60a
	1997	15a	71b	81.8b	61.8b	13.6a	3.4a	11.0a	47.8a	198.7a	182.4a	2.78b
	LSD	**8**	**7**	**5.5**	**8.3**	**9.0**	**0.6**	**4.7**	**22.8**	**125.6**	**28.8**	**0.03**
B. rapa	1995	39b	47a	44.6a	41.8ab	47.4c	6.7c	36.3b	134.6b	620.5b	97.8b	2.60b
	1996	39b	84b	79.1c	37.0a	24.0b	5.5b	16.6a	25.0a	89.2a	49.5a	2.16a
	1997	27a	77b	61.3b	48.5b	11.3a	2.5a	9.0a	34.4a	150.6a	118.5c	2.24a
	LSD	**12**	**8**	**7.3**	**8.5**	**8.6**	**0.9**	**8.2**	**16.7**	**97.7**	**15.4**	**0.10**
B. napus	1995	21b	31a	52.1a	50.3a	18.6c	6.1b	19.7c	75.8b	318.1b	237.2b	3.85c
	1996	56c	45b	107.4c	74.7b	10.7b	6.2b	14.6b	22.6a	77.6a	179.5a	3.13c
	1997	16a	73c	82.8b	69.5b	6.1a	3.0a	7.3a	22.5a	102.7a	165.5a	3.63b
	LSD	**5**	**5**	**5.8**	**8.3**	**1.9**	**0.3**	**2.3**	**7.8**	**33.8**	**21.9**	**0.08**

[†] similar means within species followed by the same letter are not significantly different (LSD, p=0.05).

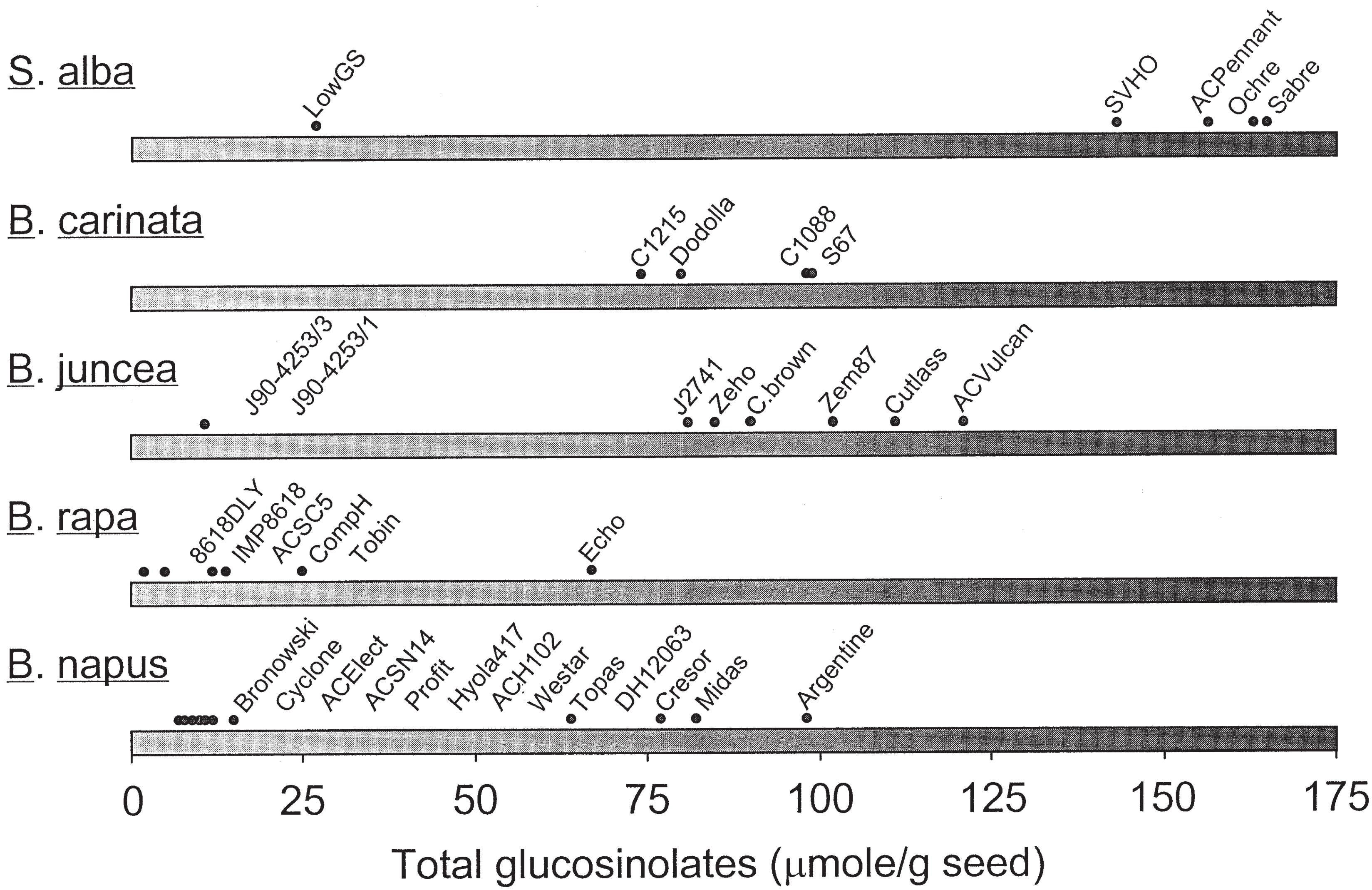

Figure 1. Concentration of glucosinolates in seed of selected lines of <u>Sinapis alba</u> and four <u>Brassica</u> species.

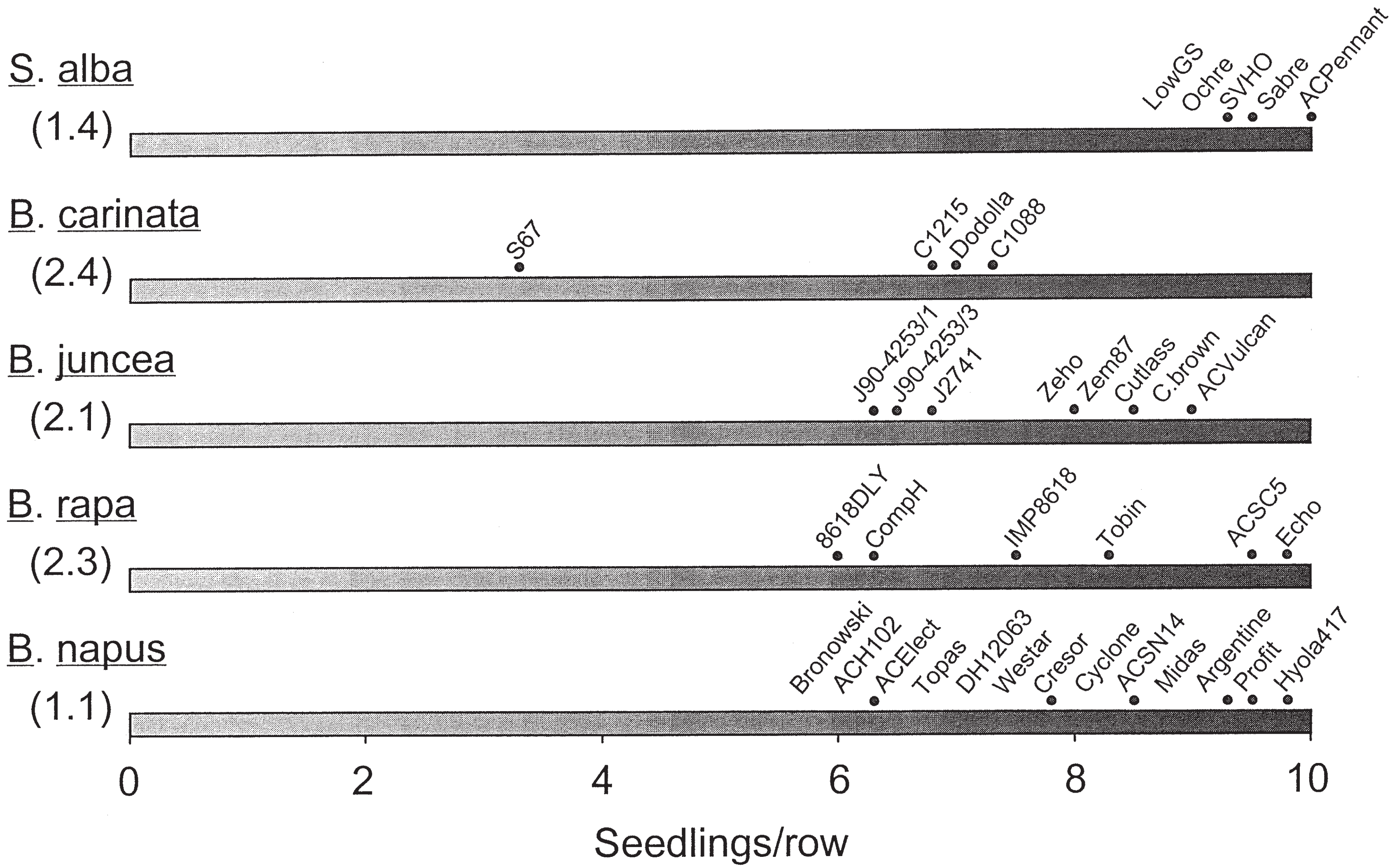

Fig. 2. Seedlings per row in selected lines of S. alba and four Brassica species grown at 7° C and 16L/8D photoperiod. Counts taken 13 days after planting (LSD in parenthesis).

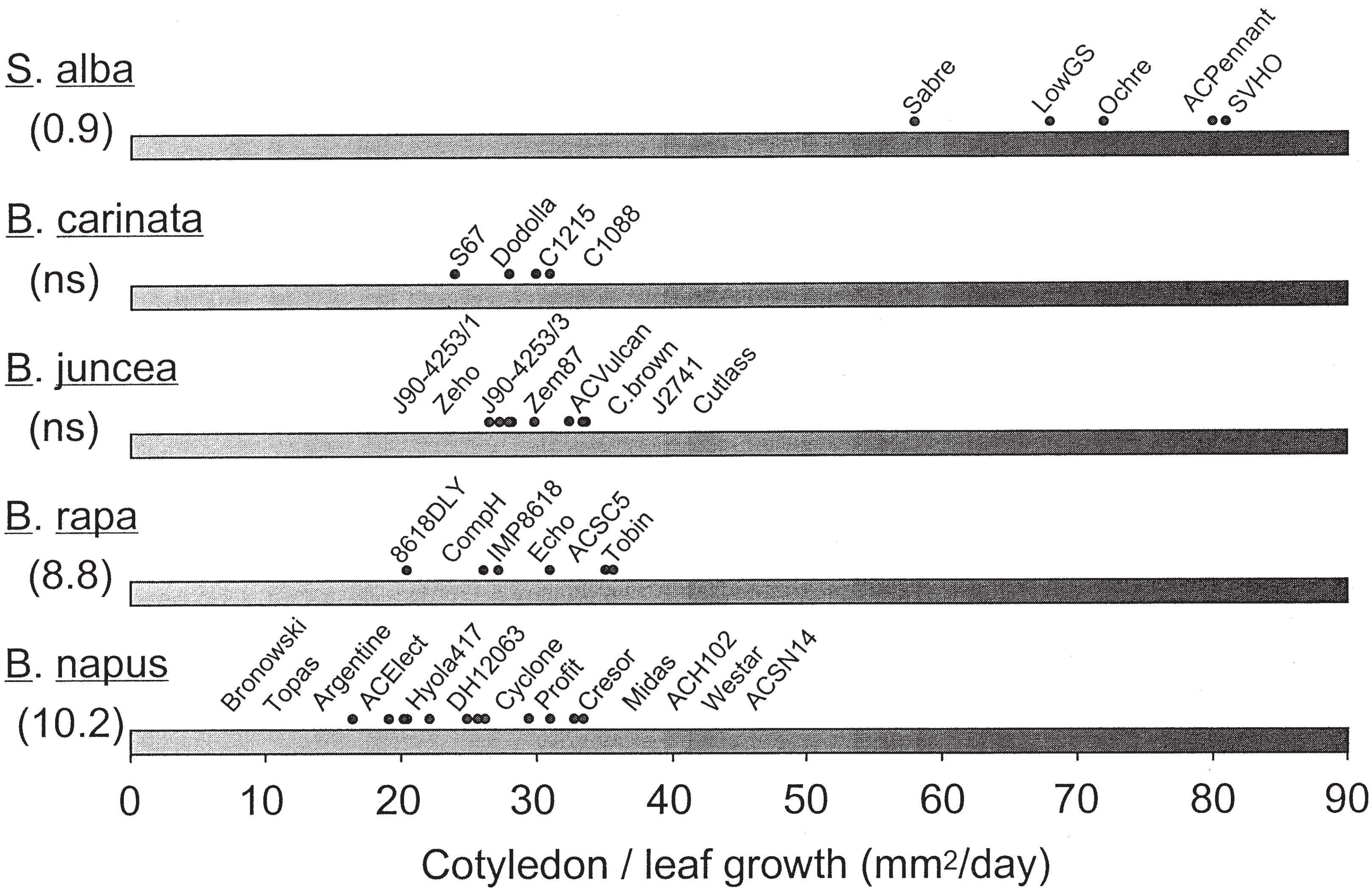

Fig. 3. Rate of cotyledon/leaf growth of selected lines of S. alba and four Brassica species grown at 7° C and 16L/8D photoperiod. Measurements taken 15 and 29 days after planting.

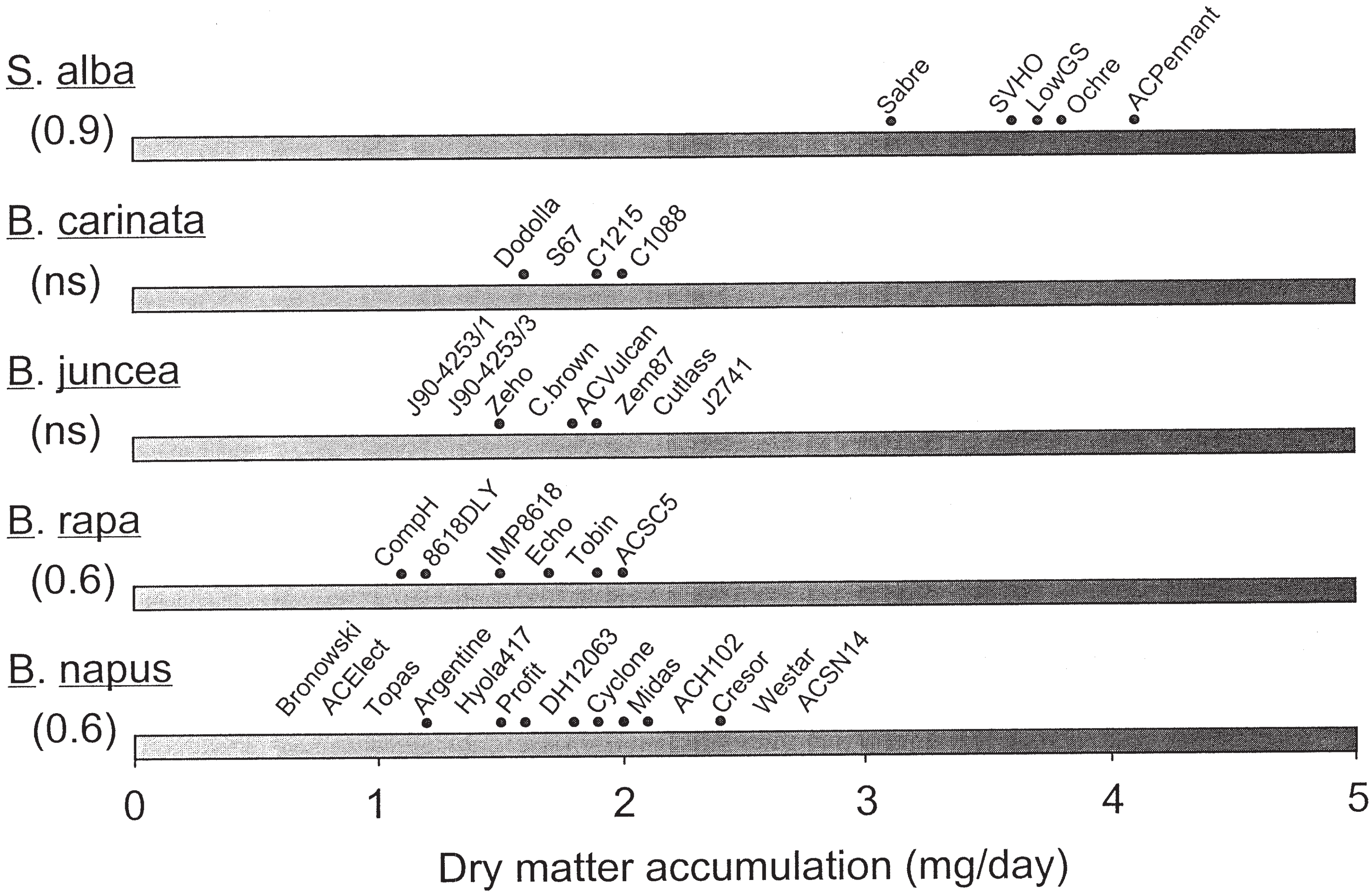

Fig. 4. Rate of dry matter accumulation in selected lines of S. alba and four Brassica species grown at 7° C and 16L/8D photoperiod. Measurements taken 15 and 29 days after planting.

Fig. 5. Seedlings per row in selected lines of S. alba and four Brassica species grown at 12° C and 16L/8D photoperiod. Counts taken 7 days after planting.

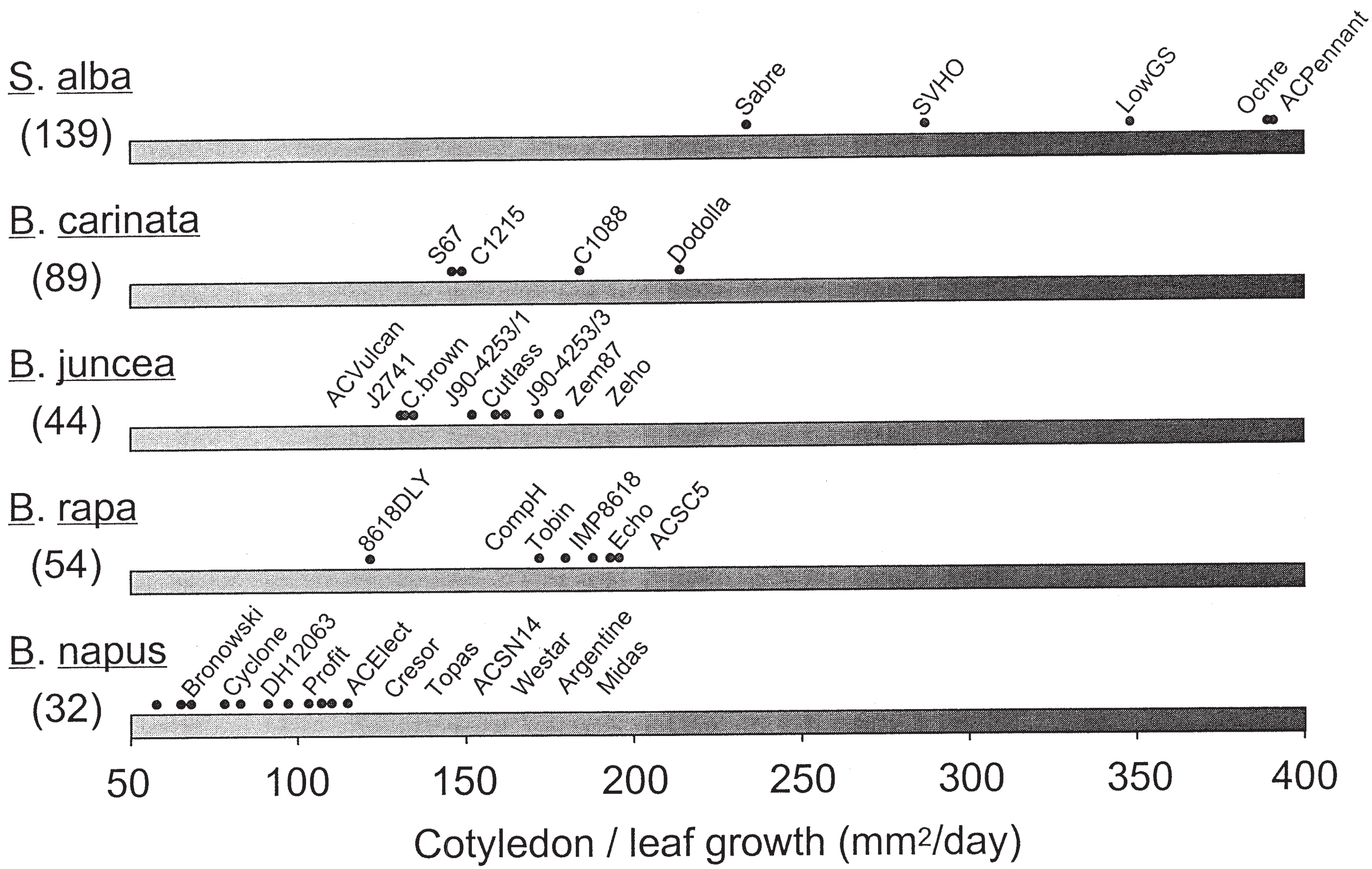

Fig. 6. Rate of cotyledon/leaf growth of selected lines of S. alba and four Brassica species grown at 12° C and 16L/8D photoperiod. Measurements taken 11 and 18 days after planting.

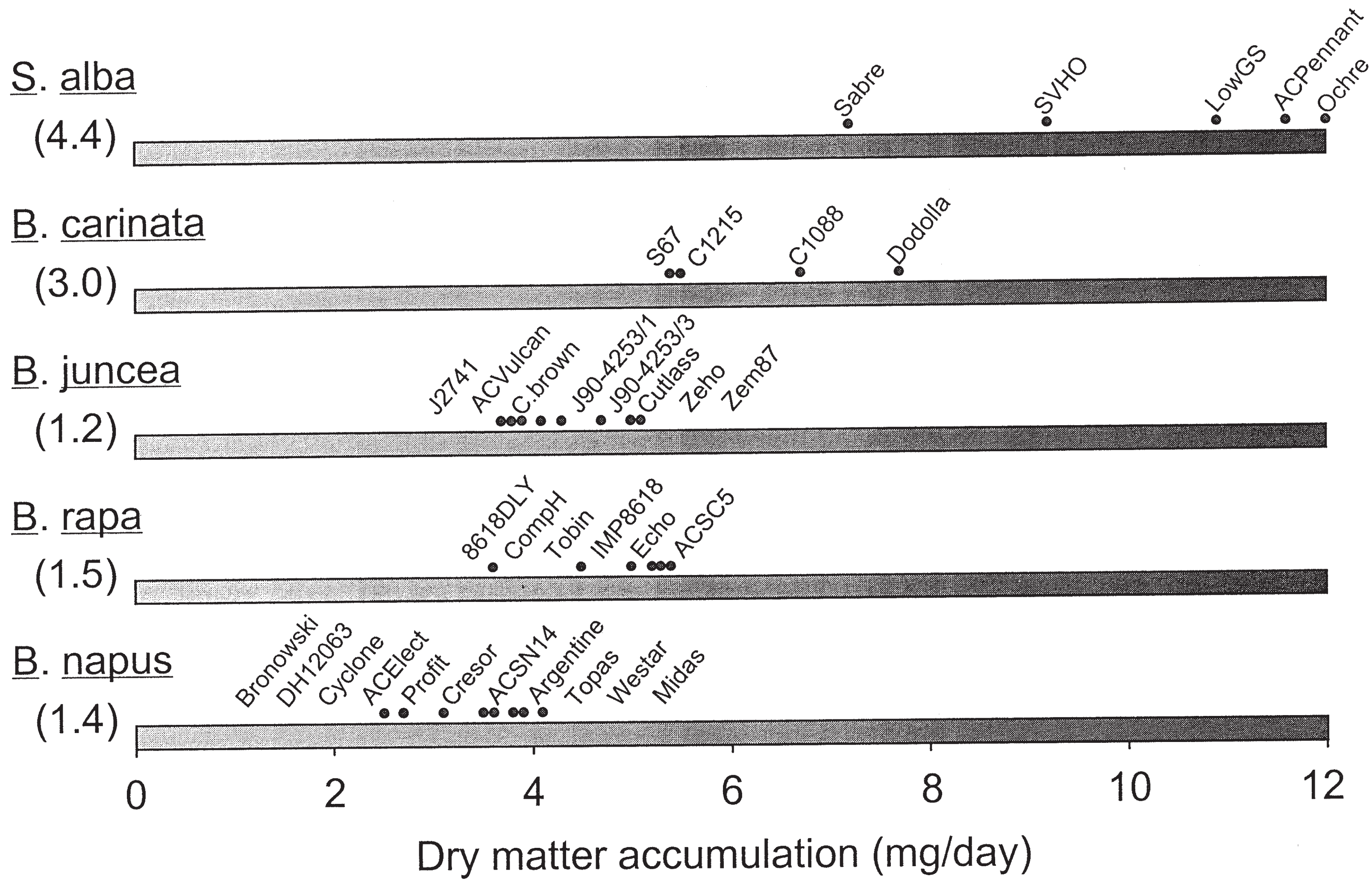

Fig. 7. Rate of dry matter accumulation in selected lines of S. alba and four Brassica species grown at 12º C and 16L/8D photoperiod. Measurements taken 11 and 18 days after planting.

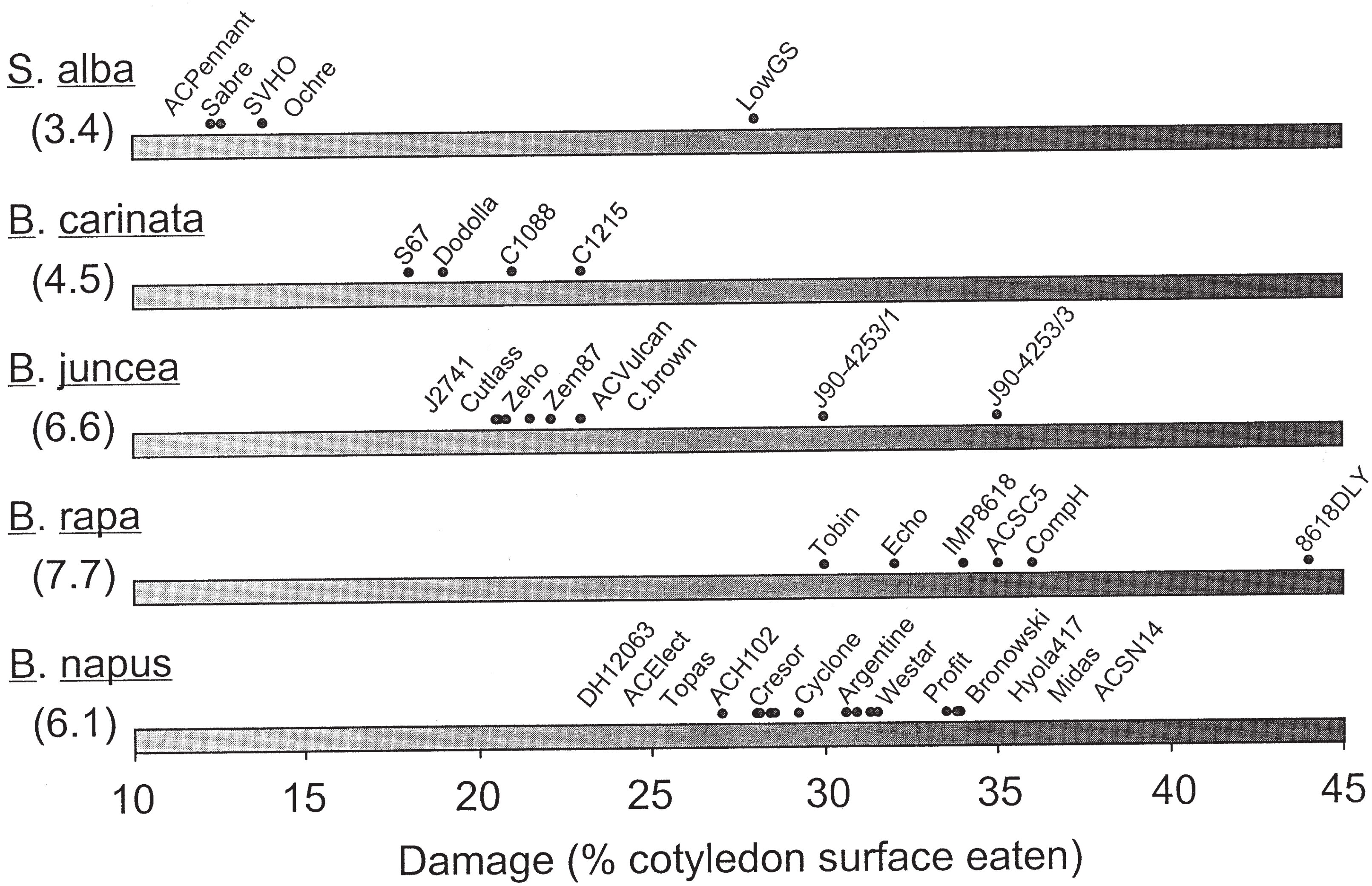

Fig. 8. Flea beetle damage to selected lines of S. alba and four Brassica species in 1995-1997. Damage assessed 15 days after seeding.

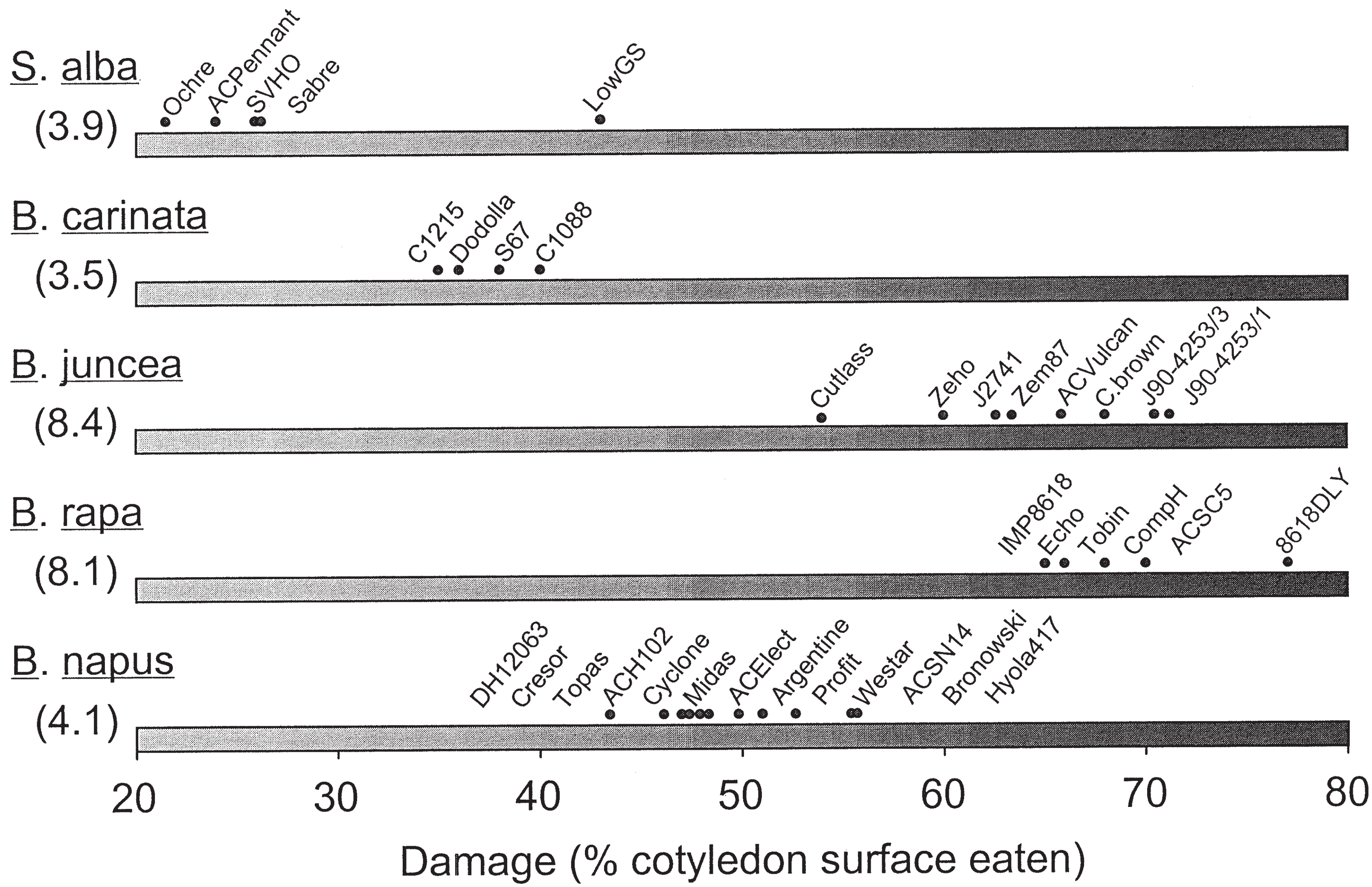

Fig. 9. Flea beetle damage to selected lines of S. alba and four Brassica species in 1995-1997. Damage assessed 22 days after seeding.

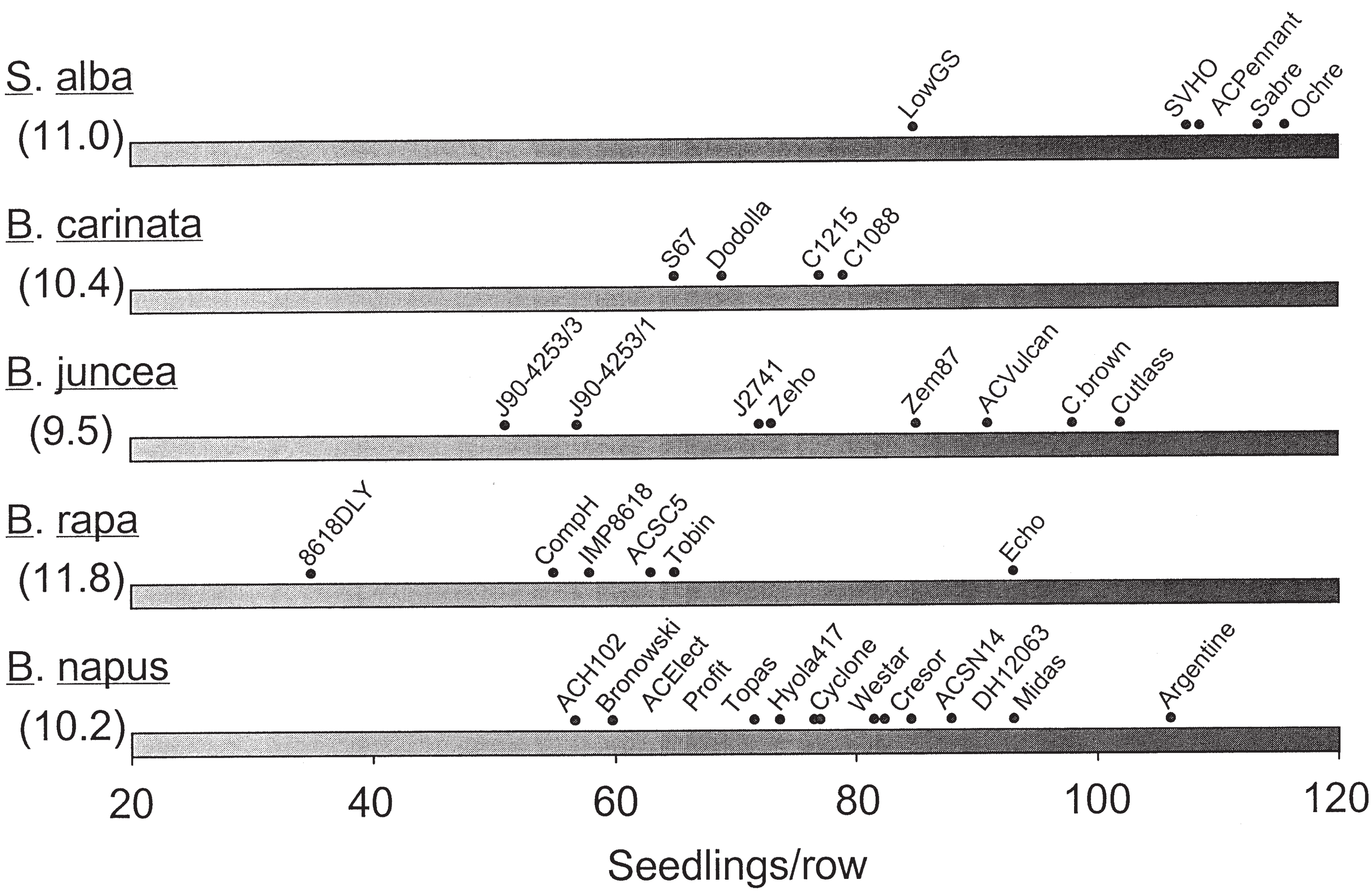

Fig. 10. Seedlings per row in selected lines of S. alba and four Brassica species in 1995-1997. Counts taken 16 days after seeding.

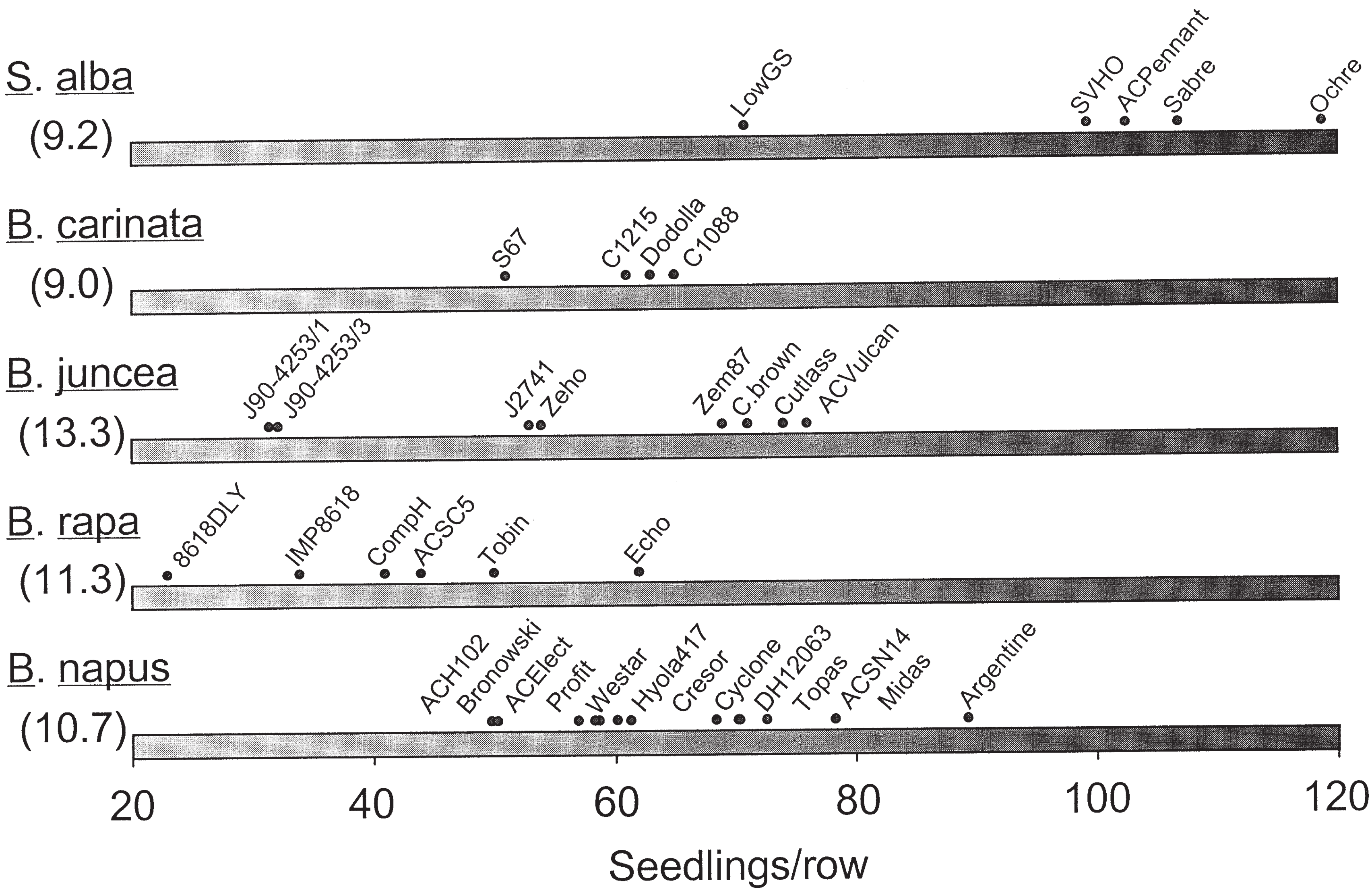

Fig. 11. Seedlings per row in selected lines of S. alba and four Brassica species in 1995-1997. Counts taken 23 days after seeding.

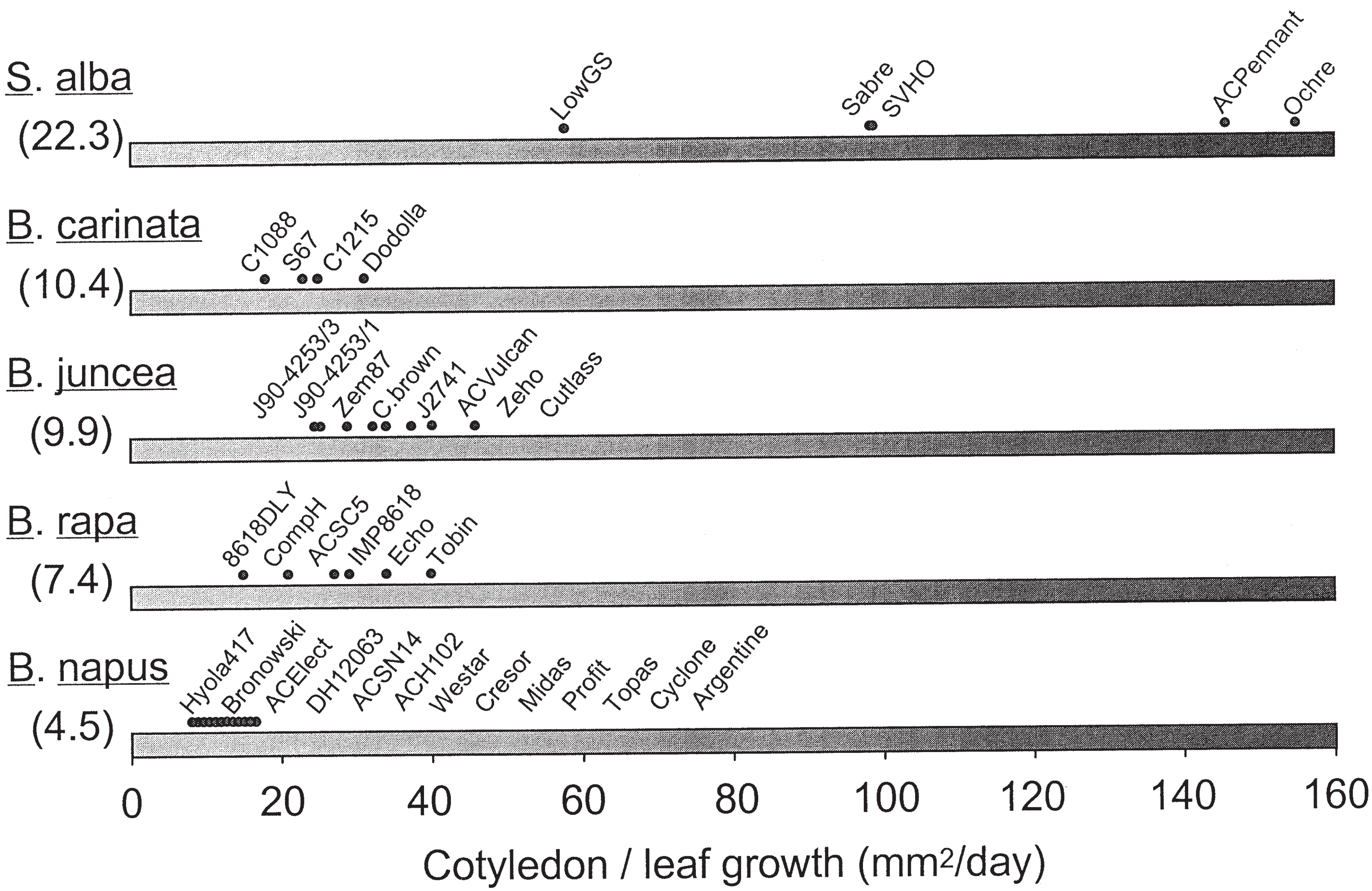

Fig. 12. Rate of cotyledon/leaf growth in selected lines of S. alba and four Brassica species in 1995-1997. Measurements taken 14 and 21 days after seeding.

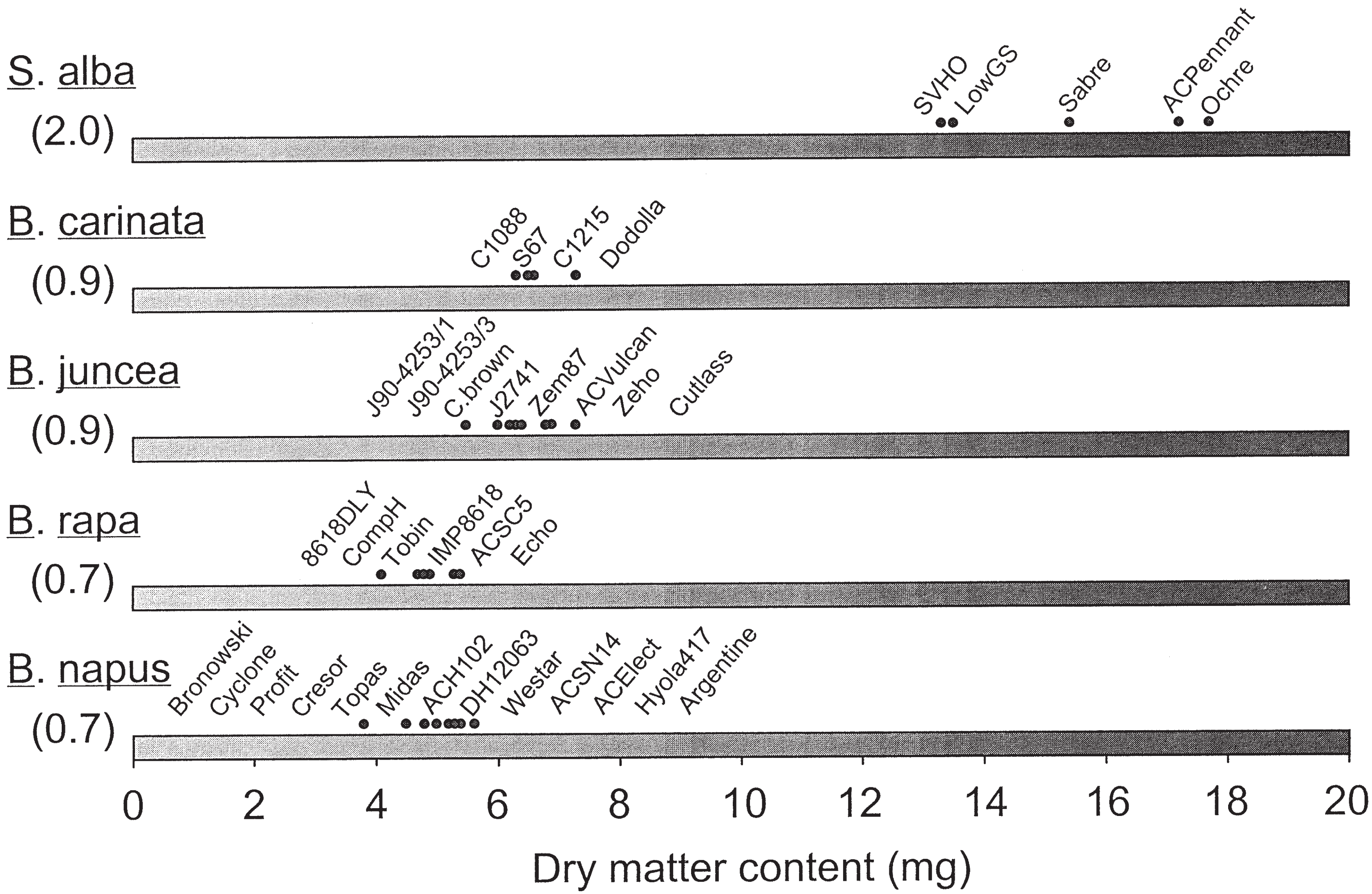

Fig. 13. Dry matter content of selected lines of S. alba and four Brassica species in 1995-1997. Measurements taken 14 days after seeding.

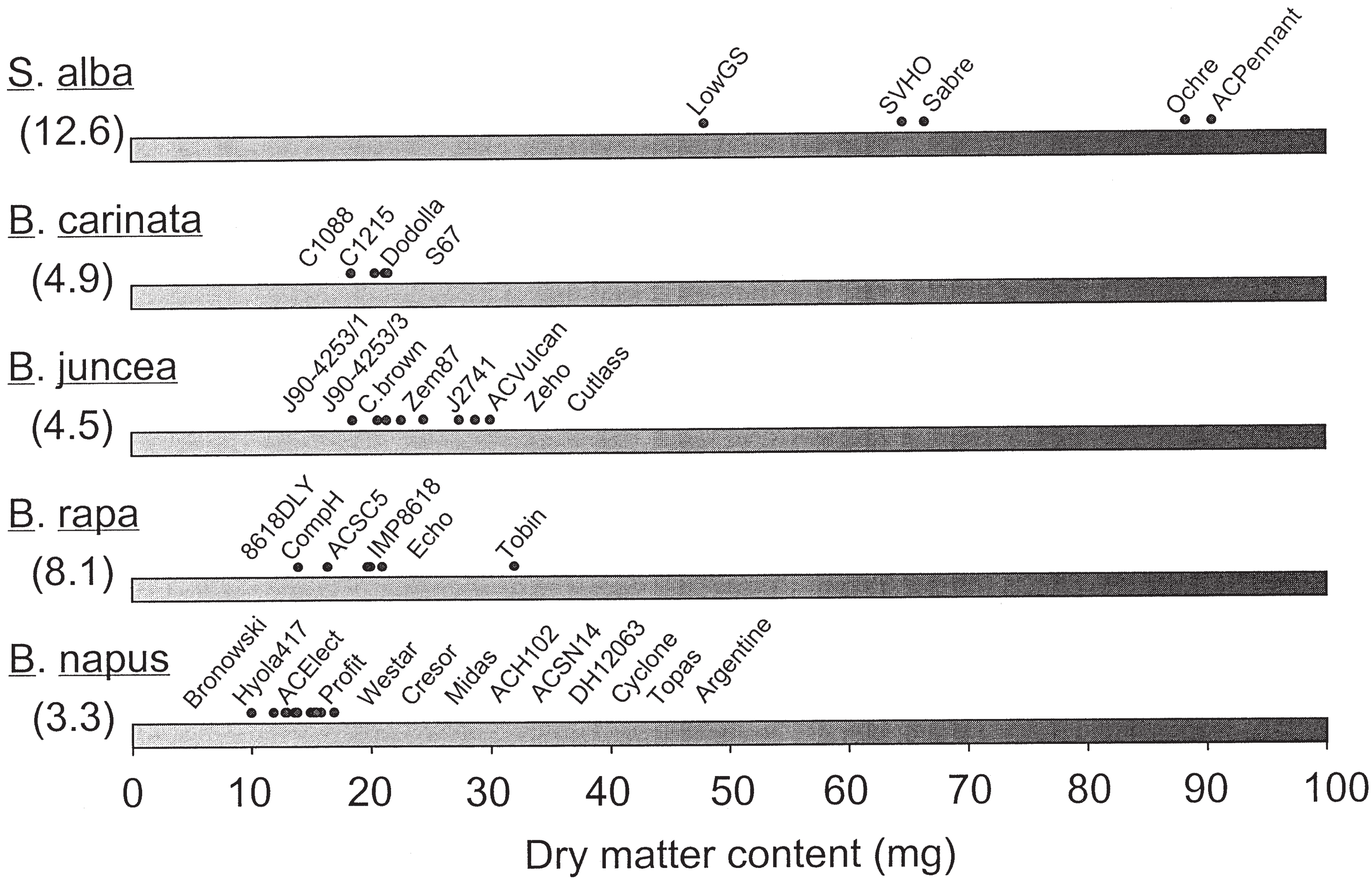

Fig. 14. Dry matter content of selected lines of S. alba and four Brassica species in 1995-1997. Measurements taken 21 days after seeding.

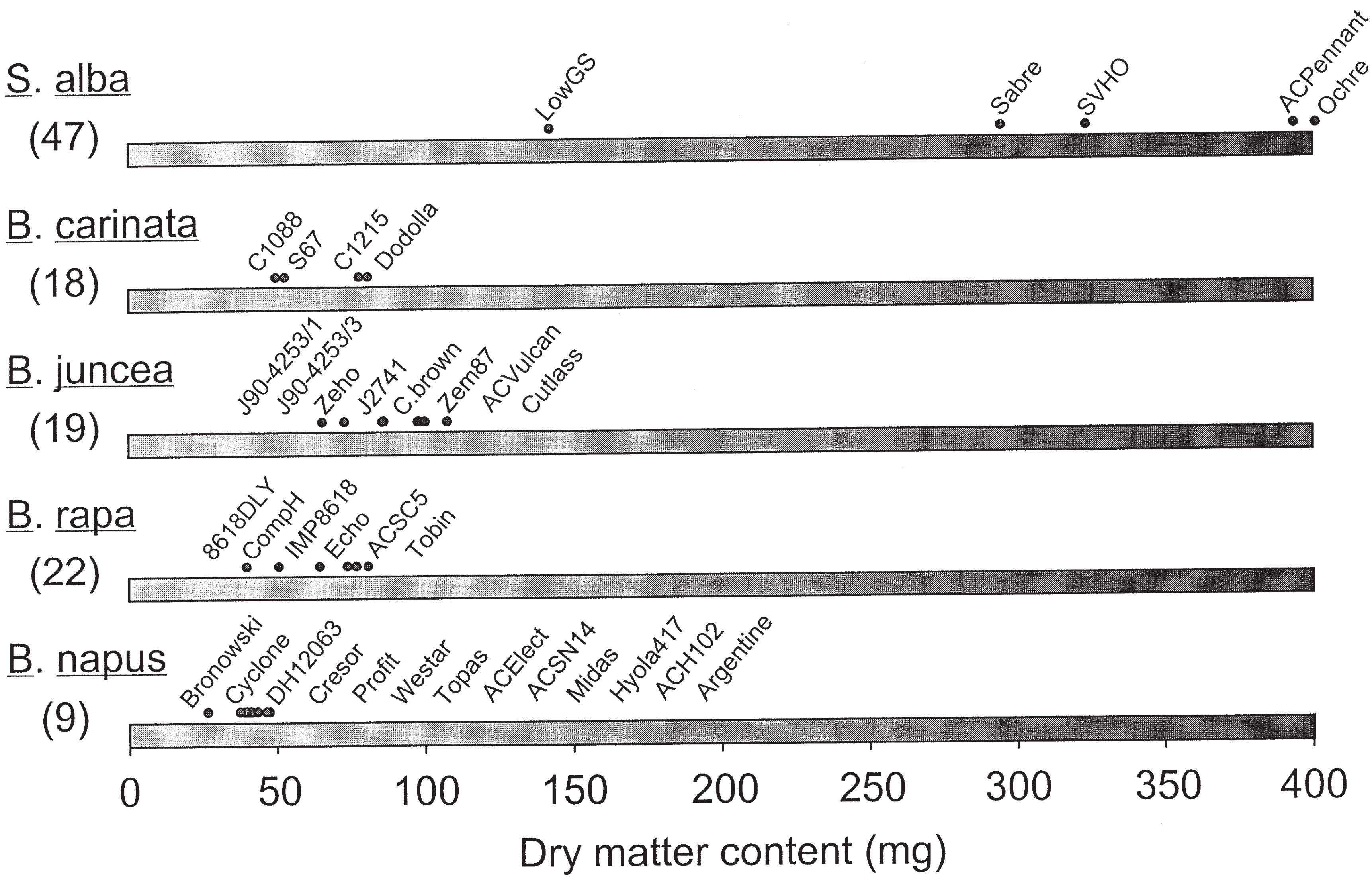

Fig. 15. Dry matter content of selected lines of S. alba and four Brassica species in 1995-1997. Measurements taken 28 days after seeding.

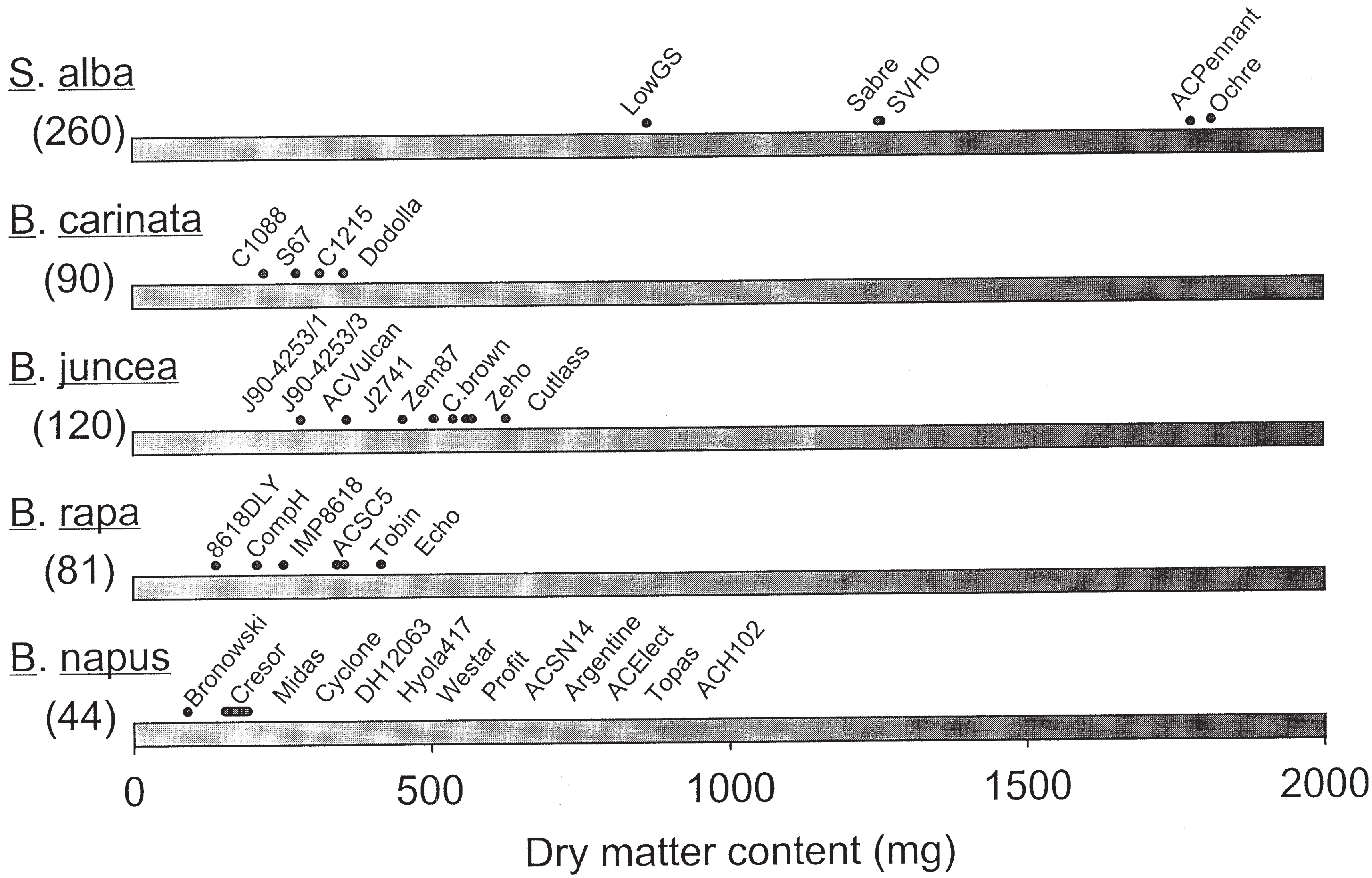

Fig. 16. Dry matter content of selected lines of S. alba and four Brassica species in 1995-1997. Measurements taken 35 days after seeding.

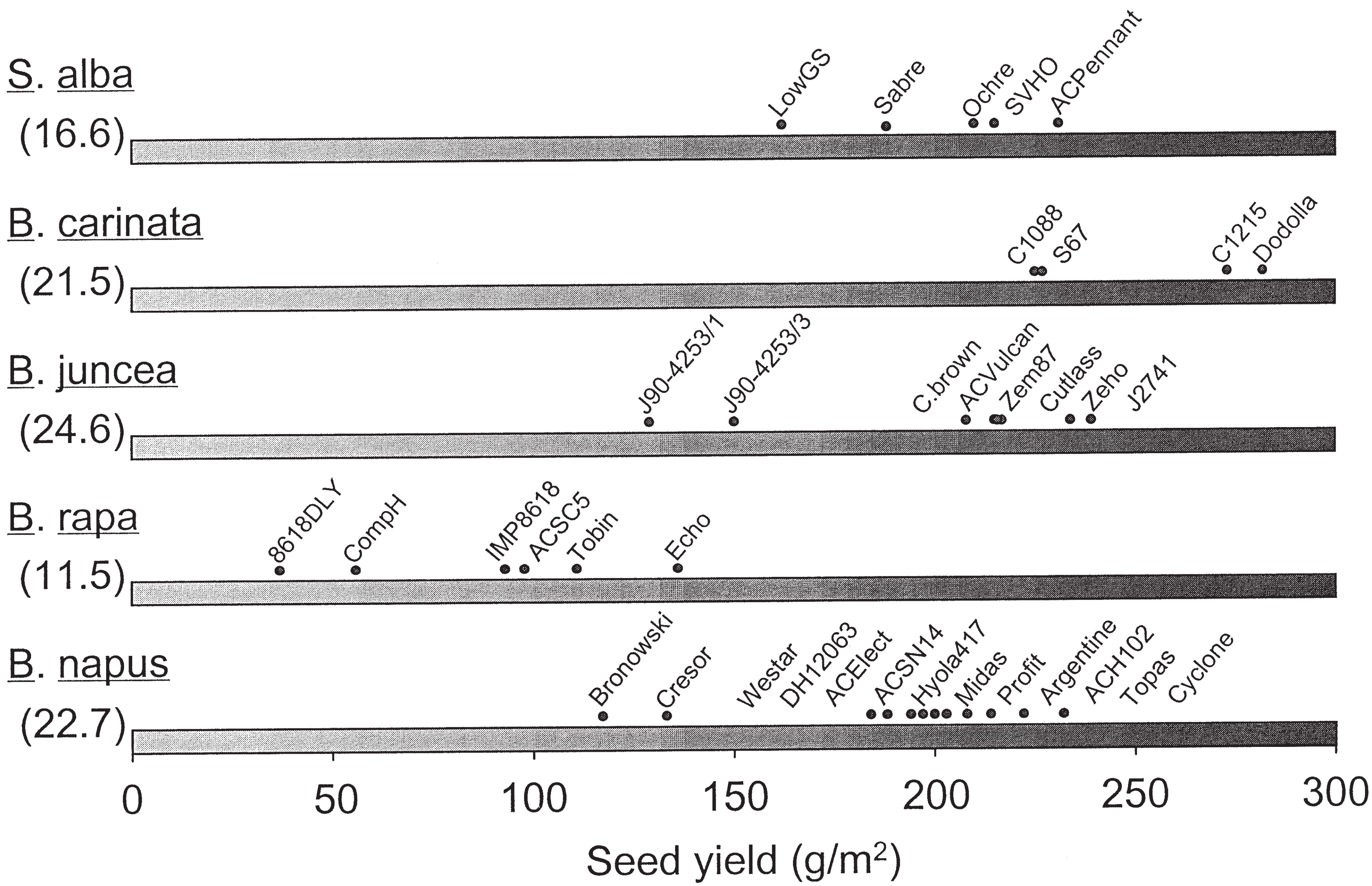

Fig. 17. Seed yield of selected lines of S. alba and four Brassica species in 1995-1997.

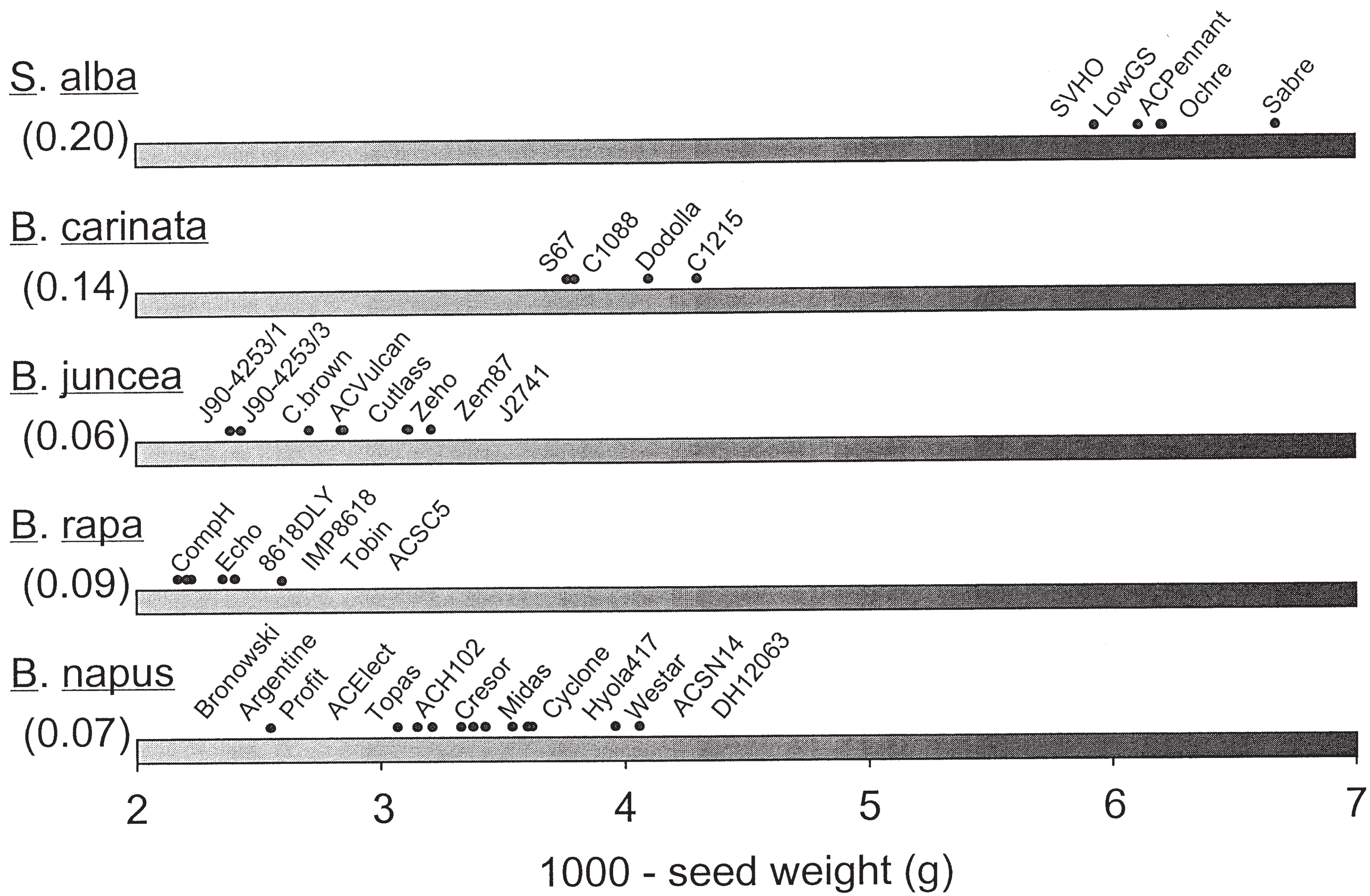

Fig. 18. Thousand-seed weight of harvested seed of selected lines of S. alba and four Brassica species in 1995-1997.