Identification of Crucifer Accessions from the NC-7 and NE-9 Plant Introduction Collections That Are Resistant to Black Rot (*Xanthomonas campestris* pv. *campestris*) Races 1 and 4

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Abstract. Black rot, caused by *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson (Xcc), is a serious disease of vegetable crucifers worldwide. The USDA NC-7 and NE-9 regional PI stations maintain vegetable, mustard, and oilseed crucifers, of which 4084 accessions were available for testing, representing 23 genera and 125 species. These accessions were evaluated for resistance to black rot after wound inoculation with race 1 of the pathogen. Accessions that were symptomless for race 1 of Xcc were replanted and inoculated with race 4 of the pathogen to identify accessions with resistance to both races. Symptomless responses were observed in 362 accessions of the mustard species (*Brassica juncea*, *Brassica carinata*, and *Brassica nigra*), in particular, *B. juncea* for which 353 of the 389 accessions tested were symptomless. Resistance was identified in five accessions of *B. carinata* out of 63 evaluated (PI 193460, PI 193959, PI 194254, PI 280230, PI 633077) determined by repeated symptomless responses after inoculation and four accessions of *B. nigra* from the 83 evaluated (PI 197401, A 25399, A 25401, PI 458981). Five accessions of *Brassica rapa* (PI 633154, A9285, PI 340208, PI 597831, PI 173847) were identified, which represent promising new sources of resistance to Xcc. Incomplete resistance was identified in an accession of *Eruca sativa* (PI 633207), an accession of *Lepidium* spp. (PI 633265), an accession of *Sinapis arvensis* (PI 296079), and two accessions of *B. napus* (PI 469733 and PI 469828). These identified accessions represent germplasm that can be used in breeding for resistance to Xcc in vegetable crucifers through interspecific crossing.

Black rot is a bacterial disease of crucifer species caused by *Xanthomonas campestris* pv. *campestris* (Xcc). Xcc is prevalent worldwide and is a destructive disease of *Brassica oleracea* vegetables such as cabbage, broccoli, and cauliflower (Williams, 1980). Xcc is seed-borne and also can overwinter on cruciferous weeds and wild relatives of cultivated *Brassica* crops (Cook et al., 1952; Schaad and Dianese, 1981). Symptoms of the disease include blackening of the veins in petioles and characteristic V-shaped lesions originating from the leaf margin, which enlarge causing the plant to wilt and eventually rot. Currently, the most effective

approaches to controlling black rot are through good agricultural practices, hot water treatment of seeds, and the use of cultivars with moderate resistance to the disease (Griffiths and Roe, 2005). However, these approaches have a limited effect with unpredictable black rot outbreaks occurring throughout growing regions, highlighting the need for incorporation of effective and stable resistance into cultivated varieties. When grown in a conducive environment, symptoms typically appear 10 to 14 d after infection (Williams, 1980).

Studies have previously focused on resistance derived from *B. oleracea*, including the cabbage cultivar Early Fuji (Bain, 1952), the inheritance of which was reported to be controlled by a single recessive gene with two modifiers (Williams et al., 1972). Resistance has also been documented in *B. oleracea* PIs, including the cabbage accession PI

436606 from China, also determined to be controlled by multiple genes (Dickson and Hunter, 1987; Hunter et al., 1987). These sources have been used in the development of black rot-resistant breeding lines, including Badger #16 (Williams, University of Wisconsin); NY4002 (Dickson, Cornell University); and Cornell 101, Cornell 102, and Cornell 103 (Griffiths, Cornell University). However, the resistance is typically incomplete and difficult to incorporate into hybrid cultivars (Camargo et al., 1995). Resistance has been reported in the mustard species *B. nigra*, *B. juncea*, and *B. carinata* (Guo et al., 1991; Taylor et al., 2002; Tonguc and Griffiths, 2004a; Westman et al., 1999), including *B. juncea* accessions PI 633077 and PI 633078 (previously A 19182 and A 19183), and *B. carinata* accessions PI 199947 and PI 199949 (Guo et al., 1991) and used in the creation of interspecific hybrids (Tonguc et al., 2003; Tonguc and Griffiths, 2004b).

Xcc has been characterized into at least six distinct races, the most important of these being races 1 and 4, which account for over 90% of black rot disease worldwide (Vicente et al., 2001). *B. oleracea* accessions have not been identified that exhibit complete resistance to races 1 and 4, but breeding lines have been developed that exhibit incomplete resistance to these races. Related crucifer species, including *B. carinata* and *B. juncea*, exhibit resistance to Xcc races 1 and 4, that appear to be controlled by a single gene (Guo et al., 1991; Hansen and Earle, 1995; Taylor et al., 2002; Tonguc et al., 2003; Tonguc and Griffiths, 2004b; Vicente et al., 2002).

To effectively use germplasm resources for interspecific hybridization with *B. oleracea*, it will be important to determine the presence and frequency of Xcc resistance not just within cultivated *Brassica* vegetables, but also within related crucifer accessions. Resistance may then be exploited through interspecific crosses of *B. oleracea* with related species. Crucifer accessions could provide important resistance sources for the development of hybrid *Brassica* vegetables by contributing new resistance genes for Xcc or genes that can be incorporated into cole crops more effectively. The aim of this research was to evaluate crucifer species at the juvenile stage to quantify the presence, frequency, and potential use of accessions for introgression of Xcc resistance. To achieve this, the crucifer accessions from the NC-7 (Ames, IA) and NE-9 (Geneva, NY) USDA regional PI centers were inoculated and evaluated for resistance to race 1 and race 4 of Xcc using the wound inoculation technique (Griffiths and Roe, 2005).

Materials and Methods

Plant material. The USDA crucifer species are maintained at the NC-7 and NE-9 regional PI centers with vegetable crucifers being maintained primarily at the NE-9 collection and oilseed and mustard accessions being maintained in the NC-7 collection. The

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crucifer collections held at NE-9 and NC-7 comprise 2857 and 3129, respectively ($\approx 70\%$ of which belong to *Brassica* spp. with the remainder representing related crucifer species). These 5985 accessions comprise a total of 125 crucifer species representing 23 genera of which 4084 were available for evaluation of resistance to Xcc (Table 1). Eight seeds of each of the 4084 accessions were sown in greenhouses at Geneva, NY, in 32-cell (125 cm³) Styrofoam trays in 'Cornell Mix' (Boodley and Sheldrake, 1982) with one seed per cell (Speedling, Sun City, FL) with multiple planting dates between June 2005 and June 2006. Cabbage cultivars were planted as susceptible controls.

Inoculation. The accessions were grown to the two to three true-leaf stage at ≈ 3 to 4 weeks dependent on the species being tested. Seeds were sown in a greenhouse at 23/20 °C day/night with a 14-h photoperiod under 1000-W metal halide lamps (300 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) in preparation for the inoculation. Temperatures were raised to 26/23 °C after inoculation to enhance disease responses. Isolates of Xcc determined to be race 1 and race 4 based on the differential cultivar screening (Vicente et al., 2001) were recovered from infected cabbages in New York (Helene Dillard, Cornell University), which were used to determine resistance of the crucifer accessions to Xcc. These Xcc isolates were grown on YDCP medium (Shelton and Hunter, 1985) for 3 to 4 d and used to needle-inoculate the accessions and control plants. The wound inoculation (Shaw and Kado, 1988) involved piercing two of the true leaves either side of the midrib with needles dipped in the Xcc isolates (Griffiths and Roe, 2005) for at least two leaves per plant. The inoculation was undertaken at the two to three true-leaf stage. Plants were evaluated 10 to 14 d after the inoculation using a rating scale of 1 to 5 (1 = completely resistant, 5 = completely susceptible), whereby 1 = symptomless, 2 = minimal symptoms from the point of wounding, 3 = symptoms beyond point of wounding, 4 = some systemic movement beyond the infected leaf, and 5 = highly susceptible systemic response resulting in plant death (Tonguc et al., 2003). The initial inoculation involved testing eight plants each of 4084 accessions with a race 1 isolate of Xcc. The 561 accessions that were symptomless after the Xcc race 1 inoculation were replanted and evaluated with the race 4 isolate to identify accessions that exhibited resistance to both races 1 and 4.

Results

All control plants exhibited black rot symptoms when wound-inoculated. Of the 4084 accessions, 561 were identified for a retest determined by evaluation of at least six plants with zero or very minimal infection from the point of infection after inoculation with race 1 Xcc inoculation. The vast majority of the 561 accessions exhibiting symptomless responses after inoculation with race 1 Xcc belonged to the mustard species *B.*

Table 1. Crucifer species available from the NC-7 and NE-9 regional PI centers that were evaluated for *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson resistance (total 4084).

Species	Number of accessions
<i>Alyssum alyssoides</i>	5
<i>Alyssum bracteatum</i>	1
<i>Alyssum dasycarpum</i> var. <i>dasycarpum</i>	1
<i>Alyssum dasycarpum</i> var. <i>minus</i>	1
<i>Alyssum desertorum</i>	1
<i>Alyssum flahaultianum</i>	1
<i>Alyssum granatense</i>	2
<i>Alyssum lenense</i>	1
<i>Alyssum linifolium</i>	1
<i>Alyssum minutum</i>	1
<i>Alyssum montanum</i>	1
<i>Alyssum nebrodense</i>	1
<i>Alyssum scutigerum</i>	1
<i>Alyssum simplex</i>	3
<i>Alyssum stapfii</i>	1
<i>Alyssum strigosum</i>	1
<i>Alyssum tortuosum</i>	1
<i>Alyssum wulfenianum</i>	1
<i>Aurinia corymbosa</i>	1
<i>Barbarea intermedia</i>	1
<i>Barbarea verna</i>	1
<i>Berteroa incana</i>	10
<i>Biscutella didyma</i> subsp. <i>didyma</i>	1
<i>Biscutella didyma</i> subsp. <i>lyrata</i>	1
<i>Brassica barrelieri</i>	2
<i>Brassica carinata</i>	63
<i>Brassica deflexa</i>	1
<i>Brassica deflexa</i> subsp. <i>leptocarpa</i>	1
<i>Brassica fruticulosa</i>	2
<i>Brassica fruticulosa</i> subsp. <i>fruticulosa</i>	1
<i>Brassica fruticulosa</i> subsp. <i>glaberrima</i>	1
<i>Brassica fruticulosa</i> subsp. <i>mauritanica</i>	1
<i>Brassica fruticulosa</i> subsp. <i>pomeliana</i>	1
<i>Brassica fruticulosa</i> subsp. <i>radicata</i>	1
<i>Brassica gravinae</i> var. <i>brachyloma</i>	1
<i>Brassica gravinae</i> var. <i>djurdjurae</i>	1
<i>Brassica juncea</i>	388
<i>Brassica juncea</i> var. <i>longidens</i>	1
<i>Brassica maurorum</i>	1
<i>Brassica napus</i>	509
<i>Brassica napus</i> var. <i>napus</i>	49
<i>Brassica nigra</i>	83
<i>Brassica oleracea</i>	7
<i>Brassica oleracea</i> var. <i>acephala</i>	1
<i>Brassica oleracea</i> var. <i>aff acephala</i>	6
<i>Brassica oleracea</i> var. <i>alboglabra</i>	12
<i>Brassica oleracea</i> var. <i>botrytis</i>	251
<i>Brassica oleracea</i> var. <i>capitata</i>	305
<i>Brassica oleracea</i> var. <i>costata</i>	12
<i>Brassica oleracea</i> var. <i>gemmifera</i>	37
<i>Brassica oleracea</i> var. <i>gongylodes</i>	9
<i>Brassica oleracea</i> var. <i>italica</i>	43
<i>Brassica oleracea</i> var. <i>medullosa</i>	2
<i>Brassica oleracea</i> var. <i>oleracea</i>	1
<i>Brassica oleracea</i> var. <i>palmifolia</i>	1
<i>Brassica oleracea</i> var. <i>ramosa</i>	1
<i>Brassica oleracea</i> var. <i>sabauda</i>	12
<i>Brassica oleracea</i> var. <i>sabellica</i>	10
<i>Brassica oleracea</i> var. <i>selenesia</i>	7
<i>Brassica rapa</i>	548
<i>Brassica rapa</i> subsp. <i>campestris</i>	2
<i>Brassica rapa</i> subsp. <i>chinensis</i>	43
<i>Brassica rapa</i> subsp. <i>dichotoma</i>	32
<i>Brassica rapa</i> subsp. <i>japonica</i>	2
<i>Brassica rapa</i> subsp. <i>narinosa</i>	2
<i>Brassica rapa</i> subsp. <i>nipposinica</i>	1
<i>Brassica rapa</i> subsp. <i>oleifera</i>	16
<i>Brassica rapa</i> subsp. <i>rapa</i>	24
<i>Brassica rapa</i> subsp. <i>rapifera</i>	5
<i>Brassica rapa</i> subsp. <i>trilocularis</i>	30
<i>Brassica rapa</i> var. <i>parachinensis</i>	4
<i>Brassica rapa</i> var. <i>pekinensis</i>	113
<i>Brassica rapa</i> var. <i>silvestris</i>	1

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Table 1. (Continued) Crucifer species available from the NC-7 and NE-9 regional PI centers that were evaluated for *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson resistance (total 4084).

Species	Number of accessions
<i>Brassica rapa</i> var. <i>utilis</i>	3
<i>Brassica repanda</i> subsp. <i>almeriensis</i>	1
<i>Brassica souliei</i> subsp. <i>amplexicaulis</i>	1
<i>Brassica</i> sp.	3
<i>Brassica tournefortii</i>	20
<i>Camelina alyssum</i>	1
<i>Camelina hispida</i> var. <i>grandiflora</i>	1
<i>Camelina laxa</i>	1
<i>Camelina microcarpa</i>	8
<i>Camelina rumelica</i> subsp. <i>transcaspica</i>	1
<i>Camelina sativa</i>	36
<i>Crambe abyssinica</i>	83
<i>Crambe filiformis</i>	10
<i>Crambe hispanica</i>	2
<i>Crambe hispanica</i> subsp. <i>glabrata</i>	17
<i>Crambe hispanica</i> subsp. <i>hispanica</i>	35
<i>Crambe juncea</i>	2
<i>Crambe kralikii</i>	1
<i>Crambe maritima</i>	1
<i>Crambe pritzelii</i>	1
<i>Crambe</i> sp.	2
<i>Crambe tataria</i>	1
<i>Diplotaxis eruroides</i> subsp. <i>Eruroides</i>	1
<i>Diplotaxis muralis</i>	1
<i>Diplotaxis tenuifolia</i>	2
<i>Enarthrocarpus arcuatus</i>	1
<i>Eruca pinnatifida</i>	2
<i>Eruca sativa</i>	172
<i>Eruca sativa</i> subsp. <i>longirostris</i>	1
<i>Eruca vesicaria</i>	4
<i>Erucastrum brevirostre</i>	1
<i>Erucastrum elatum</i>	1
<i>Erucastrum elatum</i> var. <i>microspermum</i>	1
<i>Erucastrum elatum</i> var. <i>scabriusculum</i>	1
<i>Erucastrum leucanthum</i>	3
<i>Erucastrum nasturtifolium</i>	1
<i>Erucastrum nasturtifolium</i> subsp. <i>sudrei</i>	1
<i>Erucastrum rivanum</i>	1
<i>Erucastrum varium</i>	1
<i>Erucastrum varium</i> subsp. <i>varium</i>	1
<i>Erucastrum virgatum</i>	1
<i>Erucastrum virgatum</i> subsp. <i>baeticum</i>	1
<i>Erucastrum virgatum</i> subsp. <i>pseudosinapis</i>	1
<i>Erucastrum virgatum</i> subsp. <i>virgatum</i>	1
<i>Erysimum asperum</i>	1
<i>Erysimum aucherianum</i>	1
<i>Erysimum baeticum</i>	1
<i>Erysimum cheiranthoides</i>	3
<i>Erysimum crassipes</i>	1
<i>Erysimum creticum</i>	1
<i>Erysimum cuspidatum</i>	2
<i>Erysimum diffusum</i>	2
<i>Erysimum duriaei</i> subsp. <i>pyrenaicum</i>	1
<i>Erysimum favargerii</i>	1
<i>Erysimum graecum</i>	1
<i>Erysimum gramineum</i>	1
<i>Erysimum incanum</i>	1
<i>Erysimum inconspicuum</i> var. <i>coarctatum</i>	1
<i>Erysimum linifolium</i>	1
<i>Erysimum nevadense</i> subsp. <i>collisparsum</i>	1
<i>Erysimum nevadense</i> subsp. <i>rondae</i>	1
<i>Erysimum odoratum</i>	1
<i>Erysimum olympicum</i>	1
<i>Erysimum penyalarensense</i>	1
<i>Erysimum raulinii</i>	1
<i>Erysimum repandum</i>	3
<i>Erysimum scabrum</i>	1
<i>Erysimum sisymbrioides</i>	1
<i>Erysimum smyrnaeum</i>	1
<i>Erysimum virgatum</i>	3
<i>Erysimum witmannii</i>	1
<i>Hesperis kotschyana</i>	1
<i>Hesperis matronalis</i>	4

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carinata, *B. nigra*, and *B. juncea*, in particular *B. juncea*, accessions, from which 323 were determined to have a mean rating of 1 when inoculated with Xcc. Additionally, five *B. carinata* (PI 193460, PI 193959, PI 194254, PI 280230, PI 633077) and four *B. nigra* (PI 197401, A25399, A25401, PI 458981) accessions were determined to be resistant based on symptomless responses to the inoculation. The list of mustard accessions determined to be resistant is available through the GRIN web site for the NC-7 regional PI station. Because the majority of resistant accessions within *B. juncea* were determined to be resistant to Xcc, a third test focused on crucifer accessions not belonging to mustard species. This involved retesting 134 accessions belonging to 17 crucifer species, the individual accessions of which are listed in Table 2.

The most promising 10 accessions were selected from this screen and focused on non-mustard species so as to represent new sources of resistance for breeding purposes (Table 3). Minimal symptom responses were observed in an accession of *Eruca sativa* (PI 633207), an accession of *Lepidium* spp. (PI 633265), an accession of *Sinapis arvensis* (PI 296079), and two accessions of *B. napus* (PI 469733 and PI 469828). Based on this more extensive screen, five accessions were identified representing newly identified Xcc-resistant sources in a species more easily crossed to *B. oleracea* (all belonged to *B. rapa* or subspecies of *B. rapa*). The five accessions A 9285, PI 173847, PI 340208, PI 597831, and PI 633154 were evaluated in a final test of five plants with Xcc races 1 and 4 and were scored with ratings of 1 or 2 in all plants tested (Table 4) and represent newly identified Xcc sources that can be used for breeding black rot-resistant *Brassica* vegetables after interspecific crosses with *B. oleracea*.

Discussion

Host plant resistance is an important approach to controlling Xcc, particularly in the economically important *Brassica* vegetable species such as cabbage, cauliflower, and broccoli. No *B. oleracea* cultivars with complete resistance to the most common Xcc races 1 and 4 have been developed. However, cabbage breeding lines, including Badger #16 (P.H. Williams, Univ. of Wisconsin); Cornell 101, 102, and 103; and some commercial cultivars, have been documented as incompletely resistant Xcc (Griffiths and Roe, 2005). Incomplete resistance to Xcc in *B. oleracea* species continues to be problematic worldwide despite the use of remote seed increase facilities and hot water treatment of seeds, highlighting the need to use more effective resistance genes from outside the species through interspecific crossing (Hansen and Earle, 1995; Tonguc et al., 2003; Tonguc and Griffiths, 2004b).

Previous work with interspecific sources of resistance has been undertaken, including the transfer of resistance from *B. carinata*

Table 1. (Continued) Crucifer species available from the NC-7 and NE-9 regional PI centers that were evaluated for *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson resistance (total 4084).

Species	Number of accessions
<i>Hesperis sibirica</i>	1
<i>Hirschfeldia incana</i>	1
<i>Hirschfeldia incana</i> subsp. <i>consobrina</i>	1
<i>Hirschfeldia incana</i> subsp. <i>Geniculata</i>	1
<i>Iberis amara</i>	2
<i>Isatis glauca</i>	1
<i>Isatis tinctoria</i>	1
<i>Lepidium alluaudii</i>	1
<i>Lepidium apetalum</i>	1
<i>Lepidium bonariense</i>	1
<i>Lepidium campestre</i>	8
<i>Lepidium densiflorum</i>	2
<i>Lepidium graminifolium</i>	1
<i>Lepidium heterophyllum</i>	1
<i>Lepidium hirtum</i> subsp. <i>atlanticum</i>	1
<i>Lepidium hirtum</i> subsp. <i>calycotrichum</i>	1
<i>Lepidium hirtum</i> subsp. <i>dhayense</i>	1
<i>Lepidium hirtum</i> subsp. <i>nebrodense</i>	1
<i>Lepidium meyenii</i>	1
<i>Lepidium perfoliatum</i>	2
<i>Lepidium ruderae</i>	3
<i>Lepidium sativum</i>	77
<i>Lepidium</i> sp.	3
<i>Lepidium spinosum</i>	2
<i>Lepidium virginicum</i>	1
<i>Lepidium virginicum</i> var. <i>pubescens</i>	1
<i>Matthiola incana</i>	1
<i>Matthiola longipetala</i>	1
<i>Raphanus sativa</i>	626
<i>Sinapis alba</i>	116
<i>Sinapis alba</i> subsp. <i>alba</i>	1
<i>Sinapis alba</i> subsp. <i>mairei</i>	2
<i>Sinapis arvensis</i>	35
<i>Sinapis arvensis</i> subsp. <i>arvensis</i>	18
<i>Sinapis flexuosa</i>	1
<i>Thlaspi alpestre</i>	1
<i>Thlaspi arvense</i>	5
<i>Thlaspi nevadense</i>	1
<i>Thlaspi perfoliatum</i> subsp. <i>tineoi</i>	1
<i>X Brassicoraphanus</i> sp.	1
Total	4,084

Table 2. Species and specific accessions re-evaluated for resistance to *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson races 1 and 4.

Species	Accession	Species	Accession	Species	Accession
<i>Brassica carinata</i>	PI193460	<i>Brassica napus</i> , concl.	PI469878	<i>Brassica rapa</i> , concl.	PI340199
	PI193959 ^z		PI469889		PI384534 ^z
	PI194254 ^z		PI469906		PI391548 ^z
	PI197403		PI469911		PI419212
	PI231046		PI469912		PI426177 ^z
	PI280230		PI469916		PI426258
	PI633077		PI469924		PI426266
	PI633078		PI469955 ^z		PI426268 ^z
	PI633080		PI469959 ^z		PI426271
<i>Brassica fruticulosa</i>	Ames 21302		PI469974		PI426277
<i>Brassica napus</i>	Ames 6096 ^z		PI470080 ^z		PI426286 ^z
	Ames 26633	<i>Brassica nigra</i>	PI633140 ^z		PI537016
	Ames 26635 ^z		PI131512		PI633154
	PI251614		PI169067		PI633158
	PI458919		PI173860		PI633161
	PI458949		PI183920		Ames 9285
	PI458956 ^z		PI197401		PI340208
	PI458967 ^z		PI426410		PI597831
	PI458979		PI633143		PI173847
	PI458980		PI633145		PI390962 ^z
	PI469732		Ames 25399		PI390963 ^z
	PI469733		Ames 25401 ^z		PI390964 ^z

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accession PI199947 to *B. oleracea* (Hansen and Earle, 1995) through protoplast fusion, which has proved difficult to stabilize in a *B. oleracea* plant type (Tonguc et al., 2003). Complications arising from interspecific crosses with *B. oleracea* through sexual crosses include different chromosome numbers in the parents. These barriers can be overcome with techniques including embryo rescue and protoplast fusion, but complications such as aneuploidy in breeding lines can also occur. Successful introgression of black rot resistance using the mustard species *B. juncea* has also been evaluated (Tonguc and Griffiths, 2004b) using accessions A 19182 and A 19183 identified from the NC-7 *B. carinata* collection, which were determined to be incorrectly identified. These accessions have since been recategorized as *B. juncea* accessions PI 633077 and PI 633078, respectively. The accessions were morphologically very distinct from other *B. carinata* accessions evaluated (Tonguc and Griffiths, 2004a) and subsequently reidentified by Gomez-Campo as *B. juncea*. The accessions are of an uncertain Canadian source that was acquired by the NC-7 collection.

Black rot resistance can be expressed at the juvenile, mature, or both juvenile and mature plant stages (Hunter et al., 1987). Differential responses in disease reactions of accessions and species in this study were observed that were likely influenced by plant type and growth rate. The vigorous growth of the oilseed and mustard species and the rapid transition to flowering compromised accurate rating of Xcc symptoms based on the 1 to 5 scale typically used. Rating was modified based on the plant species type to make a determination of resistance to Xcc.

Accessions previously used in interspecific transfer of resistance to Xcc (Hansen and Earle, 1995; Tonguc and Griffiths, 2004a) have belonged to the species *B. carinata* and *B. juncea*, which are B-genome crucifers according to the relationships of *Brassica* species determined by U (1935). The barriers to successful transfer from B-genome *Brassica* species are challenging and likely more difficult than transfer from A-genome and C-genome types as a result of genetic distance (Cunha et al., 2004). The identification of the *B. rapa* accessions PI 633154, A9285, PI 340208, PI 597831, and PI 173847 could prove important in enabling transfer of resistance to Xcc from a different species with potentially fewer crossing barriers. Of the five *B. rapa* accessions identified with resistance to Xcc, all have the oilseed plant growth type, and four of the accessions have been identified as subspecies of *B. rapa*. It is possible that one or more of these accessions has been misidentified in the *B. rapa* species, because the vast majority of resistant accessions belong to the related *B. juncea* species. Interspecific crossing to generate hybrids after natural crosspollinations is currently being undertaken to determine whether techniques such as protoplast fusion or embryo rescue would also be required for these newly identified sources to transfer Xcc resistance.

Table 2. (Continued) Species and specific accessions re-evaluated for resistance to *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson races 1 and 4.

Species	Accession	Species	Accession	Species	Accession
	PI469734	<i>Brassica oleracea</i>	PI458981		Ames 19215 ^z
	PI469750 ^z		G30727 ^z		G30804 ^z
	PI469752		G30734 ^z		PI597833
	PI469761 ^z		PI600985 ^z	<i>Camelina sativa</i>	NSL74254 ^z
	PI469807	<i>Brassica rapa</i>	PI358284 ^z	<i>Crambe abbyssinica</i>	NSL74278 ^z
	PI469808		Ames 21738		PI633205 ^z
	PI469809		PI163497	<i>Eruca sativa</i>	PI633207
	PI469818 ^z		PI169070 ^z		PI633226 ^z
	PI469819		PI174803	<i>Erysimum diffusum</i>	PI586611
	PI469828		PI175063	<i>Hesperis matronalis</i>	PI633241
	PI469829		PI179643		PI597856
	PI469837 ^z		PI204683 ^z	<i>Lepidium heterophyllum</i>	PI175762 ^z
	PI469845		PI217932	<i>Lepidium sativum</i>	PI253154 ^z
	PI469846		PI217936 ^z		PI633265
	PI469847 ^z		PI226505	<i>Lepidium</i>	PI305277
	PI469850		PI250138	<i>Sinapis alba</i>	PI633308
	PI469851		PI254360		PI633316
	PI469856		PI269431 ^z		PI633348 ^z
	PI469860		PI269446 ^z		PI597862
	PI469862		PI303135		PI633370
	PI469865		PI312124 ^z	<i>Sinapis arvensis</i>	PI633371
	PI469872 ^z		PI340184		

^zSusceptible.

Table 3. Accessions selected for final evaluation with *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson races 1 and 4.

Species	Accession	Rating
<i>Brassica napus</i>	PI 469733	1–2, minimal response
<i>Brassica napus</i>	PI 469828	1–2, minimal response
<i>Brassica rapa</i>	PI 633154	1, symptomless
<i>Brassica rapa</i> subsp. <i>dichotoma</i>	Ames 9285	1, symptomless
<i>Brassica rapa</i> subsp. <i>dichotoma</i>	PI 340208	1, symptomless
<i>Brassica rapa</i> subsp. <i>oleifera</i>	PI 597831	1, symptomless
<i>Brassica rapa</i> subsp. <i>trilocularis</i>	PI 173847	1, symptomless
<i>Eruca sativa</i>	PI 633207	1–2, minimal response
<i>Lepidium</i> sp.	PI 633265	1–2, minimal response
<i>Sinapis arvensis</i> subsp. <i>arvensis</i>	PI 296079	1–2, minimal response

Table 4. *B. rapa* accessions identified as resistant to *Xanthomonas campestris* pv. *campestris* (Pam.) Dawson (Xcc) races 1 and 4 in final retest.

Accession	Species	Xcc race 1	Xcc race 4
Ames9285	<i>Brassica rapa</i> subsp. <i>dichotoma</i>	1-1-1-1-1	1-1-1-1-1
PI 173847	<i>Brassica rapa</i> subsp. <i>trilocularis</i>	2-1-2-1-1	1-1-1-1-1
PI 340208	<i>Brassica rapa</i> subsp. <i>dichotoma</i>	1-1-1-1-1	1-1-1-1-1
PI 597831	<i>Brassica rapa</i> subsp. <i>oleifera</i>	1-1-1-1-1	1-1-1-1-1
PI 633154	<i>Brassica rapa</i>	2-1-1-1-1	1-1-1-1-1

The accessions identified in this study represent newly identified sources exhibiting resistance to the two major worldwide Xcc races 1 and 4. These accessions can be used to transfer this resistance to *Brassica* vegetables through interspecific hybridization. They represent sources identified as *B. rapa*, which may have less barriers to the transfer of Xcc resistance than those encountered transferring resistance from *B. juncea* nad *B. carinata* accessions (Tonguc et al., 2003; Tonguc and Griffiths, 2004b). If interspecific hybrids with *B. oleracea* can be successfully generated, these accessions can be used to introgress Xcc resistance into *Brassica* vegetable species, reducing the worldwide limitations to production caused by this pathogen.

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