**New host resistances to *Pseudocercosporella capsellae* and implications for white leaf spot management in *Brassicaceae* crops**

*Niroshini Gunasinghea, Ming Pei Youa, Xi Xiang Lic, Surinder S. Bangad, Shashi K. Bangad and Martin J. Barbettia,b,\**

*a**School of Plant Biology, Faculty of Science, The University of Western Australia, 35 Stirling Highway, Crawley, WA, 6009, Australia*

*b The UWA Institute of Agriculture, Faculty of Science, The University of Western Australia, 35 Stirling Highway, Crawley, WA, 6009, Australia*

*c Department of Germplasm Resources, Institute of Vegetable and Flowers, Chinese Academy of Agricultural Sciences, Beijing, People’s Republic of China*

*d Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, India;*

\*Corresponding author at: School of Plant Biology, Faculty of Science, The University of Western Australia, 35 Stirling Highway, Crawley, WA, 6009, Australia. Tel.: +61 8 64883924.

*E-mail address:* martin.barbetti@uwa.edu.au (M.J. Barbetti)

**ABSTRACT**

Effective host resistance is the most cost-effective long term prospect for successful management of white leaf spot disease (*Pseudocercosporella capsellae*) in *Brassicaceae*. In two separate field trials, 168 genotypes were screened. In the first trial, lines of *Brassica oleracea* var. *capitata* (59), *B. napus* (34), *B. juncea* (6) and *B. juncea* containing wild weedy *Brassicaceae* introgression(s) (14) were arranged; and in the second, Australian historic and current *B. napus* (45) and *B. juncea* (10) varieties were screened. There was wide variation in expression of resistance, from complete resistance to highly susceptible as assessed by two disease parameters, viz. (i), Area Under Disease Progress Curve (AUDPC) for percent leaves diseased (values 0 - 221.2) and (ii) Percent Leaf Collapse Index (%LCI) values for leaf collapse due to disease (0 – 38.7). *Brassica oleracea* var. *capitata* was overall the most resistant species, while *B. juncea* the most susceptible with the majority having AUDPC values >75 and *B. napus* was intermediate.Five *B. oleracea* var. *capitata* genotypes were completely resistant, with 0 AUDPC and %LCI values. Pioneer® 45Y22 (RR) ‘Mystic’ and ‘Wahoo’ were also highly resistant, with the least %LCI (<3.7) and AUDPC (< 20) of the Australian *B. napus* varieties. In contrast, ‘Thunder TT’ (AUDPC -133.6; %CLI - 15.6) and ‘Carbine’ (AUDPC – 73.8; %CLI - 12.5) were the most susceptible lines in first and second trials, respectively. The particularly high susceptibility of newly released *B. juncea* varieties such as ‘Xceed OasisCL’ highlights the risk of significant losses in such susceptible varieties when deployed in areas with high degree pressure for white leaf spot disease. There was no association between AUDPC or % CLI with year of Australian varietal release, indicating that Australian breeding programs not made improvement for resistance to white leaf spot over the past two or more decades. Resistant varieties identified in this experiment can now not only be utilized in breeding programs to significantly improve overall crop resistance and management of white leaf spot disease, but also directly deployed to lower the severe inoculum load challenging current varieties.

*Keywords*: *Brassica*; white leaf spot; *Pseudocercosporella capsellae*; resistance; oilseed rape; mustard; cabbage

1. **Introduction**

White leaf spot (*Pseudocercosporella capsellae*) occurs across many *Brassicaceae* including oilseed, vegetable, condiment and fodder *Brassica* species, and results in significant yield losses worldwide ([Barbetti and Khangura, 2000](#_ENREF_4" \o "Barbetti, 2000 #190); [Crossan, 1954](#_ENREF_11" \o "Crossan, 1954 #127); [Deighton, 1973](#_ENREF_12" \o "Deighton, 1973 #40); [Koike](#_ENREF_19" \o "Koike, 2007 #139) *[et al.](#_ENREF_19" \o "Koike, 2007 #139)*[, 2007](#_ENREF_19" \o "Koike, 2007 #139); [Penaud, 1987](#_ENREF_23" \o "Penaud, 1987 #66); [Petrie and Vanterpool, 1978](#_ENREF_24" \o "Petrie, 1978 #7)). For example, in France, [Penaud (1987](#_ENREF_23" \o "Penaud, 1987 #66)) and [Amelung and Daebeler (1988](#_ENREF_1" \o "Amelung, 1988 #21)) reported white leaf spot as a major threat to oil seed rape; while in Western Oregon in the USA it seriously impacts commercial seed fields of forage Brassicas and “field” turnip .

In Australia, yield losses of 15-20% are not uncommon on the more susceptible oilseed *Brassica* varieties ([Barbetti and Khangura, 2000](#_ENREF_4" \o "Barbetti, 2000 #190); [Khangura](#_ENREF_18" \o "Khangura, 2014 #405) *[et al](#_ENREF_18" \o "Khangura, 2014 #405)*[., 2014](#_ENREF_18" \o "Khangura, 2014 #405)). There, it is common on both oilseed rape (*B. napus*) and on Indian mustard (*B. juncea*) (Eshraghi *et al.,* 2007). It also occurs in *Brassicaceae* on *B. rapa* and *B. juncea* vegetable types, some *B. oleracea* types, such as *B. oleracea* var. *botrytis* ([Lancaster, 2006](#_ENREF_20" \o "Lancaster, 2006 #204)) and *B. oleracea* var. *italica* ([Lancaster, 2006](#_ENREF_20" \o "Lancaster, 2006 #204)), and on *B. campestris* var. *chinensis*, *B*. *campestris* var. *rapa*, and *B. napus* var. *naprobrassica* ([Shivas, 1989](#_ENREF_26" \o "Shivas, 1989 #221)).

Over the past two decades, the significance of white leaf spot has increased in Australia, particularly since the deployment of the ‘Surpass type’ major gene resistance against blackleg disease (*Leptosphaeria maculans*) as these varieties were inherently susceptible to white leaf spot disease (M.J. Barbetti, unpubl.). The prevalence of white leaf spot significance has also increased in the UK, and global change in climate has been suggested as a cause due to warmer/wetter winters that favour disease spread and development ([Inman](#_ENREF_17" \o "Inman, 1997 #17) *[et al.](#_ENREF_17" \o "Inman, 1997 #17)* [1997](#_ENREF_17" \o "Inman, 1997 #17)).

Cultural and fungicidal controls remain the focus for management, but they generally provide inadequate control and are considered cost-prohibitive for managing disease in broad-acre *Brassica* production ([Inman, 1992](#_ENREF_16" \o "Inman, 1992 #129)). The general increasing severity of this disease has focused research into finding more effective and reliable control measures to cost-effectively manage this disease. However, breeding for resistance against white leaf spot has not been given priority in breeding programs due to other pathogens being considered of greater economic significance ([Inman, 1992)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.z337ya). This is despite recent field screening studies in Australia by [Eshraghi](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio) *[et al.](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio)* [(2007)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio) and [Gunasinghe](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh) *[et al.](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh)*[, (2013)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh) having demonstrated opportunities to locate resistance for commercially important oilseed, vegetable, and weedy *Brassica* species. Hence, field studies were undertaken to screen 168 *Brassica* genotypes for their relative resistances to *P. capsellae*. In one trial, *B. oleracea* var. *capitata*, *B. napus,* *B. juncea* and also *B. juncea* genotypes containing introgressions from wild weedy *Brassicaceae* from Australia, India or China were screened. A second trial included historic and current Australian *B. napus* and *B. juncea* commercial varieties.

**2. Materials & methods**

*2.1. Field site details*

Two separate field screening trials were undertaken during the Australian 2013 winter/spring cropping season to determine relative host resistances present across different *Brassica* species accessed from Australia, India and China. Trials were conducted in a nylon mesh covered area (to exclude insect pests) at the University of Western Australia Field Station in Shenton Park, Western Australia. Test genotypes were a arranged in complete randomized block design with four replications. Fifteen seeds per genotype were sown in single 1m rows with 0.22 m spacing between rows. Certain genotypes were repeated across both trials to allow comparisons between the two trials.

*2.2. Individual field trials*

Field trial 1 was sown on 23May 2013 with of 113 genotypes from Australia, China and India including *B. oleracea* var. *capitata* (59), *B. napus* (34) and *B. juncea* (20) with *B. juncea* containing wild weedy *Brassicaceae* introgressions (14). Field trial 2 was sown on 7June 2013 and with historic and current Australian *B. napus* (45) and *B. juncea* (10) varieties.

*2.3. P. capsellae Isolates used*

Four single spore isolates of *P. capsellae* were used: UWA Wln-15, UWA Wlra-7, UWA Wlr-8 and UWA Wlj-5 that had beenisolated from different diseased host species in Western Australia. UWA Wln-15 was derived from infected *B. napus* leaves collected from Calingiri, Western Australia (WA) in 2007; isolate UWA Wlra-7 was from *Raphanus raphanistrum* (wild radish) leaves collected in 2005 from West Calingiri, WA; isolates UWA Wlr-8 and UWA Wlj-5 were collected in 2005 from white leaf spot lesions of *B. rapa* at Perth, Western Australia, and *B. juncea* at Shenton Park, Western Australia, respectively. These different isolates were used as they are considered to represent variation found within *P. capsellae* populations in Australia (Gunasinghe *et al*., 2015) and this approach moderates possible pathotype-specific or race-specific responses to the pathogen on test genotypes. Subsequently, isolates of *P. capsellae* were maintained as lyophilised ampoules until these trials were initiated. Each isolate was revived by sub-culturing onto freshly made Malt Extract Agar medium (MEA: malt extract 20.0 g L-1, glucose 20.0 g L-1, agar 15.0 g L-1 and peptone 1.0 g L-1).

 *2.4. Inoculum preparation and inoculation of plants*

A mixture of mycelial fragments (4x 106 mL-1) across the four isolates (used in equal proportion) was utilised as the inoculum ([Eshraghi](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio) *[et al](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio)*[., 2007,](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.44sinio) [Gunasinghe](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh) *[et al](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh)*[., 2013)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh). A mycelial suspension was chosen over a conidial suspension to initiate the disease epidemic as the pathogen, at best, sporulates poorly on agar media ([Crossan, 1954](#_ENREF_11" \o "Crossan, 1954 #127); [Miller and McWhorter, 1948](#_ENREF_22" \o "Miller, 1948 #125)).

Isolates sub-cultured on to MEA were incubated at 20oC for at least two weeks and mycelium scraped from the leading edge of each isolate were aseptically transferred into Erlenmeyer flasks (250 mL) containing 150 mL of Malt Extract Broth (MEB: malt extract 20.0 g L-1, glucose 20.0 g L-1, and peptone 1.0 g L-1). The liquid cultures were incubated on a rotary platform shaker (Innova™ 2100, New Brunswick Scientific) at 150 rpm at 25oC. After 14 days, cultures of all four isolates with were mixed in equal volumes and blended for 5 min (Kambrook®, Mega Blender) to make the inoculum mixture of *P. capsellae* mycelial fragments. The final concentration of mycelial fragments was adjusted to 4 x 106 mL-1 fragments using a haemocytometer. Plants at the 4-6 leaf stage (approximately 7-8 weeks of age) were inoculated with the mycelial fragments mixture (4 x 106 mL-1) using a hand-held and hand-operated aerosol sprayer. Thereafter, another two sequential inoculations were made at two-week intervals. Inoculum was applied in the late afternoon followed by the conducive, high humidity environment overnight which would maximise infection.

 *2.5. Disease assessments*

Plants were assessed weekly for white leaf spot disease from approximately 30 days after the third inoculation for four weeks. Disease incidence and the amount of leaf collapse due to white leaf spot were assessed on each genotype in both field trials as follows.

First, the percentage leaves diseased was assessed for each of 10 plants per each row for each genotype using a 0 - 10 disease incidence scale for white leaf spot leaf ([Barbetti, 1987](#_ENREF_3" \o "Barbetti, 1987 #202); [Eshraghi](#_ENREF_13" \o "Eshraghi, 2007 #93) *[et al.](#_ENREF_13" \o "Eshraghi, 2007 #93)*[, 2007](#_ENREF_13" \o "Eshraghi, 2007 #93)), where 0 = nil disease, 1 = 1–10%, 2 = 11–20%, 3 = 21–30%, 4 = 31–40%, 5 = 41–50%, 6 = 51–60%, 7 = 61–70%, 8 = 71–80%, 9 = 81–90%, 10 = 91–100% of leaves diseased. Area under disease progress curve (AUDPC) values for each genotype were subsequently calculated from these independent disease incidence scores using the formula Y= ∑ [(Xi + Xi+1)/2] (ti+1 - ti), where Y is the AUDPC, Xi is the white leaf spot leaf disease incidence of the ith evaluation, Xi+1 is the white leaf spot score of the i+1th evaluation and (ti+1 - ti) is the number of days between two evaluations ([Campbell and Madden, 1990](#_ENREF_8" \o "Campbell, 1990 #222)). AUDPC was chosen because resistance against *P. capsellae* is likely quantitative such that AUDPC provides the most appropriate estimate for where the accumulated disease incidence and/or severity is assessed multiple times ([Vale](#_ENREF_29" \o "Vale, 2001 #63) *[et al.](#_ENREF_29" \o "Vale, 2001 #63)*[, 2001](#_ENREF_29" \o "Vale, 2001 #63)). Secondly, the extent of leaf collapse caused by white leaf spot disease was assessed on a 0 - 10 scale where 0 = nil collapse and 10 = >90% of leaves collapsed from *P. capsellae* infection as use by [Barbetti and Nichols (2005](#_ENREF_5" \o "Barbetti, 2005 #223)) for *Cercospora zebrina* on subterranean clover (*Trifolium subterraneum*). Subsequently, each 0 - 10 leaf collapse score was converted into Percent Leaf Collapse Index (%LCI) based on the methods described by [McKinney (1923](#_ENREF_21" \o "McKinney, 1923 #250)), where:

%LCI = {[(a × 0) + (b × 1) + (c × 2) + (d × 3)+(e × 4) + …….(k x10)] × 100} / [(a + b + c + d + ……k) × 10)]

and where a, b, c, d, e ……j are the number of plants with leaf collapse scores of 0, 1, 2, 3, 4, …..10, respectively.

*2.6. Data analysis*

For each field trial, the AUDPC values for % leaves diseased and % LCI for leaf collapse were calculated. Each field trial dataset was then analysed separately using one-way ANOVA with GenStat Release 14.2 (14th Edition, Lawes Agricultural Trust, Rothamsted Research, UK). Significant differences between genotypes were separated using Fisher’s least significant differences (LSDs). Correlations were made between two disease assessment methods (AUDPC and %CLI) within each field trial dataset and, in trial 2, also the relationship of AUDPC and %CLI with year of varietal release determined via significance of *r*. Further, the relationship of AUDPC and country of origin for varieties of *B. napus* and *B. juncea* in field trial one was determined separately by using an unbalanced one-way ANOVA using GenStat Release 14.2.

 **3. Results**

For both field trials, disease symptoms were evident by 15 days post-inoculation (dpi); and there were significant differences (*P* < 0.001) among test genotypes (trial 1, Table 1; trial 2, Table 2).

*3.1. Field trial 1*

Across the 113 different genotypes from the three *Brassica* species (*B. napus*, *B. juncea* and *B. oleracea* var. *capitata*), there was wide variation in AUDPC values, ranging from 0 to 221.2 (Table 1). Fifty nine *B. oleracea* var. *capitata* genotypes tested were clearly the most resistant, with AUDPC values ranging from 0 to 68.25. Five genotypes of *B. oleracea* var. *capitata*, viz. V04A0007, V04A0048, V04A0050, V04A0146, and V04A0143, demonstrated complete resistance, having 0 AUDPC value. We believe this is the first high level resistance reported in *B. oleracea* var. *capitata*. Nevertheless, *B. oleracea* var. *capitata* genotypes V04A0216 and V04A0074 showed the highest disease incidence of this species, with relative resistance rankings 62 and 58 out of 113, respectively. The most susceptible were the 20 genotypes of *B. juncea* (e.g., Fig. 1A)*,* with AUDPC values ranging from 71.7 to 221.2. Of these, MJBT1033, MJBT1032 and MJBT1097 were the most susceptible, with AUDPC values of 211.7, 218.1 and 221.2, respectively. Thirty four genotypes of *B. napus* were intermediate in terms of resistance (e.g., Fig. 1B), with AUDPC values ranging from 64.7 to 133.6. Of these, Rainbow from Australia (AUDPC – 64.7) and YM18 (AUDPC – 65.0) from China were the most resistant, while Thunder TT, the most susceptible variety with AUDPC - 133.6 (Table 1).

There was strong positive correlation (*P* < 0.001, *r* = 0.96) between two different disease assessment methodologies, viz. AUDPC for percentage of leaves diseased and extent of leaf collapse (% LCI) from disease showing the same general patterns of resistance or susceptibility across test genotypes. Therefore, considering %CLI, as in AUDPC values, *B. oleracea* var. *capitata* genotypes were the most resistant, having lowest %CLI (range 0-8.1), and with six genotypes with complete resistance (viz. V04A0007, V04A0048, V04A0050, V04A0147, V04A0071 and V04A0040). The range of %CLI for highly susceptible *B. juncea* genotypes was from 18.1 to 38.7. *B. juncea* genotypes; MJBT1032, MJBT1097 and MJBT1129 were the most susceptible with %CLI values of 38.7, 36.9 and 35.8, respectively. The %CLI values across *B. napus* genotypes were intermediate between *B. oleracea* var. *capitata* and *B. juncea*, with values ranging 8.1 to 17.5 (Table 1).

Further, in terms of country of origin, a greater number of resistant genotypes originated from China and *B. juncea* genotypes from China were significantly (*P* < 0.001) more resistant from the genotypes of other two countries, Australia and India.

*3.2. Field trial 2*

In terms of both AUDPC and %LCI, the most resistant with AUDPC < 20 or %CLI < 3.7 were *B. napus* genotypes, Pioneer® 45Y22 (RR), ATR Wahoo and Mystic (Table 2). In contrast, *B. juncea* Xceed Oasis CL, Sahara CL and JB0Z-814156 were the most susceptible among the Australian varieties having greatest AUDPC (> 125) and greatest %CLI (>18) (Table 2). Overall, for both AUDPC and %CLI, *B. juncea* genotypes were more susceptible compared with *B. napus* varieties. This was illustrated by 45 varieties of *B. napus* with AUDPC ranging from 15.7 t0 73.8 and %CLI from 3.7 to 12.5; in comparison with the range for AUPDC and %CLI for the 10 highly susceptible *B. juncea* varietiesof 75.7-159.6 and 13.1-18.7, respectively (Table 2). There was no significant (*P* > 0.05) correlation between levels of resistance/susceptibility in comparison with year of varietal release in Australia for either AUDPC (*R2* =0.023) (Fig 2a) or %CLI (*R2* =0.017) (Fig. 2b).

Differences were observed in the level of disease expression across some common varieties between trials such as Charlton, ATR Stingray, Pinnacle, Thunder TT, Rainbow, Rivette, Tarcoola and ATR Gem.

*3.3. Comparisons of the three Brassica species from combined data across trials 1 and 2*

Despite some differences in overall disease levels between the two trials there were apparent differences in resistance expression between three *Brassica* species in terms of AUDPC values (Fig. 3) or % CLI (data not shown). Seventy nine selections of *B. napus* showed the widest range in disease development in terms of AUDPC for percentage leaves diseased, ranging from 15.7 to 133.6 for *B. oleracea* var. *capitata*, 59 selections did not show high variation in AUDPC values, only ranging from 0-68.2. However, this was overall clearly the most resistant species. In contrast, 30 *B. juncea* genotypes showed greatest range in AUDPC values (71.7-221.2), and showed overall greater susceptibility of Indian mustard to white leaf spot disease (Fig. 3).

1. **Discussion**

The 168 genotypes across three *Brassica* species over the two field trials, *B. napus*, *B. juncea,* and *B. oleracea* var. *capitata*, displayed wide range in host resistance reactions to *P. capsellae;* from complete resistance to highly susceptible. *B. oleracea* var. *capitata* was the species with greatest resistance, with five genotypes completely resistant. We believe this is the first report of complete resistance to *P. capsellae* in *B. oleracea*. A previous study by [Gunasinghe](#_ENREF_15" \o "Gunasinghe, 2013 #287) *[et al.](#_ENREF_15" \o "Gunasinghe, 2013 #287)* [(2013](#_ENREF_15" \o "Gunasinghe, 2013 #287)) reported high resistance but not complete resistance in some genotypes of *B. oleracea* var. *capitata;* a study where most Asian leafy vegetables such as *B. rapa* var. *rosularis*, *B. campestris* var*. chinensis and B. rapa* were extremely susceptible to *P. capsellae*, and as was *B. juncea* in the current study. This confirms the particularly high value of resistance in *B. oleracea* var. *capitata* in the current study. Furthermore, resistances in *B. oleracea* var*. capitata* and *B. napus* in the current study, along with high level resistances in some genotypes of *Crambe abyssinica, Eruca sativa and Eruca vesicaria* reported earlier by [Gunasinghe](#_ENREF_15" \o "Gunasinghe, 2013 #287) *[et al.](#_ENREF_15" \o "Gunasinghe, 2013 #287)* [(2013](#_ENREF_15" \o "Gunasinghe, 2013 #287)), together offer prospects for delivering high levels of resistance to white leaf spot across future oilseed and vegetable *Brassicaceae*. It is likely that at least some of these resistance sources/types are genetically distinct, further increasing their value to breeding programs.

 Overall, while expressions of resistance in *B. napus* varieties were intermediate compared with *B. juncea* and *B. oleracea* var. *capitata*, *B. napus* varieties Rainbow, Skipton and Charlton demonstrated strong resistance against white leaf spot disease both in previous screening studies by [Gunasinghe](#_ENREF_15" \o "Gunasinghe, 2013 #287) *[et al.](#_ENREF_15" \o "Gunasinghe, 2013 #287)* [(2013](#_ENREF_15" \o "Gunasinghe, 2013 #287)) and [Eshraghi](#_ENREF_13" \o "Eshraghi, 2007 #93) *[et al.](#_ENREF_13" \o "Eshraghi, 2007 #93)* [(2007](#_ENREF_13" \o "Eshraghi, 2007 #93)), and again in the current study. Some were highly resistant [e.g. ‘Pioneer® 45Y22 (RR)’, ‘ATR Wahoo’, ‘Skipton’] but others highly susceptible (e.g. ‘Thunder TT’, ‘Tranby’). ‘Pioneer® 45Y22 (RR)’ was released in 2011 and ‘ATR Wahoo’ was released in 2013, the former as a Roundup Ready variety and the latter is a variety with triazine tolerance ([Bucat, 2015](#_ENREF_6" \o "Bucat, 2015 #414); [Ware, 2014](#_ENREF_30" \o "Ware, 2014 #416)). That ‘Pioneer® 45Y22 (RR)’ and ‘ATR Wahoo’ are the most resistant *B. napus* varieties and are also rated as either in the ‘medium risk’ or ‘no risk’ groups for blackleg disease, respectively ([Anonymous, 2013](#_ENREF_2" \o "Anonymous, 2013 #329)), is fortuitous. Similarly, ‘Mystic’, released in 1998, also demonstrated consistent high level resistance against *P. capsellae* (this study) and against Sclerotinia stem rot (*Sclerotinia sclerotiorum*) ([Uloth](#_ENREF_27" \o "Uloth, 2015 #484) *[et al](#_ENREF_27" \o "Uloth, 2015 #484)*[., 2015](#_ENREF_27" \o "Uloth, 2015 #484); [Uloth](#_ENREF_28" \o "Uloth, 2013 #260) *[et al](#_ENREF_28" \o "Uloth, 2013 #260)*[., 2013](#_ENREF_28" \o "Uloth, 2013 #260)). Such ‘dual disease’ resistances are of particular value to breeding programs. Also, that Gunasinghe *et al.,* (2013) found *B. napus* varieties in general were more resistant than *B. juncea* genotypes is promising for oilseed rape. In contrast, the very high susceptibility of Indian-and Australian-derived *B. juncea* varieties and genotypes to white leaf spot disease is of major concern. Currently, India does not have *P. capsellae* in *B. juncea* and if it is introduced into India, the outcome could potentially be catastrophic for India’s mustard production in particular, and perhaps also for some other oilseed and vegetable *Brassica* species. Similarly, for Australia, that *B. juncea* ‘Xceed Oasis CL’, the first herbicide tolerant Clearfield tolerant juncea canola released in Australia ([Ware, 2014](#_ENREF_30" \o "Ware, 2014 #416)) with a high level of blackleg resistance ([Anonymous, 2013](#_ENREF_2" \o "Anonymous, 2013 #329)), is highly susceptible to *P. capsellae* (relative resistance ranking 56/57) is of concern for Australia. This is especially so as several other recently released *B. juncea* varieties such as Dune and Sahara CL are also very susceptible. Further, 'Xceed Oasis CL’ is also highly susceptible to *S. sclerotiorum* ([Uloth](#_ENREF_27" \o "Uloth, 2015 #484) *[et al.](#_ENREF_27" \o "Uloth, 2015 #484)*[, 2015](#_ENREF_27" \o "Uloth, 2015 #484)). Consequently, there is an urgent need to locate effective resistance to *P. capsellae*, for both India and Australia. For India, as insurance against its accidental introduction there, and in Australia, in order to preserve and exploit the full potential of *B. juncea* as an oilseed crop particularly suitable for low rainfall areas across the southern Australian grain-belt ([Burton](#_ENREF_7" \o "Burton, 2003 #192) *[et al.](#_ENREF_7" \o "Burton, 2003 #192)*[, 2003](#_ENREF_7" \o "Burton, 2003 #192)).

In the current study, *B. napus* from China overall showed greatest expression of resistance. In contrast, in an earlier study by [Gunasinghe](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh) *[et al](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh)*[., (2013)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.2jxsxqh), *B. napus* varieties from India were in general more susceptible to *P. capsellae* than Australian or Chinese genotypes. This is perhaps a legacy from the fact that *B. napus* genotypes from India were distinctly separated from *B. napus* genotypes in Australia and China ([Chen](#_ENREF_10" \o "Chen, 2008 #255) *[et al.,](#_ENREF_10" \o "Chen, 2008 #255)* [2008](#_ENREF_10" \o "Chen, 2008 #255)). However, in the current study, *B. juncea,* genotypes from China were again more resistant than those from Australia or India as found in a previous study by [Gunasinghe](#_ENREF_15" \o "Gunasinghe, 2013 #287) *[et a](#_ENREF_15" \o "Gunasinghe, 2013 #287)*[l. (2013](#_ENREF_15" \o "Gunasinghe, 2013 #287)). The extreme susceptibility of *B. juncea* genotypes MJBT1097, MJBT1032 and MJBT1033 was unexpected, as these genotypes containing introgression(s) from wild weedy *Brassicaceae* had shown extremely strong host resistance to Sclerotinia stem rot in the earlier studies of [Garg](#_ENREF_14" \o "Garg, 2010 #429) *[et al](#_ENREF_14" \o "Garg, 2010 #429)*[. (2010](#_ENREF_14" \o "Garg, 2010 #429)). These and other highly susceptible *B. juncea* genotypes need to be used with care in breeding programs, for example, where resistance to Sclerotinia stem rot was being targeted, so as not to increase susceptibility to *P. capsellae* in an already overall disease-susceptible species.

There was no trend of improvement in resistance to white leaf spot disease in Australian *B. napus* canola and *B. juncea* mustard varieties released since 1998 to date. This is not unexpected, as historically white leaf spot resistance has not been considered a high priority for inclusion in disease resistance breeding programs for broad-acre oilseed or horticultural *Brassicaceae* species either in Australia ([Salisbury and Barbetti, 2011](#_ENREF_25" \o "Salisbury, 2011 #238)), UK, or elsewhere (Inman *et al.* 1992). Regardless, *B. napus* varieties with high resistance to white leaf spot were noted among both historical (Monty, Mystic) and newly released varieties, Pioneer® 45Y22 (RR) (released 20110 and ATR Wahoo (released 2013). As white leaf spot lesions in Australia are generally mistaken for blackleg, the absence of extremely susceptible varieties in *B. napus* could also be due to incidental and/or inherent selection occurring over past decades during which resistance development was focussed against blackleg disease. However, extreme susceptibility of some of the newly released *B. juncea* varieties and the greater general susceptibility of *B. juncea* highlights the value of now including white leaf spot resistance as a secondary priority in future breeding programs, not only for *B. napus* but particularly for *B. juncea*.

There were some differences in the level of expression of resistance across some common varieties between trials, for example, Charlton, ATR Stingray, Pinnacle, Thunder TT, Rainbow, Rivette, Tarcoola, ATR Gem. Disease development of varieties such as ATR Stingray and Charlton in two trials (comparatively high disease in trial one and lower disease in trial two) demonstrates that varieties with intermediate resistance can achieve improved resistant under warmer and drier conditions less favourable for disease development as occurred later in the season in trial 2 due to its delayed sowing. Similarly, [Chandler (1965](#_ENREF_9" \o "Chandler, 1965 #130)) also noted that while white leaf spot can cause complete crop loss of turnip under irrigation, it is considered of minor importance in that crop under less conducive conditions in the absence of irrigation.

The general increase in worldwide significance of white leaf spot over past decades ([Penaud, 1987,](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.49x2ik5) [Amelung and Daebeler, 1988,](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.30j0zll) [Inman, 1992,](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.z337ya) [Khangura](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.4i7ojhp) *[et al](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.4i7ojhp)*[., 2014,](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.4i7ojhp) Ocamb, 2014 [)](file:///C%3A%5C%5CUsers%5C%5C00042760%5C%5CDesktop%5C%5CGunashinge%20et%20al%20-%20New%20Resistances%20to%20WLS%20%20-%20Crop%20Protection%20Sept%202015%20PLAGSCAN%20VERSION%207%20Sept.docx%22%20%5Cl%20%22h.lnxbz9), the inability of chemical control to reliably and cost-effectively suppress this disease ([Inman, 1992](#_ENREF_16" \o "Inman, 1992 #129)), and the high level resistances identified in the current study, together highlight the need for inclusion of host resistance to white leaf spot disease as a priority in varietal recommendations and in breeding programs. This is especially so for the more susceptible species like *B. juncea*. The highly resistant genotypes identified in this study are important sources of resistance across oilseed *B. napus* and *B. juncea,* and also horticultural *B. oleracea,* for development of new more resistant varieties. The first immunity to this disease in *B. oleracea* var. *capitata* and the range of other high level host resistances such as in *B. napus* identified in this study should be utilized for new crop resistance to significantly improve management of this disease. Finally, disease resistance also highlights the potential for significant reductions in fungicide usage, potentially even eliminating current reliance upon fungicidal controls for management of white leaf spot disease worldwide through effective breeding to make the resistance durable.

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**References**

Amelung, D., Daebeler, F., 1988. White spot (*Pseudocercosporella capsellae*/Ell. et Ev. Deighton) - A new disease of winter rape in the German Democratic Republic. Nachrichtenblatt fuer den Pflanzenschutz in der DDR 42, 73 - 74.

Anonymous, 2013. Fact sheet Blackleg Management Guide. Grains research and development coroporation.

Barbetti, M.J., 1987. Effects of three foliar diseases on biomass and seed yield for 11 cultivars of subterranean clover. Plant Dis. 71, 350-353.

Barbetti, M.J., Khangura, R., 2000. Fungal diseases of canola in Western Australia. Bulletin 4406, 15.

Barbetti, M.J., Nichols, P.G.H., 2005. Field performance of subterranean clover germplasm in relation to severity of *Cercospora* disease. Australas. Plant. Pathol. 34, 197-201.

Bucat, J., 2015. Canola variety guide for 2015 cropping season. Department of Agriculture and Food Western Australia. .

Burton, W., Salisbury, P., Potts, D., 2003. The potential of canola quality *Brassica juncea* as an oilseed crop for Australia, 13th Australian Research Assembly on Brassicas Tamworth, NSW, Australia, pp. 62-64.

Campbell, C.L., Madden, L.V., 1990. Temporal analysis of epidemics. I. Description and comparison of disease progress curves., Introduction to Plant Disease Epidemiology. John Wiley & Sons., New York, pp. 161-202.

Chandler, W.A., 1965. Fungicidal control of anthracnose and white spot of turnip greens. Plant Dis. Rep. 49, 419 - 422.

Chen, s., Nelson, M.N., Ghamkhar, K., Fu, T., Cowling, W.A., 2008. Divergent patterns of allelic diversity from similar origins: the case of oilseed rape (*Brassica napus* L.) in China and Australia. Genome 51, 1-10.

Crossan, D.F., 1954. *Cercosporella* leafspot of crucifers. North Carolina Agricultural Experiment Station Technical Bulletin 109, 23.

Ocamb, C., 2014. White Leaf Spot and Gray Stem in Crucifer Seed Crops in Western Oregon. OSU-Corvallis, OSU-Corvallis.

Deighton, F.C., 1973. Studies on *Cercospora* and allied genera. Mycological Papers 133, 42-46.

Eshraghi, L., Barbetti, M.J., Li, H., Danehloueipour, N., Sivasithamparam, K., 2007. Resistance in oilseed rape (*Brassica napus*) and Indian mustard (*Brassica juncea*) to a mixture of *Pseudocercosporella capsellae* isolates from Western Australia. Field Crops Reserch 101, 37-43.

Garg, H., Atri, C., Sandhu, P., Kaur, B., Renton, M., Banga, S., Singh, H., Singh, C., Barbetti, M., Banga, S., 2010. High level of resistance to *Sclerotinia sclerotiorum* in introgression lines derived from hybridization between wild crucifers and the crop *Brassica* species, *B. napus* and *B. juncea*. Field Crops Res. 117, 51-58.

Gunasinghe, N., You, M.P., Banga, S.S., Barbetti, M.J., 2013. High level resistance to *Pseudocercosporella capsellae* offers new opportunities to deploy host resistance to effectively manage white leaf spot disease across major cruciferous crops. Eur. J. Plant Pathol. 138, 873-890.

Inman, A.J., 1992. The biology and epidomiology of white leaf spot (*Pseudocercosporella capsellae*) on oilseed rape., Department of Plant Pathology. The University of London, p. 303.

Inman, A.J., Fitt, B.D.L., Welham, S.J., Evans, R.L., Murray, D.A., 1997. Effects of temperature, cultivar and isolate on the incubation period of white leaf spot (*Mycosphaerella capsellae*) on oilseed rape (*Brassica napus*). Ann. Appl. Biol. 130, 239-253.

Khangura, R., Marcroft, S., Elliott, V., Van de Wouw, A., Lindbeck, K., Ware, A., MacLeod, W., Davidson, J., Howlett, B., 2014. National Survey of canola diseases other than blackleg and Sclerotinia. Proceedings of the National Meeting on Fungal Diseases of Canola, 19 February 2014, University of Melbourne, Parkville.

Koike, S.T., Gladders, P., Paulus, A.O., 2007. Vegetable diseases: a color handbook. Academic Press, San Diego, USA.

Lancaster, R., 2006. Diseases of vegetable brassicas. Farmnote 39/90 4.

McKinney, H.H., 1923. Influence of soil temperature and moisture on infection of wheat seedlings by *Helminthosporium sativum*. Journal of Agricultural Research 26, 195-217.

Miller, P.W., McWhorter, F.P., 1948. A disease of cabbage and other crucifers due to *Cercosporella brassicae*. Phytopathology 38, 893 - 898.

Penaud, A., 1987. La maladie des taches blanches du colza. Phytoma 95, 23 - 26.

Petrie, G.A., Vanterpool, T.C., 1978. *Pseudocercosporella capsellae*, the cause of white leaf spot and grey stem of cruciferae in Western Canada. Can. Plant Dis. Surv. 58, 69-72.

Salisbury, P.A., Barbetti, M.J., 2011. Breeding oilseed Brassica for climate change, In: Yadav, S.S., Redden, R.T., Hatfield, J.S., Lotze-Campen, H., Hall, A. (Eds.), Crop Adaptation to Climate Change. John Wiley & Sons Ltd., Chichester, West Sussex, UK., pp. 448-463.

Shivas, R.G., 1989. Fungal and bacterial diseases of plants in Western Australia. J. R. Soc. West. Aust. 72, 1 - 62.

Uloth, M., You, M., Barbetti, M., 2015. Comparison of host resistance to Sclerotinia stem rot in historic and current *Brassica napus* and *B. juncea* and critical management implications. Crop Pasture Sci. 66, 841-848.

Uloth, M., You, M.P., Finnegan, P.M., Banga, S.S., Banga, S.K., Yi, H., Salisbury, P.A., Barbetti, M.J., 2013. New sources of resistance to *Sclerotinia sclerotiorum* for crucifer crops. Field Crops Res. (In Press).

Vale, F.X.R., Parlevliet, J.E., Zambolim, L., 2001. Concepts in plant disease resistance. Fitopatologia Brasileira 26, 577-589.

Ware, A., 2014. Canola variety sowing guide 2015, 2015 South Australian Research and Development Institute Sowing Guide. South Australian Research and Development Institute, Adelaide. <http://www.sardi.sa.gov.au/__data/assets/pdf_file/0011/45965/canola.pdf>, p. 3640.

Table 1: Field trial 1: Genotype responses under field conditions at Shenton Park Field Station, Western Australia, following inoculations of *Pseudocercosporella capsellae* as measured in Area Under Disease Progress Curve (AUDPC) in relation to the percent leaves diseased and as Percent Leaf Collapse Index (%LCI) for *Brassica napus* (34), *B. oleracea L. var. capitata L.* (59)and *B. juncea* (20) genotypes. A relative ranking score for each genotype (1 to 113, within brackets) was given depending on the level of resistance, with 1 the highest level of resistance and 113 the most susceptible of the genotypes tested. The lines common to both fields are highlighted in bold font.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Species** | **Genotype** | **Country of Origin** | **%LCI** | **AUDPC** |
| *B. oleracea* var. *capitata* | V04A0007 | China | 0.0 | (1) | 0.0 | (1) |
| *B. oleracea* var. *capitata* | V04A0048 | China | 0.0 | (1) | 0.0 | (1) |
| *B. oleracea* var. *capitata* | V04A0050 | China | 0.0 | (1) | 0.0 | (1) |
| *B. oleracea* var. *capitata* | V04A0146 | China | 0.6 | (7) | 0.0 | (1) |
| *B. oleracea* var. *capitata* | V04A0143 | China | 1.7 | (21) | 0.0 | (1) |
| *B. oleracea* var. *capitata* | V04A0147 | China | 0.0 | (1) | 1.8 | (6) |
| *B. oleracea* var. *capitata* | V04A0065 | China | 1.3 | (11) | 2.3 | (7) |
| *B. oleracea* var. *capitata* | V04A0071 | China | 0.0 | (1) | 2.8 | (8) |
| *B. oleracea* var. *capitata* | V04A0040 | China | 0.0 | (1) | 5.1 | (9) |
| *B. oleracea* var. *capitata* | V04A0150 | China | 0.6 | (7) | 5.1 | (9) |
| *B. oleracea* var. *capitata* | V04A0033 | China | 0.6 | (7) | 6.4 | (11) |
| *B. oleracea* var. *capitata* | V04A0142 | China | 1.3 | (11) | 6.4 | (11) |
| *B. oleracea* var. *capitata* | V04A0001 | China | 1.3 | (11) | 7.1 | (13) |
| *B. oleracea* var. *capitata* | V04A0193 | China | 0.6 | (7) | 9.3 | (14) |
| *B. oleracea* var. *capitata* | V04A0019 | China | 1.9 | (21) | 10.1 | (15) |
| *B. oleracea* var. *capitata* | V04A0153 | China | 1.3 | (11) | 10.6 | (16) |
| *B. oleracea* var. *capitata* | V04A0035 | China | 1.9 | (21) | 10.9 | (17) |
| *B. oleracea* var. *capitata* | V04A0148 | China | 3.1 | (43) | 11.0 | (18) |
| *B. oleracea* var. *capitata* | V04A0038 | China | 1.3 | (11) | 11.8 | (19) |
| *B. oleracea* var. *capitata* | V04A0045 | China | 1.7 | (21) | 11.8 | (20) |
| *B. oleracea* var. *capitata* | V04A0155 | China | 2.5 | (33) | 11.9 | (21) |
| *B. oleracea* var. *capitata* | V04A0212 | China | 2.5 | (33) | 11.9 | (21) |
| *B. oleracea* var. *capitata* | V04A0215 | China | 3.8 | (50) | 12.8 | (23) |
| *B. oleracea* var. *capitata* | V04A0144 | China | 1.7 | (21) | 13.0 | (24) |
| *B. oleracea* var. *capitata* | V04A0195 | China | 1.7 | (21) | 13.5 | (25) |
| *B. oleracea* var. *capitata* | V04A0063 | China | 1.3 | (11) | 14.2 | (26) |
| *B. oleracea* var. *capitata* | V04A0036 | China | 1.9 | (21) | 14.8 | (28) |
| *B. oleracea* var. *capitata* | V04A0015 | China | 1.3 | (11) | 15.4 | (29) |
| *B. oleracea* var. *capitata* | V04A0194 | China | 1.3 | (11) | 15.4 | (30) |
| *B. oleracea* var. *capitata* | V04A0152 | China | 1.5 | (11) | 15.9 | (31) |
| *B. oleracea* var. *capitata* | V04A0141 | China | 2.3 | (33) | 16.4 | (32) |
| *B. oleracea* var. *capitata* | V04A0037 | China | 1.9] | (21) | 16.9 | (33 |
| *B. oleracea* var. *capitata* | V04A0218 | China | 1.9 | (21) | 17.3 | (34) |
| *B. oleracea* var. *capitata* | V04A0017 | China | 2.5 | (33) | 19.5 | (35) |
| *B. oleracea* var. *capitata* | V04A0032 | China | 1.9 | (21) | 20.3 | (35) |
| *B. oleracea* var. *capitata* | V04A0149 | China | 2.5 | (33) | 20.5 | (36) |
| *B. oleracea* var. *capitata* | V04A0151 | China | 3.1 | (43) | 21.0 | (37) |
| *B. oleracea* var. *capitata* | V04A0145 | China | 1.9 | (21) | 21.1 | (38) |
| *B. oleracea* var. *capitata* | V04A0023 | China | 4.5 | (51) | 22.0 | (39) |
| *B. oleracea* var. *capitata* | V04A0027 | China | 3.1 | (43) | 22.1 | (40) |
| *B. oleracea* var. *capitata* | V04A0049 | China | 5.6 | (54) | 22.9 | (41) |
| *B. oleracea* var. *capitata* | V04A0075 | China | 2.5 | (33) | 23.0 | (42) |
| *B. oleracea* var. *capitata* | V04A0214 | China | 1.9 | (21) | 23.6 | (43) |
| *B. oleracea* var. *capitata* | V04A0154 | China | 3.1 | (43) | 23.6 | (44) |
| *B. oleracea* var. *capitata* | V04A0077 | China | 2.3 | (33) | 23.8 | (45) |
| *B. oleracea* var. *capitata* | V04A0072 | China | 4.4 | (51) | 23.8 | (46) |
| *B. oleracea* var. *capitata* | V04A0018 | China | 3.1 | (43) | 24.1 | (47) |
| *B. oleracea* var. *capitata* | V04A0076 | China | 3.1 | (43) | 24.1 | (47) |
| *B. oleracea* var. *capitata* | V04A0073 | China | 1.3 | (11) | 25.5 | (49) |
| *B. oleracea* var. *capitata* | V04A0217 | China | 2.3 | (33) | 28.3 | (50) |
| *B. oleracea* var. *capitata* | V04A0210 | China | 2.3 | (33) | 29.3 | (51) |
| *B. oleracea* var. *capitata* | V04A0011 | China | 3.1 | (43) | 30.3 | (52) |
| *B. oleracea* var. *capitata* | V04A0034 | China | 5.6 | (55) | 35.5 | (53) |
| *B. oleracea* var. *capitata* | V04A0196 | China | 2.5 | (33) | 36.1 | (54) |
| *B. oleracea* var. *capitata* | V04A0211 | China | 5.0 | (53) | 49.0 | (55) |
| *B. oleracea* var. *capitata* | V04A0192 | China | 6.9 | (57) | 50.8 | (56) |
| *B. oleracea* var. *capitata* | V04A0213 | China | 6.9 | (57) | 53.4 | (57) |
| *B. oleracea* var. *capitata* | V04A0074 | China | 6.3 | (56) | 53.6 | (58) |
| ***B. napus*** | **Rainbow** | **Australia** | **8.1** | **(59)** | **64.8** | **(59)** |
| *B. napus* | YM18 | China | 8.8 | (62) | 65.0 | (60) |
| *B. napus* | ZY006 | China | 10.0 | (65) | 66.4 | (61) |
| *B. oleracea* var. *capitata* | V04A0216 | China | 8.3 | (59) | 68.3 | (62) |
| *B. napus* | Hyden | Australia | 8.8 | (62) | 68.4 | (33) |
| *B. juncea* | Ringot | China | 13.1 | (79) | 71.8 | (64) |
| *B. juncea* | B. juncea-#2 | China | 18.1 | (95) | 75.0 | (65) |
| *B. napus* | YM04 | China | 8.1 | (59) | 76.3 | (66) |
| ***B. napus*** | **ATR Gem** | **Australia** | **9.4** | **(64)** | **76.6** | **(67)** |
| *B. napus* | CrusherTT | Australia | 11.9 | (70) | 80.1 | (68 |
| *B. napus* | YM17 | China | 11.3 | (68) | 80.6 | (69) |
| ***B. napus*** | **Tarcoola** | **Australia** | **10.0** | **(65)** | **82.1** | **(70)** |
| ***B. napus*** | **Rivette** | **Australia** | **11.9** | **(70)** | **82.8** | **(71)** |
| *B. napus* | Grace | Australia | 11.9 | (70) | 85.3 | (72) |
| *B. napus* | Mystic#2 | Australia | 13.1 | (79) | 89.9 | **(**73**)** |
| *B. napus* | NC2 | India | 11.3 | (68) | 91.1 | (74) |
| ***B. napus*** | **Charlton** | **Australia** | **12.5** | **(73)** | **91.4** | **(75)** |
| *B. napus* | Surpass-400 | Australia | 10.0 | (65) | 94.3 | (76) |
| *B. napus* | 45C75 | Australia | 15.0 | (84) | 95.4 | (77) |
| *B. juncea* | Xinyou 9 | China | 15.0 | (84) | 96.8 | (78) |
| *B. napus* | CB Scaddan | Australia | 15.0 | (84) | 98.8 | (78) |
| *B. napus* | Jackpot TT | Australia | 12.5 | (73) | 99.5 | (80) |
| *B. napus* |  06-6-3792 | China | 13.1 | (79) | 99.6 | (81) |
| *B. napus* | NC4 | India | 16.3 | (91) | 99.6 | (81) |
| *B. napus* | CB Argyle | Australia | 12.5 | (73) | 102.3 | (83) |
| *B. napus* | 43C80 | Australia | 14.4 | (82) | 103.1 | (84) |
| *B. juncea* | Montara | China | 20.0 | (96) | 105.3 | (85) |
| *B. napus* | 44C73 | Australia | 15.6 | (88) | 105.6 | (86) |
| *B. napus* | Beacon | Australia | 13.8 | (81) | 106.5 | (87) |
| *B. napus* | 44C79 | Australia | 12.5 | (73) | 107.8 | (88) |
| *B. napus* | NC1 | India | 16.3 | (91) | 110.0 | (89) |
| ***B. napus*** | **Pinnacle** | **Australia** | **12.5** | **(73)** | **113.5** | **(90)** |
| *B. napus* | BonanzaTT | Australia | 15.6 | (88) | 114.4 | (91) |
| ***B. napus*** | **ATR Stingray** | **Australia** | **16.9** | **(93)** | **119.0** | **(92)** |
| *B. napus* | FighterTT | Australia | 12.5 | (73) | 120.2 | (93) |
| *B. napus* | NC3 | India | 17.5 | (94) | 120.9 | (94) |
| *B. napus* | 06-p71-2 | China | 14.4 | (82) | 128.1 | (95) |
| *B. napus* | Tranby | Australia | 15.0 | (84) | 131.8 | (96) |
| ***B. napus*** | **Thunder TT** | **Australia** | **15.6** | **(88)** | **133.6** | **(97)** |
| *B. juncea* | MJBA1107 | India | 23.1 | (98) | 150.9 | (98) |
| *B. juncea* | MJBT1036 | India | 26.3 | (99) | 171.3 | (999) |
| *B. juncea* | MJBA1070 | India | 27.5 | (100) | 175.4 | (100) |
| *B. juncea* | MJBT1100 | India | 27.5 | (100) | 180.9 | (101) |
| *B. juncea* | JM06018 | Australia | 28.1 | (101) | 181.8 | (102) |
| *B. juncea* | MJBA1149 | India | 28.8 | (102) | 192.9 | (103) |
| *B. juncea* | MJBT1030 | India | 30.0 | (103) | 193.8 | (104) |
| *B. juncea* | MJBT1129 | India | 35.8 | (110) | 196.3 | (105) |
| *B. juncea* | JM06006 | Australia | 32.5 | (106) | 198.4 | (106) |
| *B. juncea* | MJBT1081 | India | 34.4 | (108) | 200.4 | (107) |
| *B. juncea* | MJBT1098 | India | 35.6 | (109) | 204.6 | (108) |
| *B. juncea* | MJBT1057 | India | 31.3 | (104) | 207.4 | (109) |
| *B. juncea* | MJBA1074 | India | 32.5 | (106) | 210.6 | (110) |
| *B. juncea* | MJBT1033 | India | 31.9 | (105) | 211.8 | (111) |
| *B. juncea* | MJBT1032 | India | 38.8 | (112) | 218.1 | (112) |
| *B. juncea* | MJBT1097 | India | 36.9 | (111) | 221.3 | (113) |

L.s.d at P≤ 0.05 = 6.93 41.3

Significance (P = 0.001)

**Table 2:** Field trial 2: Genotype responses under field conditions following inoculation of *Pseudocercosporella capsellae* as measured as Area Under Disease Progress Curve (AUDPC) in relation to the percent leaves diseased and as Percent Leaf Collapse Index (%LCI) for 55 Australian varieties of *Brassica napus* (45) *and B. juncea* (10)*.* A relative ranking score for each genotype (1 to 55, within brackets) was given depending on the level of resistance; with 1 the highest level of resistance and 55 the most susceptible. The lines common for both fields are highlighted in bold font.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Species** | **Variety** | **Year** | **Breeder** | **%LCI** | **AUDPC** |
| *B. napus* | Pioneer ® 45Y22 (RR) | 2011 | DuPont Pioneer | 3.8 | (2) | 15.7 | (1) |
| *B. napus* | Mystic | 1998 | DPI Victoria | 3.8 | (2) | 17.3 | (2)  |
| *B. napus* | ATR Wahoo | 2013 | Nuseed | 3.1 | (1) | 19.3 | (3)  |
| *B. napus* | Bravo TT | 2005 | Nuseed | 4.4 | (4) | 21.3 | (4)  |
| *B. napus* | Skipton | 2004 | NSW DPI | 5.0 | (11) | 23.8 | (5)  |
| *B. napus* | Warrior | 2005 | NSW DPI | 4.4 | (4) | 24.2 | (6)  |
| *B. napus* | VT 525G | Not released | Seednet | 5.0 | (11) | 24.4 | (7)  |
| *B. napus* | CB Atomic HT | 2012 | Canola Breeders | 4.4 | (4) | 25.4 | (8)  |
| *B. napus* | ATR Bonito | 2013 | Nuseed | 4.4 | (4) | 25.7 | (9 )  |
| *B. juncea* | VT 535G | Not released | Seednet | 5.6 | (18) | 25.7 | (9)  |
| ***B. napus*** | **Charlton** | **1997** | **DPI Victoria** | **4.4** | **(4)** | **26.2** | **(11)**  |
| *B. napus* | Pioneer ® 43Y23 (RR) | 2013 | DuPont Pioneer | 5.6 | (18) | 26.4 | (12)  |
| *B. napus* | Monty | 1996 | NSW DPI | 5.0 | (11) | 26.4 | (13)(13)  |
| *B. napus* | Outback | 2002 | AgSeed-research | 6.3 | (23) | 26.7 | (14)  |
| *B. napus* | Pioneer ® 45Y86 (CL) | 2012 | DuPont Pioneer | 4.4 | (4) | 27.7 | (15)  |
| ***B. napus*** | **Tarcoola** | **2007** | **SARDI/NSW DPI** | **5.6** | **(18)** | **29.8** | **(16)**  |
| ***B. napus*** | **Pinnacle** | **1998** | **DPI Victoria** | **5.0** | **(11)** | **30.7** | **(17)**  |
| ***B. napus*** | **Rivette** | **2002** | **NSWAg** | **6.3** | **(22)** | **31.3** | **(18)**  |
| ***B. napus*** | **ATR Stingray** | **2011** | **Nuseed** | **5.6** | **(18)** | **32.3** | **(19)**  |
| *B. napus* | GT Cobra | 2011 | NuSeed | 5.0 | (11) | 34.3 | (20)  |
| *B. napus* | Karoo | 1998 | DPI Victoria | 4.4 | (4) | 34.7 | (21)  |
| *B. napus* | Pioneer ® 44Y84 (CL) | 2010 | DuPont Pioneer | 5.6 | (18) | 37.8 | (22)  |
| ***B. napus*** | **ATR Gem** | **2011** | **Nuseed** | **6.3** | **(22)** | **38.2** | **(23)**  |
| *B. napus* | Dunkeld | 1993 | DPI Victoria | 6.3 | (22) | 39.2 | (24)  |
| *B. napus* | GT Viper | 2011 | NuSeed | 6.9 | (29) | 39.7 | (25)  |
| *B. napus* | AV Garnet | 2007 | DPI Victoria | 5.0 | (11) | 39.7 | (26)  |
| *B. napus* | Cobbler | 2007 | Nuseed | 6.9 | (29) | 40.4 | (27)  |
| *B. napus* | AV Garnet | 2007 |  DPI Victoria | 6.3 | (22) | 42.7 | (38)  |
| *B. napus* | Marlin | 2006 | DPI Victoria | 7.5 | (32) | 42.8 | (29)  |
| *B. napus* | Trigold TT | 2005 | NPZ Australia | 5.0 | (11) | 44.4 | (30)  |
| *B. napus* | CB Tango | 2013 | Canola Breeders | 6.3 | (22) | 44.7 | (31)  |
| ***B. napus*** | **Rainbow** | **1993** | **DPI Victoria** | **9.4** | **(40)** | **44.7** | **(32)**  |
| *B. napus* | Oscar | 1992 | NSWAg | 6.9 | (29) | 45.2 | (33)  |
| *B. napus* | CB Nitro HT | 2013 | Canola Breeders   | 10.6 | (44) | 45.7 | (34)  |
| *B. napus* | Archer | 2012 | Heritage Seeds | 7.5 | (32) | 47.7 | (35)  |
| *B. napus* | Pioneer ® (CL) | 2012 | DuPont Pioneer | 8.8 | (38) | 51.7 | (36)  |
| *B. napus* | Nuseed GT50 | 2013 | NuSeed | 9.4 | (40) | 53.7 | (37)  |
| *B. napus* | Narendra | 1994 | DAFWA | 7.5 | (32) | 54.6 | (38)  |
| *B. napus* | CB Sturt TT | 2012 | DuPont Pioneer  | 7.5 | (32) | 54.7 | (39)  |
| *B. napus* | Opal | 2006 | DPI Victoria | 8.1 | (36) | 55.2 | (40)  |
| *B. napus* | CB Telfer TT | 2006 | Canola Breeders  | 8.3 | (37) | 57.3 | (41)  |
| ***B. napus*** | **Thunder TT** | **2005** | **Pacific Seeds** | **9.4** | **(40)** | **63.3** | **(42)**  |
| *B. napus* | Tanami TT | 2007 | NPZ Australia | 10.0 | (43) | 64.6 | (43)  |
| *B. napus* | CB Agamax | 2011 | Canola Breeders | 8.8 | (38) | 66.1 | (44)  |
| *B. napus* | Carbine | 2012 | Heritage seeds | 12.5 | (45) | 73.8 | (45)  |
| *B. juncea* | JB0T-907988 | Not released | Seednet | 13.1 | (45) | 75.7 | (46)  |
| *B. juncea* | 397 | Not released | DPI Victoria/CSIRO | 16.3 | (49) | 88.2 | (47)  |
| *B. juncea* | Xceed ® VT X121 CL |  2013 |  Seednet | 16.3 | (49) | 92.3 | (48)  |
| *B. juncea* | Mickey | 2002 | CSIRO | 16.9 | (51) | 93.8 | (49)  |
| *B. juncea* | JB0T-907957 | Not released | Seednet | 13.3 | (47) | 95.5 | (50)  |
| *B. juncea* | JB0T-908982 | Not released | Seednet | 15.0 | (48) | 105.2 | (51)  |
| *B. juncea* | Dune | 2007 | Ag Victoria | 19.4 | (55) | 108.8 | (52)  |
| *B. juncea* | Sahara CL | 2009 | DPI Victoria/Viterra | 18.1 | (52) | 117.3 | (53)  |
| *B. juncea* | Xceed Oasis CL | 2009 | Seednet | 18.1 | (52) | 125.8 | (54)  |
| *B. juncea* | JB0Z-814156 | Not released | Seednet | 18.8 | (54) | 159.6 | (55)  |
| *Significance (varieties) (P = 0.001)* |  |  |  |  |  |
| *L.s.d at P≤ 0.05 =* |  |  | *6.453* | *37.67* |  |

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**Fig. 1.** Showing general high incidence and large coalescing lesions and leaf collapse on a susceptible *Brassica juncea* genotype (**a**), and, lower overall incidence and smaller small lesions on a resistant *Brassica* *napus* genotype (**b**).

**Fig. 2**. Association between varietal release and disease severity as indicated by Area Under Disease Progress Curve (AUDPC) (**2a**) or Percentage Leaf Collapse Index (% CLI ) (**2b**) across (49) Australian *B. napus* (41) and *B. juncea* (8) varieties.

**Fig. 3.** Levels of resistance expressed across three *Brassica* species (168) from combined data of field trial 1 and field trial 2, viz. *B. napus* (79 genotypes), *B. oleracea* (59 genotypes) and *B. juncea* (30 genotypes), as measured by Area Under Disease Progress Curve (AUDPC) of percentage of leaves diseased.