Solanum gourlayi—a Source of Cyst Nematode Resistance in Potato Breeding

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Abstract

The potato cyst nematodes (PCN) *Globodera rostochiensis* and *G. pallida* are among the most important pests causing significant yield loss in potato production. Cultivating resistant cultivars of potato is the most effective and environmentally safe method for protecting potato crops against nematodes. However, widespread cultivation of cultivars resistant to *G. rostochiensis* can affect the reproduction of *G. pallida*. Therefore, breeding for resistance to nematodes remains among the major aims of potato breeding programmes. Many wild *Solanum* species could be valuable sources of nematode resistance. This study examined the resistance to *G. pallida* identified in two accessions of the wild species *Solanum gourlayi*. Both accessions demonstrated resistance to pathotypes Pa2 and Pa3, but show asymmetric distribution of resistance among the progeny clones. The presented distributions of resistance scores indicate quantitative nature of resistance to *G. pallida*. Furthermore, this resistance is specific to each pathotype and may be controlled by different genes. We also conclude that there is a need for independent evaluation of resistance for both pathotypes of *G. pallida* (Pa2 and Pa3).

Keywords *Globodera pallida* · Pathotypes Pa2 and Pa3 · Potato breeding · *Solanum gourlayi*

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Introduction

The potato cyst nematodes (PCN) *Globodera rostochiensis* and *G. pallida* are the most important pests that feed on potato roots (Evans and Trudgill 1992). Yield loss caused by PCN is estimated to be as high as 50% (Nicol et al. 2011). Both PCN species are included in the list of quarantine pathogens in many countries (Smith et al. 1992). Growing resistant cultivars is economically the most effective and environmentally safe method for protecting potato crops against PCN (EPPO/OEPP 2004). However, the widespread cultivation of cultivars resistant to only *G. rostochiensis* may increase the reproduction of *G. pallida*. In recent years, the increased spread of *G. pallida* among populations of nematodes has been observed in Europe (Širca et al. 2012; EPPO 2012, 2013; Nježić et al. 2014). The cultivation of potato cultivars with resistance to multiple *Globodera* species may effectively provide protection against the wide spectrum of PCN pathotypes.

Resistance to nematodes was not initially found within *Solanum tuberosum* ssp. *tuberosum*. Thus, breeding for resistance to nematodes is based on resistance identified in other *Solanum* species (Dalamu et al. 2012). The dominant gene *Gpa2* associated with resistance to *G. pallida* pathotype Pa2 was found in *S. tuberosum* ssp. *andigena* (van der Voort et al. 1999). The dominant gene *H2* was found in *S. multidissectum*, which confers resistance against *G. pallida* pathotype Pa1 (Dunnett 1961; Strachan et al. 2019). Quantitative resistance was identified in the wild species *S. tuberosum* ssp. *andigena*, together with the large effect QTL *GpaIV^{s_{adg}}* (Bradshaw et al. 1998; Bryan et al. 2004), and in *S. vernei* together with *Gpa5* (van der Voort et al. 2000; Bryan et al. 2002). However, both these genes confer only partial levels of resistance to *G. pallida* pathotypes Pa2 and Pa3. Caromel et al. (2005) identified that cooperating resistance loci *GpaV^{s_{spl}}* and *GpaXI^{s_{spl}}* originating from *S. sparsipilum* resulted in a strong hypersensitive response on the roots infected with *G. pallida* Pa2/3. However, many loci conferring resistance to *G. pallida* originate from wild species accessions that have not been introduced into advanced breeding material.

Solanum gourlayi (*grl*) is one of the sources of resistance to *G. pallida* identified among accessions of wild *Solanum* species (Ruiz de Galarreta et al. 1998; Castelli et al. 2005). The major aim of our research was to examine the nematode resistance identified in two accessions of the wild species *S. gourlayi*.

Materials and Methods

Plant Material

Two accessions of *S. gourlayi* (*grl*) were obtained in the form of seeds from the Centre for Genetic Resources, the Netherlands (CGN): CGN22342 and CGN17592. Both of these accessions were described as resistant to pathotypes Pa2 and Pa3 of *G. pallida* (CGN gene bank description n.d.; links in references). Clone Sg 3/3 was obtained from seeds of accession CGN22342 ($2n = 24$ chromosomes), and clone Sg 2/7 was obtained from seeds of accession CGN17592 ($2n = 24$ chromosomes). The resistance of these clones was

confirmed in a glasshouse test, and then these clones were used as resistant parents in crosses with the susceptible diploid clone DW 94-4235 (resistance score 1), obtained in a crossing programme performed in Młochów Research Centre. One hundred and forty progeny clones were obtained from the cross DW 94-4235 × Sg 2/7 and 104 progeny clones were obtained from the cross DW 94-4235 × Sg 3/3.

Test for Nematode Resistance

The test was performed according to Przetakiewicz and Milczarek (2017). The resistance screening was conducted in two independent phenotypic tests. Ten tubers per genotype were planted separately in pots with 1 l of soil (Universal Kronenerde soil) containing nematode cysts (5 eggs × ml⁻¹ of soil) of either *G. pallida* Pa2 (5 tubers) or Pa3 (5 tubers). The pathotypes used for inoculation were the Pa3 population “Chavornay” and pathotype Pa2 obtained from the collection of the Federal Research Centre for Cultivated Plants, Germany (JKI). Plants were grown in a glasshouse for 3 months and then the plants (with soil) were removed and the cysts counted. The relative susceptibility of the tested accessions/progeny clones was calculated according to the following formula:

$$(\text{Pf of tested sample})/(\text{Pf of susceptible standard cultivar}) \times 100\%$$

where Pf is the mean number of cysts determined by counting all cysts from all replicates; cv. Desiree was used as a susceptible standard.

Resistance was scored on a 9-grade scale, where score 9 indicates the highest level of resistance according to the EU Council Directive 2007/33/EC. The progeny clone was regarded as resistant when the score was higher than 5-moderate resistance score (Table 1).

Table 1 Calculation of resistance score on basis of relative susceptibility

Relative susceptibility (%)	Resistance score
< 1	9 (very high) ^a
1.1–3	8 (high to very high)
3.1–5	7 (high)
5.1–10	6 (moderate to high)
10.1–15	5 (moderate)
15.1–25	4 (low to moderate)
25.1–50	3 (low)
50.1–100	2 (very low to low)
> 100	1 (very low)

^a According to Przetakiewicz and Milczarek (2017)

Statistical Analyses

The Pearson correlation coefficient for resistance to pathotypes Pa2 and Pa3 was performed with the STATISTICA data analysis software system, version 10 (www.statsoft.com).

Results

After inoculation with the *G. pallida* pathotypes Pa2 and Pa3, the mean cyst count over the replicates was established for each tested genotype. The cyst count ranged from 0 to 528 cysts for pathotype Pa2 and from 0 to 532 cysts for pathotype Pa3. The susceptible control (Desiree) developed on average 458 cysts of pathotype Pa2 and 468 cysts of pathotype Pa3. The mean number of cysts counted per tested genotype was used for calculation of resistance scores. The clone was regarded as resistant when the score was higher than 5 (under 45 and 47 cysts counted for Pa2 and Pa3, respectively).

Clone Sg 3/3 was highly resistant to pathotype Pa2 (resistance score 8) and to pathotype Pa3 (resistance score 9). Clone Sg 2/7 was highly resistant to pathotype Pa2 (resistance score 9) and resistant to pathotype Pa3 (resistance score 7).

Cyst count and the resistance score for each tested progeny clone are shown in Supplementary Table 1. Among the progeny of DW 94-4235 × Sg 3/3, 95 (95%) of the clones were resistant to pathotype Pa2 (resistance score > 5). Only 11 (12%) of the clones were resistant to Pa3 (Fig. 1). From among 95 clones resistant to pathotype Pa2, 11 clones were resistant to pathotype Pa3. The Pearson correlation coefficient for resistance to pathotypes Pa2 and Pa3 was $r = 0.26^*$ in population DW 94-4235 × Sg 3/3.

Among the progeny of DW 94-4235 × Sg 2/7, the distribution of resistance to pathotype Pa2 was bimodal (Fig. 2). In general, 23 (17%) of the clones from this progeny were resistant to pathotype Pa2 whereas a total of 80 (61%) of the clones were found to be resistant to Pa3 (Fig. 2). From among 80 clones resistant to pathotype Pa3, 15 clones were resistant to pathotype Pa2. The Pearson correlation coefficient for resistance to pathotypes Pa2 and Pa3 was $r = 0.08$ in population DW 94-4235 × Sg 2/7.

Fig. 1 Frequency distribution of resistance to pathotypes Pa2 and Pa3 of *G. pallida* in the progeny of DW 94-4235 × Sg 3/3. Resistance level 9 indicates the highest level of resistance

Fig. 2 Frequency distribution of resistance to pathotypes Pa2 and Pa3 of *G. pallida* in the progeny of DW 94-4235 × Sg 2/7. Resistance level 9 indicates the highest level of resistance

Discussion

Cultivating resistant cultivars of potato is the most effective and environmentally safe method for protecting potato crops against pests and diseases. Potato breeding for resistance is partially based on introgression of resistance genes from wild potato species (Gebhardt and Valkonen 2001). Among *Solanum* spp. evaluated for nematode resistance, *S. gourlayi* was recognised as a source of resistance to *G. pallida* (Dalamu et al. 2012). Van Soest et al. (1983) concluded that both resistant and susceptible accessions can be found in the gene pool of *S. gourlayi*. Uhrig and Wenzel (1981) found that the percentage of resistant clones in the *S. gourlayi* hybrids was higher compared with the *S. vernei* hybrids. Chavez et al. (1988) in their research-derived hybrids of tetraploid *S. gourlayi* rated high resistance to P4A, with > 50% resistant in crosses with *S. tuberosum* ssp. *andigena*, and over 97% in crosses with ssp. *tuberosum*, but susceptible to P5A. In that investigation, two populations of *G. pallida* from South America were used, which are designated P4A and P5A according to the pathotype scheme of Canto-Saenz and de Scurrah (1977). The results of our work indicate that the evaluated accessions of *S. gourlayi* are sources for nematode resistance that can be incorporated into practical potato breeding programmes.

European populations of *G. pallida* are divided into three groups of pathotypes, namely Pa1, Pa2 and Pa3, based on their different pathogenic characteristics (Kort et al. 1977). Many authors, while evaluating sources of resistance, treat the pathotypes Pa2 and Pa3 as one. Resistance to the *G. pallida* pathotypes Pa2/Pa3 is used to indicate resistance to pathotypes Pa2 and/or Pa3 (Sattarzadeh et al. 2006). However, taking into account the results of this work, we conclude that resistance tests should be conducted independently for every pathotype. Although the evaluated resistant parental forms (*grl* accessions) demonstrated resistance to both pathotypes Pa2 and Pa3, this resistance was segregated among the progeny clones. Figures 1 and 2 show the asymmetric distributions of resistances to each tested pathotype of *G. pallida* in the evaluated progenies. Most of the clones

tested from the progeny of DW 94-4235 × Sg 3/3 were highly resistant to pathotype Pa2 and susceptible to pathotype Pa3. In turn, most of the clones tested from the progeny of DW 94-4235 × Sg 2/7 were highly resistant to pathotype Pa3 but susceptible to pathotype Pa2. The Pearson correlation coefficients for resistance to pathotypes Pa2 and Pa3 for these populations were low. The presented distributions of resistance scores (Figs. 1 and 2) indicate the quantitative nature of resistance to *G. pallida*. Furthermore, this resistance is specific to each pathotype and may be controlled by different genes. There is a need of further investigation of the genetic basis of this resistance.

Author's Contribution D.M. conceived and coordinated the project and co-wrote the paper. A.P.P. carried out phenotyping studies. B.F., B.T. and J.P. participated in the design of the studies and co-wrote the paper. All authors reviewed the manuscript.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Statement of Human and Animal Right This article does not contain any studies with human or animal subjects performed by any of the authors.

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