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POTATOES & PESTS PAPAS

Actionable Science Against Nematodes

Figure 1. Potato cyst nematode, *Globodera pallida*, important pest of potato globally. Photos from Dandurand's Laboratory at University of Idaho.

IN THIS ISSUE

New research mapping resistance to potato cyst nematode in Idaho

Idaho is famous for its potatoes and for being the top producing state of russet skinned potatoes. However, these potatoes face a hidden enemy, a microscopic roundworm which can be devastating to the Idaho potato industry. These microscopic roundworms, known as potato cyst nematodes (PCN; *Globodera pallida* and *G. rostochiensis*) have been a problem to potato farmers for years. The golden nematode *G. rostochiensis*. infest fields only in New York, and the pale cyst nematode, *G. pallida*, is found only in Idaho. Researchers, regulators and farmers are working together to safeguard the U.S. potato industry.

One new approach to this challenge comes from recent research conducted by geneticist Dr Joseph Kuhl and nematologist Dr Louise-Marie Dandurand from the University of Idaho, working together with potato breeder Dr Richard Novy and plant pathologist Dr Jonathan Whitworth from USDA-Aberdeen. By crossing

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the PCN-resistant variety 'Eden', with the non PCN-resistant russet-skinned variety 'Western Russet', we have identified promising offspring exhibiting resistance against these harmful roundworms.

This research highlights the potential for breeding PCN-resistant russet varieties and is an important step toward developing more PCN-resistant potato varieties ensuring a strong future for the Idaho potato industry.

Developing potato cyst nematode-resistant in Idaho

Potatoes are a staple food for people around the world (Devoux et al., 2020), but their cultivation is threatened by the potato cyst nematodes (PCN). The PCN, including *G. pallida* and *G. rostochiensis,* are among the most important international potato pests (Figure 1).

In the United States, a major potato producer and consumer, PCN are found in the Northeast (New York) and the Northwest (Idaho). Since the first U.S. detection of *G. pallida* in Idaho in 2006, the United States Department of Agriculture-Animal, Plant Health Inspection Service (USDA-APHIS), through regulatory actions, has successfully contained the infestation. PCN is challenge for potato producer due to their ability to persist in the soil for extended periods. Since PCN poses a considerable threat to the potato crop in the U.S, and it is important to identify opportunities for effective control of this pest.

In Idaho, the primary focus of potato production is processing, particularly of russet skinned potatoes with oblong tuber shapes suitable for french fries. However, this market class, which is predominant in the western United States, lacks resistance to PCN, presenting a challenge in the development of commercially viable resistant potato varieties. Selecting agronomically suitable offspring with PCN resistance from diverse market classes can be challenging. This challenge is pronounced in the case of *G. pallida* where several genes may be needed to contribute additively to the development of resistance.

Identifying potato clones that are resistant to PCN in breeding programs is complex due to many factors, such as limited facilities that allow testing of quarantined pests, the lengthy period required for cyst development, and the labor-intensive process of extracting cysts from soil. However, one way for breeders to accelerate this process is to utilize germplasm containing known molecular markers linked to resistance genes. While these markers provide a valuable tool for early-stage selection, they should be complemented by nematode bioassays to confirm resistance in candidate clones (Dandurand et al., 2019; Gartner et al., 2021).

The research conducted by the University of Idaho focuses mapped resistance to *G. pallida* population pathotype Pa2/3 in 227 potato progeny derived from a cross between PCN resistant 'Eden' and non PCN-resistant 'Western Russet'. By analyzing phenotypic traits related to cyst and egg development, the aim was to identify key factors contributing to *G. pallida* resistance to inform the development of durable, resistant potato varieties (Figure 2).

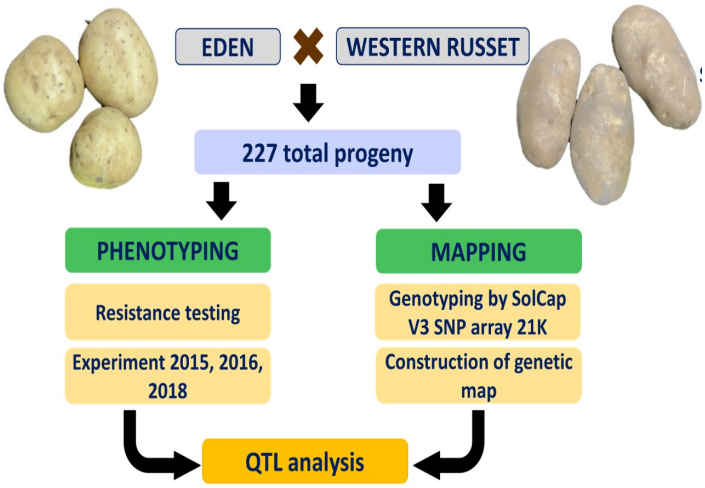


Figure 2. A scheme to tetraploid potato population genotype and phenotype analysis.

Mapping a *Globodera pallida* resistant russet-skinned population

To develop a russet-skinned potato resistant to *G. pallida*, an initial cross was made between a PCN-resistant, oval-tuber variety from Scotland, 'Eden', with a non PCN-resistant russet variety 'Western Russet'. This potato population was kindly provided by Drs Richard Novy and Jonathan Whitworth from The Potato Breeding Program at the USDA-ARS Small Grains and Potato Germplasm Research Unit in Aberdeen, Idaho. The resulting tetraploid potato population, which has four sets of chromosomes instead of the usual two, can give these potatoes variable tuber shape and size. Fortunately, some clones produced tubers with the desirable oblong shape and russet skin. To evaluate resistance to *G. pallida* pathotype Pa2/3, this tetraploid population was compared to four potato cultivars and four potato differential clones with different known levels of resistance in nematode screening. The susceptible cultivars 'Russet Burbank', 'Desiree', and 'Western Russet', along with the resistant 'Eden', were included. The cultivar 'Russet Burbank' was included as a control because it is a popular cultivar in the Pacific Northwest (Whitworth et al., 2018).

Over three years (2015-2018), Dr. Dandurand's Potato Cyst Nematode Program at the University of Idaho, Moscow, assessed a subset of the tetraploid potato population, a total of 227 potato progeny. Multiple replications (six to ten) were performed for each progeny to ensure data reliability, and phenotypic traits related to cyst and egg development were measured. The numbers of cysts and eggs per cyst were used as key indicators of female nematode reproductive success.

The diverse genetic potato population was genotyped with the Illumina Infinitum SolCAP V3 potato SNP array (21,027 SNPs) to create linkage maps (Figure 3). This analysis allowed for the identification of specific genomic regions, known as quantitative trait loci (QTL), associated with resistance to *G. pallida.*

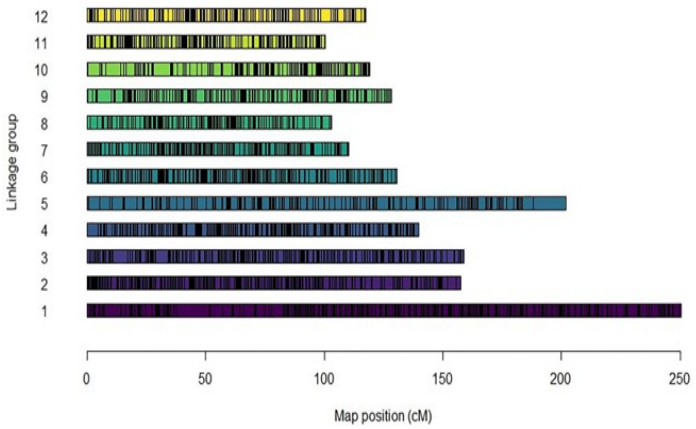


Figure 3. Distribution of the 9,412 SNP markers employed for QTL mapping in this study.

Assessment of the russet-skinned population for resistance to *Globodera pallida* pathotype Pa2/3

Phenotypic results indicated that some of the progeny resulting from this research reacted similarly to or better than the resistant parent 'Eden', which is know to be resistant to PCN. Differences in cyst and eggs per cyst traits suggest that both phenotypic traits contribute information that can be useful for development of resistance in potato. Analysis identified specific genomic regions (QTL) linked to *G. pallida* resistance. These regions are located on chromosome 4 and 6, both related to cyst and egg development (Figure 4).

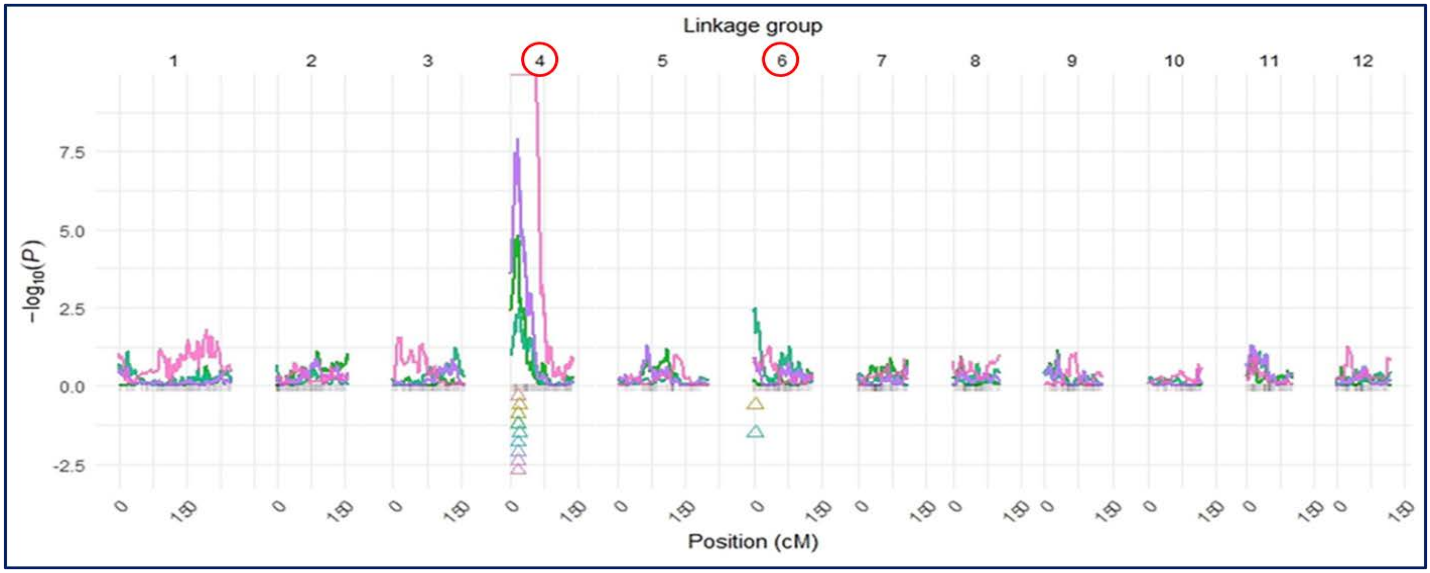
One of the most important QTL was found on chromosome 4. This QTL is linked to several traits related to PCN resistance, including the number of cysts on the potato plants. The QTL related to cysts and eggs per clone on chromosome 4 overlapped, suggesting the presence of a single major locus impacting cysts development linked to the same physical map location. This region on chromosome 4 corresponded to the largest effect QTL for resistance against *G. pallida* pathotype Pa2/3 (Figure 5a). Interestingly, the other QTL on

chromosome 4 associated with eggs per cyst trait is located in close proximity to the QTL for cyst trait (Figure 5b). The close proximity of these QTL suggests that traits of cysts and eggs per cyst development may be related, meaning a single genetic region is responsible for both traits. However, further exploration involving fine mapping of this genomic region is required to elucidate the genetic interactions or mechanism that may influence both traits. In addition to the QTL on chromosome 4, a secondary locus was detected on chromosome 6 associated with reduced eggs per cyst (Figure 5c). This is the first report to map eggs per cyst for *G. pallida* in a russet skinned tetraploid population. The results suggest that it is important to consider both the number of cysts and the number of eggs per cyst when evaluating a potato plant's resistance to PCN. This information can help scientists develop new potato varieties that are better able to fight off this international pest, *G. pallida*.

In the mapping population analyzed, the origin of resistance to *G. pallida* pathotype Pa2/3 comes from 'Eden', which is known for its resistance to *G. pallida,* and has been used in different studies for PCN resistance (Bryan et al., 2022; Whitworth et al., 2018). The QTL detected on chromosome 4 related to cyst and egg traits are linked with the known *G. pallida* resistant locus $GpaIV^{S}_{adg}$ previously mapped to this region of chromosome 4 (Bradshaw et al., 1998), and 'Eden' is known to carry this locus. This locus has been studied for years to understand how it works and to develop potatoes that are more resistant to PCN. Moreover, the molecular marker Contig 237 has been predictive for $GpaIV^{S}_{adg}$ in potato breeding popualtions (Moloney et al., 2010). In this research, Contig 237 mapped to chromosome 4 confirming its role in cyst related traits and was closely linked to cyst QTL on this chromosome.

The adoption of potato varieties resistant to *G. pallida* has been less widespread compared with varieties to *G.rostochiensis*. There are concerns about the long-term effectiveness of deployed resistance and the complex genetic structure of *G. pallida* resistance is one of the contributing factors (Evans & Stone, 1977; Varypatakis et al., 2019). Identification of potato progeny with better resistance than 'Eden' provides valuable insights into the potential resistance of the progeny evaluated against this pathogen. Understanding the genetic basic of resistance is fundamental to the development of effective breeding strategies for PCN management to combat *G. pallida* infestations and improve potato crop resilience.

Figure 4. QTL maps for cysts and eggs traits on chromosomes 4 and 6.



Interestingly, this research indicates that number of cysts is a valuable trait to detect resistance, but considering eggs per cyst trait improves the predictive power and may potentially represent novel genomic regions associated with resistance.

Overcoming the *Globodera pallida* challenge

Idaho is the leading potato production state in the U.S., but *G. pallida* pathotype Pa2/3 is present in a small number of quarantined potato fields in the state. Although efforts have been successful to contain it, the nematode continues to be a risk for U.S. potato production. To combat this issue, scientists are working to develop potato varieties resistant against *G. pallida*. The presence of linked molecular markers is extremely useful to introduce resistance and improve the efficiency of incorporating resistance traits. Markers tightly linked to QTL for cyst and eggs traits, if developed into diagnostic markers, would be useful to develop new varieties.

This research has provided important genetic information associated with *G. palllida* resistance in a tetraploid potato population. The identification of specific regions, on chromosome 4 and 6, linked to reduced cyst and egg phenotypes can be further explored for the development of markers of *G. pallida* resistance in the russet skinned potato. Ideally, the newly developed markers will be universally applicable in populations other than the one used in this research. Moreover, potato breeders can pursue the introgression into tetraploid breeding clones of multiple resistance sources. The progeny selected with alleles resistant to *G. pallida* can be evaluated phenotypically to characterize the behavior, fitness and aggressiveness of *G. pallida* related with cyst and eggs per cyst development. It is important to understand the phenotypic contribution of these alleles in progeny so that a more comprehensive resistance might be realized. Resistance genes are important to protect potatoes from *G. pallida* pathotype Pa2/3. However, while some resistance genes have been identified with a significant impact on the management of PCN, there are still limitations to *G. pallida*. It is important that breeding programs continue to develop breeding material with effective and durable *G. pallida* resistance that also meets commercial requirements. These results increase our understanding of the resistance mechanism to *G. pallida*, particularly in the western U.S. where the russet-skinned cultivars lead potato production.

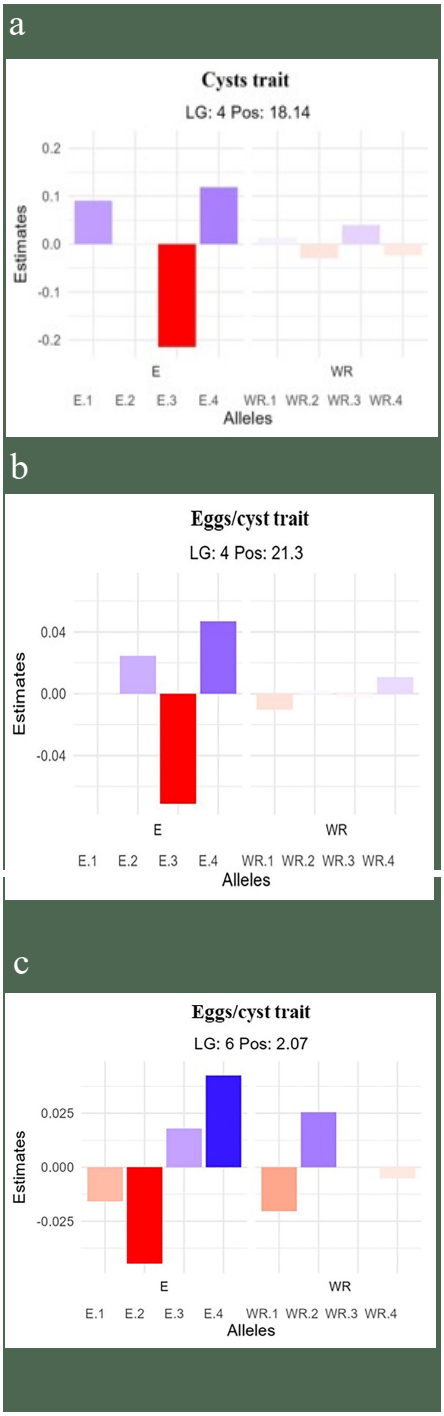


Figure 5. (a) Allele effect of cysts traits on chromosome 4. (b) Allele effect of eggs traits on chromosome 4. (c) Allelle effect of eggs traits on chromosome 6.

Meet the Postdoctoral Associate Rocio Silvestre

Rocio is a Peruvian with a deep passion for potatoes. She earned a BS in Biology from Universidad Nacional Federico Villarreal and her MSc in Biotechnology at the Universidad Nacional Mayor de San Marcos in Lima, Peru. Her professional journey began at the International Potato Center (CIP), Peru, where she was initially focused on bioinformatics for early plant virus identification. Then she moved to CIP-Genebank as the curator for the long-term in vitro conservation of potato and sweet potato breeding lines. In May 2024, she received her PhD in Plant Sciences at University of Idaho under the guidance of geneticist Dr. Joseph Kuhl.

Rocio's doctoral research focused on mapping PCN (*Globodera pallida*) resistance in tetraploid potato. She evaluated a tetraploid russet potato population to identify genetic regions valuable for *G. pallida* resistance in oblong, russet-skinned processing potatoes. Phenotypic evaluations were conducted over three years to evaluate genotypic traits related to cysts and eggs per cyst. This research characterized PCN resistance from 'Eden' and identified genetic regions associated with resistance traits. The relatively few potato cultivars available with strong resistance to *G. pallida* is a significant limitation to managing the nematode, making this new information especially beneficial to breeding programs.

Rocio is currently a postdoctoral associate at the University of Idaho working with Dr. Louise-Marie Dandurand. Her research focuses on the molecular detection, identification and genetic diversity of potato cyst nematode from South American populations.

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