OCCURRENCE, DISTRIBUTION AND CONTROL OF *HETERODERA AVENAE* AND *H. FILIPJEVI* IN THE WESTERN USA*

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SUMMARY

Heterodera avenae occurs in at least seven states in the western USA. *Heterodera filipjevi* was first reported in North America during 2008 and is currently reported only in Oregon, where it occurs as a mixture with *H. avenae*. Juveniles of both species emerge from cysts primarily during the spring. It is estimated that *H. avenae* reduces wheat yield by 21,000 t, valued at US$3.4 million, in the Pacific Northwest states of Idaho, Oregon and Washington. Neither *H. avenae* nor *H. filipjevi* pathotypes in the Pacific Northwest are adequately characterised by indexing plants of the current International Test Assortment. However, reproduction of *H. avenae* is consistently absent in wheat containing the *Cre1* gene and in barley containing the *Rha2* gene. A donor of the *Cre1* gene was crossed with locally-adapted wheat cultivars and the crosses are being screened for resistance. Rotation of winter wheat with weed-free broadleaf crops or long fallow (14 months) reduces damage to subsequent wheat but rotations often are not profitable in the driest areas of the region. Nematicides are not registered for managing damage by cereal cyst nematodes in North America. Fungal parasites of cysts and/or eggs have been detected but have not been investigated and do not appear to provide effective control in Oregon.

INTRODUCTION AND HISTORY

Heterodera avenae in North America was first reported in the Province of Ontario, Canada (Chapman 1938). Three decades later this species was present in most counties of that province (Fushtey 1966). The first detection of *H. avenae* in the United States was in Oregon (Jensen *et al*. 1975). It was subsequently reported in California (Hackney 1981), Washington (Hafez and Golden 1984), Michigan (Graney 1985), Idaho (Hafez and Golden 1985) and in additional areas of Oregon

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(Hafez *et al*. 1992, Smiley *et al*. 1994, Smiley *et al*. 2007). The distribution of *H. avenae* in the western USA now includes selected areas within the states of California, Colorado, Idaho, Montana, Oregon, Utah and Washington (Figure 1; Smiley *et al*. 2007). *H. filipjevi* was first reported in North America during 2008 (Smiley *et al*. 2008, Yan *et al*. 2008, Yan and Smiley 2009). The extent to which *H. avenae* and *H. filipjevi* are actually distributed in the western USA remains unknown because there have been no systematic surveys of these species in these regions.

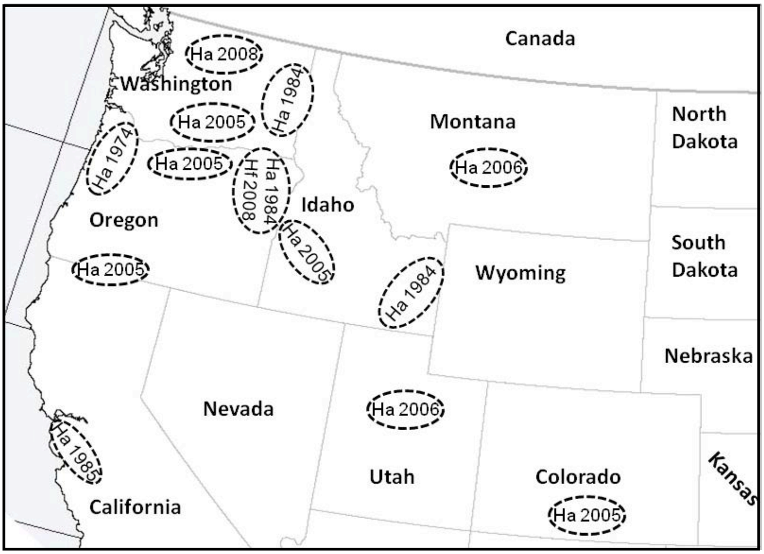

Figure 1. Location and year in which infestations of *Heterodera avenae* (Ha) and *Heterodera filipjevi* (Hf) were publicly reported in the western USA.

Crop damage assessments for *H. avenae* on wheat in Oregon were reported by Smiley *et al*. (1994, 2005). Spring and winter wheat yields in field trials were reduced as much as 25 and 50%, respectively, but it was also observed that stands of spring wheat were totally destroyed in at least some highly-infested commercial fields. Yield losses from *H. avenae* on wheat in Oregon are comparable to those reported elsewhere in the world.

Peak populations of *H. avenae* and *H. filipjevi* juveniles in Oregon occur primarily during the spring (Smiley *et al*. 2005, G. P. Yan, R. W. Smiley and H. Yan unpublished data), similar to the northern ecotype described by Rivoal (1986).

The single-dominant *Cre1* gene effectively halts reproduction of four *H. avenae* populations collected from western Oregon, eastern Oregon, southeast Idaho and eastern Washington, as illustrated by results of a recent test with selected entries of the International Test Assortment (Table 1). Cultivars containing the *Cre1* gene, such as AUS10894, Loros (63/1.7.15.12) and Ouyen have consistently been very effective against these populations in screenings performed in the glasshouse and outdoor nursery. Ouyen is an Australian hard-white spring wheat cultivar with good agronomic traits and was used as the *Cre1* gene-donor parent for crossings with spring and winter wheat cultivars adapted to the Pacific Northwest environment. Many of these crosses have been shown to be resistant to *H. avenae* in preliminary tests and are being evaluated further before being tested in naturally-infested fields. While Iskamish-K2-light exhibited resistance to each of the three soils in these tests it was rated from susceptible to resistant in earlier tests with other soils from eastern Oregon, suggesting the need for further testing to determine if multiple pathotypes may be present in the region. Wheat lines carrying the *Cre3*, *Cre7* and *Cre8* genes are susceptible to eastern Oregon populations of *H. avenae*, and lines with *Cre2* and *Cre5* are moderately resistant but variable across tests. Nevertheless, it is possible that benefits from *Cre5* may already occur across the region because the *Cre5* gene is carried by the French cultivar VPM1 which, along with many of its derivatives, has served as the source of eyespot resistance in many Pacific Northwest cultivars.

Table 1. Resistance[1] of selected entries of the International Test Assortment to populations of *Heterodera avenae* from southeast Idaho, eastern Oregon and eastern Washington.

Entry	Gene[2]	Idaho	Oregon	Washington	Mean
Barley					
Bajo Aragon 1-1	*Rha2*	0	0	1	0
Herta	-	2	5	31	13
Ortolan	*Rha1*	4	2	15	7
Oat					
Nidar II	-	15	24	60	33
Silva	-	5	2	15	7
Sun II	-	8	8	34	17
Wheat					
AUS 10894	*Cre1*	0	0	0	0
Capa	-	6	5	33	15
Iskamish-K2-light	?	0	0	1	0

[1]Mean number of white cysts (mean of 2 experiments with 7 replicates each) produced on individual plants grown during the spring in an open-bottom pot of naturally-infested soil (250 g), from which roots grew into an irrigated and fertilised bed of sand. Pre-plant populations of eggs plus juveniles from cysts were 52800, 3000 and 9760/kg of Idaho, Oregon and Washington soil, respectively. [2]Where present and known, the identity of the resistance gene is shown.

In a test in which *H. filipjevi* from eastern Oregon was screened for resistance using the International Test Assortment plus additional entries we observed reproduction at low rates in plants carrying the *Cre1* gene. This preliminary result will be re-evaluated to determine if additional sources of resistance are required where *H. avenae* and *H. filipjevi* occur in mixed populations. If so, emphasis will be given to accessions that prevented reproduction of *H. filipjevi* in the initial screening.

Resistances to Oregon populations of *H. avenae* were also detected in barley lines carrying the *Rha2* gene in Bajo Aragon 1-1, KVL191 and Martin 403-2, and the

Rha3 gene in Morocco. Likewise, resistances to the Oregon populations were detected in the oat accessions Pusa Hybrid (640318-40-2-1), Silva (KVL1414), I376 (CC4658) and IGVH72-646 (MK.H.72-646). These potential donor parents could prove useful where these crops have been damaged by *H. avenae*, such as oats in western Oregon and malting barley in Colorado.

STATUS AND PROSPECTS

H. avenae is distributed across many small grain producing regions of the western United States. It occurs in rain-fed and irrigated fields in wheat producing regions having a mean annual precipitations ranging from 250 to 1000 mm. Essentially nothing is known about the distribution of *H. filipjevi*. However, with little effort being expended to prevent further dissemination of *H. avenae*, it is assumed that *H. filipjevi* is also being disseminated. However, it is well recognised that uninfested fields can be protected from becoming infested by sanitary practices that prevent infested soil from being introduced into “clean” land.

As in other parts of the world, damage from *H. avenae* in Oregon can be controlled by reducing the frequency of host crops in the rotation, such as rotating wheat, barley or oats with a broadleaf crop or a weed-free summer fallow (Smiley *et al*. 1994, Smiley and Nicol 2009). However, rotations in the Pacific Northwest are economical mostly in irrigated crops and in dryland crops produced in high rainfall districts. Broadleaf rotation crops are generally not an economically viable option in the driest areas of the wheat belt of semiarid eastern Oregon and Washington.

Nematicides are not registered for application to wheat in the United States and there are no biological agents or seed treatments known to be effective under field conditions. Management of *H. avenae* in the western USA is will be accomplished most efficiently through genetic resistance, with an initial focus on the *Cre1* gene.

Molecular markers for the *Cre1* gene have been developed in other countries and will be an important tool in marker-assisted selection procedures for increasing the efficiency of wheat breeding programs. However, current markers are proprietary and are not readily available to other scientists. Development of a *Cre1* marker for use in North America is underway. Likewise, a molecular diagnostic test has been developed to differentiate *H. avenae* and *H. filipjevi* quickly and at little expense (Yan *et al*. 2009, Yan and Smiley 2010).

IMPACTS

Table 2 provides an estimate of land infested with potentially damaging populations of *H. avenae* and of yield reduction and economic losses from this species in the Pacific Northwest. While areas known to be infested with potentially damaging population densities represent only 0.04% of the production area, it is estimated that the overall yield suppression in the infested areas is about 10%. Reduction of wheat yield in the region is therefore estimated at 21,000 t valued at US$3.4 million.

Further education of farmers and their commercial and public-sector advisors is required to increase the level of awareness of cereal cyst nematodes. Most growers and advisory personnel in the western USA do not readily differentiate patches of depressed growth caused by cereal cyst nematodes, fungal pathogens such as *Gaeumannomyces graminis* and *Rhizoctonia solani*, and edaphic factors associated with non-uniformity of the soil substrate. For example, the growers who donated soil for studies shown in Table 1 only recently became aware that cereal cyst nematodes were the primary cause of depressed patches of wheat in their fields.

Table 2. Estimate of the impact of *Heterodera avenae* on wheat production and profitability in three Pacific Northwest states.

Wheat Statistics	Oregon	Washington	Idaho	Pacific Northwest
All wheat[1]				
area (1000 ha)	855	2,137	1,175	4,167
yield (t/ha)	3.62	3.99	4.71	4.11
production (Mt)	1.25	3.45	2.24	6.95
value[2] (million US$)	210	578	348	1,135
Impact of *H. avenae*				
area infested (%)	0.05	0.01	0.05	0.04
yield reduction in infested area (%)	0.10	0.10	0.10	0.1
reduced production (t)	6,269	3,449	11,214	20,933
total value (thousand US$)	1,047	576	1,738	3,361

[1]Data from the US National Agricultural Statistics Service for 2007. [2]Value was based upon a mean farm-gate income of 167, 167, 155 and 163 US$/ton for Oregon, Washington, Idaho and the Pacific Northwest, respectively. Wheat is produced under rain-fed or irrigated conditions in low- to intermediate-rainfall areas, with 90, 90, 60 and 80% of the harvested area being rain-fed in Oregon, Washington, Idaho and the Pacific Northwest, respectively.

RECOMMENDATIONS

North American populations have been generally absent or of minor interest in comparative global investigations of the biology of the *H. avenae* group. Future investigations of cereal cyst nematode biology, nationally and internationally, would benefit from the inclusion of populations from the western USA.

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REFERENCES

Chapman LJ (1938) Oat nematodes on winter wheat. *Scientific Agriculture* 18, 527-528.

Fushtey SG (1966) The oat nematode. Ontario Department of Agriculture Publication 453.

Graney LSO (1985) Observations on the morphology of *Heterodera carotae* and *Heterodera avenae* in Michigan USA. Journal of Nematology, 17, 519 [Abstract]

Hackney RW (1981) Oat cyst nematode found in San Mateo county. *Plant Pathology Reports. California Department of Food and Agriculture* 5, 31.

Hafez SL, Golden AM (1984) First report of oat cyst nematode in eastern Washington. *Plant Disease* 68, 351.

Hafez SL, Golden AM (1985) First report of oat cyst nematode (*Heterodera avenae*) on barley in Idaho. *Plant Disease* 69, 360.

Hafez SL, Golden AM, Rashid F, Handoo Z (1992) Plant-parasitic nematodes associated with crops in Idaho and eastern Oregon. *Nematropica* 22, 193-204.

Jensen HJ, Eshtiaghi H, Koepsell PA, Goetze H (1975) The oat cyst nematode, *Heterodera avenae*, occurs on oats in Oregon. *Plant Disease Reporter* 59, 1-3.

Rivoal R (1986) Biology of *Heterodera avenae* Wollenweber in France. IV. Comparative study of the hatching cycles of two ecotypes after their transfer to different climatic conditions. *Revue de Nématologie* 9, 405-410.

Smiley RW, Ingham RE, Uddin W, Cook GH (1994) Crop sequences for managing cereal cyst nematode and fungal pathogens of winter wheat. *Plant Disease* 78, 1142-1149.

Smiley RW, Nicol JM (2009) Nematodes which challenge global wheat production. In 'Wheat: Science and Trade.' (Ed. BF Carver) pp. 171-187. (Wiley-Blackwell: Ames, Iowa, USA)

Smiley R, Sheedy J, Pinkerton J, Easley S, Thompson A, Yan GP (2007) Cereal cyst nematode: distribution, yield reduction, and crop management strategies. *Oregon Agricultural Experiment Station Special Report* 1074, 15-29. http://extension.oregonstate.edu/catalog/html/sr/sr1074-e/05.pdf

Smiley RW, Whittaker RG, Gourlie JA, Easley SA, Ingham RE (2005) Plant-parasitic nematodes associated with reduced wheat yield in Oregon: *Heterodera avenae*. *Journal of Nematology* 37, 297-307.

Smiley RW, Yan GP, Handoo ZA (2008) First record of the cyst nematode *Heterodera filipjevi* on wheat in Oregon. *Plant Disease* 92, 1136.

Yan GP, Smiley RW (2009) Discovery of *Heterodera filipjevi* on wheat in the USA. In 'Cereal cyst nematodes: status, research and outlook.' (Eds IT Riley, JM Nicol, AA Dababat) pp. 94-99. (CIMMYT: Ankara, Turkey)

Yan GP, Smiley RW (2010) Distinguishing *Heterodera filipjevi* and *H. avenae* using PCR-RFLP and cyst morphology. *Phytopathology* 10 (in press).

Yan GP, Smiley RW, Gourlie JA, Thompson AL, Yan H (2009) Molecular identification of cyst nematodes from wheat and barley fields. *Oregon Agricultural Experiment Station Special Report* 1091, 15-26. http://extension.oregonstate.edu/catalog/html/sr/sr1091-e/sr1091_01.pdf

Yan GP, Smiley RW, Okubara PA, Easley SA, Sheedy JG, Thompson AL (2008) Molecular diagnostics of root-lesion nematodes and cereal cyst nematodes. *Oregon Agricultural Experiment Station Special Report* 1083, 93-108. http://extension.oregonstate.edu/catalog/html/sr/sr1083-e/sr1083_10.pdf

CEREAL CYST NEMATODES:
STATUS, RESEARCH AND OUTLOOK

Proceedings of the First Workshop of the
International Cereal Cyst Nematode Initiative,
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Abstract: The first meeting of the International Cereal Cyst Nematode Initiative, held in October 2009 in Turkey, involved over 60 scientists from wheat-growing regions in Asia, Australia, Europe, north Africa and North America. Cereal cyst nematodes (CCN) are damaging root parasites of barley, oat, wheat and related plants; the most important species being *Heterodera avenae*, *H. filipjevi* and *H. latipons*. Forty three papers in this volume cover: the history and status of CCN both globally and regionally; research on CCN morphological, genetic and ecology diversity; development and deployment of host resistance as the principal means of control, including advancements provided by molecular technology; and investigations into other types of control and opportunities for integrated management. The papers provide valuable insight into the impact of CCN and endeavours to provide sustainable management options for farmers. CCN's impact ranges from severe in resource-limited cropping systems with high pathotype diversity through to the now easily managed situation in Australia, with one pathotype and many resistant cultivars released. In many countries, unacceptable economic losses continue and international collaboration is needed to ensure that appropriate genetic resources and technology are developed, disseminated and applied where the need is greatest.

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Cover illustration: Irrigated winter wheat infested with *Heterodera avenae* with an intolerant cultivar (front), showing patches of stunted plants, and intolerant cultivar (back) growing in adjacent farmer's fields in Xuchang, Henan, China. Photograph: Ian T. Riley.

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