Characterisation of virulence reactions for *Heterodera avenae* populations from two localities in Algeria

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Summary - *Heterodera avenae* is widely distributed in areas where most cereal crops are produced in Algeria. However, the virulence of the Algerian populations of this nematode on individual cereal species and cultivars has not been well documented. The virulence of *H. avenae* populations from Tiaret and from Oued Smar were tested under natural outdoor conditions and in an *in vitro* test to determine reactions of nine barley, oat and wheat cultivars selected from the International differential assortment for identifying pathotypes of *H. avenae*. All nine cereal differentials expressed the same reactions to both populations. The nematodes reproduced well on the barley cultivar Emir and the wheat cultivar Capa. Resistant entries included the barley cultivars Siri, Ortolan and Morocco, the oat cultivars Nidar II and *A. sterilis* I.376, and the wheat cultivars Loros and AUS10894. This matrix of reactions indicated that *H. avenae* populations from both locations were characterized as *H. avenae* Group 1 pathotypes but did not conclusively distinguish among pathotypes Ha21, Ha31 or Ha81. The *Cre1* gene was identified as a potentially valuable source of resistance when developing wheat cultivars intended for release into these localities.

Keywords - Algeria, *Heterodera avenae*, pathotype, barley, wheat, oat.

The cereal cyst nematode *Heterodera avenae* is widely distributed throughout the temperate cereal-producing regions of the world (Rivoal & Cook, 1993). This nematode is one of the most harmful phytoparasitic nematodes affecting cereals globally (Nicol and Rivoal, 2007; Smiley and Nicol, 2009). In Algeria, since it was first reported (Scotto La Massese, 1962), *H. avenae* has become recognized as being a species that is dominant in the cereal-producing regions such as Aïn Defla, Batna, Bejaïa, Birtouta, Dahmouni, Oued Smar, Sidi Hosni, Sétif, and Tiaret (Mokabli et al., 2001, 2002; Rivoal et al., 2001). *H. avenae* has not been detected in the southern Algerian irrigated areas near Adrār (Haddadi, 1999). The strategy to manage this parasite aims to reduce or maintain its populations below harmful economic thresholds (Holgado et al., 2006).

Crop rotations and the use of resistant varieties are the most promising measures for controlling cyst nematodes (Holgado et al., 2006) and are essential elements for cropping systems (Bekal et al., 1998) because they can be used over large areas and are easily adopted, profitable and environment-friendly (Rivoal & Nicol, 2009; Nicol et al., 2009). However, the use of resistant varieties can be compromised by the appearance of new pathotypes (D'Addabo and Sasanelli, 1994; Mokabli et al., 2002; Nicol et al., 2007) which differ in virulence to specific host species and cultivars (Magnusson & Holgado, 2011).

Pathotypes are identified by testing the virulence of unknown *H. avenae* populations against differentials that include a standard group of barley (*Hordeum vulgare* L.), oat (*Avena sativa* L. and *A. Sterilis* L.) and wheat (*Triticum aestivum* L. and *T. durum* L.) cultivars. This set of differentials was proposed by Andersen & Andersen (1982b) and updated by Rivoal & Cook (1993) and by Smiley et al. (2011).

This test distinguishes three groups of pathotypes of *H. avenae* by differential resistance or susceptibility reactions of the barley cultivars Ortolan, Siri and Morocco (Nicol & Rivoal, 2007). Additional barley, oat and wheat differentials are used to define the pathotypes within each of the three groups (Andersen and Andersen, 1982b; Sanchez and Zancada, 1987; Rivoal and Cook, 1993; Smiley et al., 2011). Groups 1 & 2 include the largest number of pathotypes that occur in Europe, North Africa, and Asia (Andersen & Andersen, 1982b; Al-Hazmi et al., 2001; Mokabli et al., 2002). Pathotypes within Group 3 have been identified mostly in Australia and Europe (Nicol & Rivoal, 2007). An Algerian population from Tiaret was recently also determined to be within Group 3 (Mokabli et al., 2002). Specifically, the Tiaret population was avirulent on genotypes known to carry the *Cre1* resistance gene but was virulent on the differentials Drost and Siri. These findings differed from those of Bossis & Rivoal (1996), who reported that an Algerian population from Tiaret (Sidi Hosni) had the characteristics of *H. avenae* pathotype Ha41. Furthermore, Mokabli et al. (2002) designated Algerian populations from Bejaïa and Birtouta as representatives of a new group of pathotypes, named Group 4, characterized as being virulent on barley differentials carrying the *Rha1*, *Rha2* and *Rha3* resistance genes. It was unknown whether these contrasting results from .Tiaret represented different results from different assay methods or whether mixtures of pathotypes occur in that region. Characterization of the pathotype or pathotypes of *H. avenae* at each location is required to develop resistant cultivars (Al-Hazmi et al., 2001) that can be used as a component of integrated management systems to manage the level of damage caused by these nematodes. Several methods have been used to distinguish pathotypes of *H. avenae*. In typical outdoor tests and in tests under semi-controlled conditions in a glasshouse, differentials can be grown in naturally-infested soil (Ireholm, 1994; Smiley et al., 2011) or in soil inoculated with juveniles (Al-Hazmi et al., 2001) or gravid cysts (Sanchez and Zancada, 1987). Distinctions between resistant and susceptible genotypes is considered reliable if the susceptible control produces a mean of 20 or more new white females per plant (Andersen and Andersen, 1982a). A differential entry is considered resistant to a tested population of *H. avenae* if the number of white females produced on roots is fewer than 5% of the number that occurs on the susceptible control (Lücke, 1976). Screenings of differentials have also been performed in small tubes of sand or in Petri dishes (Mokabli et al., 2002; Rivoal et al., 1978). Fewer than 20 white females are typically produced on roots, particularly in the Petri dish method, and a plant genotype is considered resistant if the mean number of white females is less than one (Bekal et al., 1998; Rivoal et al., 2001).

The objective of this research was to re-examine the virulence of an Algerian population of *H. avenae* from the Tiaret region on a collection of cultivars from the set of international differentials used to identify pathotypes of this species. A population of *H. avenae* from an experimental station near Oued Smar was included for comparison in these tests.

Materials and methods

Populations of *H. avenae* were collected during September and October from non-irrigated wheat plots near Tiaret and Oued Smar, Algeria. Tiaret is located in the semi-arid western plains region of Algeria (35° 25’ 0” N, 1° 28’ 60” E), at 1127 m elevation and 327 mm mean annual rainfall. Non-irrigated cereals are very important crops in the Tiaret region. Sampling near Oued Smar was from the Institut Technique des Grandes Cultures (ITGC) experimental station, which is located in the sub-humid northcentral region of Algeria, near Algiers (36° 42’ 30” N, 3° 9’ 34” E) and the Mediterranean coast. The elevation near Oued Smar is 45 m and the mean annual rainfall is 598 mm. After extraction, cysts filled with eggs and juveniles were selected and were stored dry in PVC tubes in the laboratory at 20° C until used three weeks later. Specimens were submitted to the nematology laboratory at INRA, Le Rheu, France, and each collection was

determined to be *H. avenae* using morphometric diagnostic features and PCR-RFLP evaluations of ribosomal DNA (S. Valette and R. Rivoal, personal communictation).

Barley, oat and wheat differentials from the 'International Test Assortment for Defining Cereal Cyst Nematode Pathotypes' were acquired from the Nordic Gene Bank, at Alnarp, Sweden. The nine differentials that were tested are shown in Table 1. Barley cvs. Ortolan (*Rha1*), Siri (*Rha2+*) and Morocco (*Rha3+*) were used to distinguish *H. avenae* Groups 1, 2, and 3 (Andersen and Andersen, 1982b; Rivoal and Cook, 1993). Group 1 populations are avirulent to *Rha1*. Group 2 populations are virulent to *Rha1 and* avirulent to *Rha2+*. Group 3 populations are virulent to *Rha1* and *Rha2+*, and avirulent to *Rha3+*. Barley cv. Emir was used as the presumptive susceptible control for these studies (Andersen and Andersen, 1982b). Capa and Nidar II were included as presumptive susceptible controls for wheat and oats, respectively (Andersen and Andersen, 1982b; Rivoal and Cook, 1993). Screening of these differentials was performed under two conditions; outdoors in pots of soil inoculated with cysts, and in an *in vitro* test using juveniles as inoculum in a controlled-environment incubator.

Outdoor test: Potting soil was prepared by mixing a 2:1 volumetric ratio of loam and sand. The soil was sieved and then sterilized at 120°C for 30 minutes. Soil was then placed into plastic pots (15-cm high and 10-cm diam.) at the rate of 700g/pot. Eight repetitions of each cultivar were evaluated. Every pot was inoculated with 25 full cysts that were placed in a bag and buried at a depth of 5 cm, similar to the method described by Sanchez and Zancada (1987). While variability in number of viable eggs and juveniles among cysts was not counted, it was assumed that inoculating pots with 25 cysts was sufficient to minimize the importance of potential variability in numbers of eggs plus juveniles supplied to individual pots in the inoculation procedure. Two days after inoculation of soil, one pre-germinated seed was sown at 2-cm depth. The assay was incubated under natural outdoor conditions from November to May. Pots were irrigated and fertilized as needed. Regular observations were made to note differences of growth and of other possible symptoms. In May, plants were carefully removed and soil was washed from the roots. Roots were examined using a stereoscopic microscope. Cysts were extracted from the soil in every pot by using the Fenwick method to count newly-formed cysts. The capacity of the nematode to multiply on each host plant was expressed as the average number of newly-formed cysts in each pot at the end of the experiment. The standard error of the mean was also calculated.

The reaction of the host was classified according to the definition by Lücke (1976), where a population is considered resistant if the average number of white females is less than 5% of the number on the susceptible control for each cereal species. As stated previously, the presumptive susceptible controls in this study were cvs. Emir, Capa, and Nidar II for barley, wheat, and oats, respectively.

In vitro test: Nutrient agar (2%) was sterilized, poured into Petri dishes, and cooled to room temperature. Cereal grains were disinfected with a solution of 1% sodium hypochlorite for 5 min and rinsed using three successive sterile water baths of 5 min each. Seeds were then placed at 22 °C until germinated and then one seed was placed onto a Petri dish containing nutrient agar. Three replicates of each plant entry were evaluated.

Juveniles of *H. avenae* from the Tiaret and Oued Smar populations were collected individually from cysts incubated in water at room temperature to promote hatching during the winter. At other times of the year, hatching was induced by incubating the cysts at 7 °C. One root of each seedling was inoculated just behind the root cap with 35 juveniles, similar to the method described by Rivoal et al. (1978). Plates were incubated on previously sterilized shelves in an incubator set at 15 °C and a photoperiod of 16 h light and 8 h dark. Each dish was examined under a binocular microscope one day after inoculation and any juveniles that had migrated away from the root were gently moved back to the root cap, as described by Rivoal et al. (1978). After seedling growth was active, the edge of the cover of each Petri dish was notched to a depth of 5

mm with a heated scalpel, without lifting the cover, to allow the seedling shoot to emerge from the dish. Shoot growth then occurred outside the dish for the remainder of the incubation period. The very few fungal colonies that appeared on roots and seed became visible only after the sixth week of incubation, which was considered to be too late to have been of importance with respect to the life cycle of *H. avenae*. Swollen white females were clearly observable two months after inoculation. Two weeks later the plants were removed and the mean number of white females per plant and the standard error of the mean were calculated. A resistant reaction was assigned for plant genotypes having a mean of less than one white female per root system, as has been described previously for the Petri dish assay method (Bekal et al., 1998; Rivoal et al., 2001).

Results

The reaction of the international cultivars to both Algerian populations of *H. avenae* is presented in Table1. All cultivars had similar reactions to the populations from Tiaret and Oued Smar. Reactions of each cultivar were the same for the outdoor pot test and the *in vitro* assay.

For barley, only the cultivar Emir multiplied the parasite, with respective averages for the Tiaret and Oued Smar populations of 46 and 137 cysts in the outdoor assay and 4 and 5 cysts in the *in vitro* assay. Ortolan (*Rha1*), Siri (*Rha2+*) and Morocco (*Rha3+*) barley were each resistant, indicating that these *H. avenae* populations were characterized as a Group 1 pathotype. One cyst was formed on one plant of Siri in the *in vitro* assay, but the mean was well below the 1.0 cyst/plant metric used as our definition of resistance in that experiment. Group 2 and Group 3 pathotypes were additionally rejected by the avirulence of our *H. avenae* populations to oat cv. Nidar II, and to the wheat cvs. AUS 10894 and Loros, each of which carry the *Cre1* resistance gene. Both oat differentials, Nidar II and *A. sterilis* I.376, were totally resistant to both nematode populations. Capa was the only susceptible wheat cultivar, in that the *H. avenae* populations from Tiaret and Oued Smar did not reproduce on plants carrying the *Cre1* resistance gene. Respective average numbers of newly-formed cysts for the Tiaret and Oued Smar populations on Capa were 161 and 23 in the outdoor test and 5 and 3 in the in vitro test. No cysts were observed in either assay on the wheat cultivars Loros and AUS10894.

The matrix of reactions for our two *H. avenae* populations on barley (Table 1) indicated that, within Group 1, the only possibilities for pathotype assignment were for Ha11, Ha21, Ha31, and Ha81. Pathotype Ha41 was excluded on the basis of resistance of Siri and also to oat cv. Nidar II. Pathotype Ha11 was excluded on the basis of the avirulence of these populations on Nidar II. Our experiments could not differentiate between reactions expected of *H. avenae* pathotypes Ha21, Ha31, and Ha81.

Discussion

The populations of *H. avenae* from Tiaret and Oued Smar had similar resistance characteristics on all nine of the differential cereals under each assay condition. According to the definitions of Lücke (1976) and Bekal et al. (1998), for the pot test and the *in vitro* test, respectively, the tested populations were considered virulent on the wheat cultivar Capa and the barley cultivar Emir and were avirulent on the other seven cultivars. Nevertheless, the degree of virulence on the two hosts differed for these two populations. The population of Tiaret was more virulent on Capa than on Emir. Conversely, the population of Oued Smar was less aggressive on Capa than on Emir. This variation was probably related to intrinsic differences in their capacity for reproduction (Rivoal et al., 2001; Rivoal & Nicol, 2009) and host preference (Magnusson & Holgado, 2011), possibly associated with the different climates in which these populations developed in two different geographical regions. The barley cultivars Ortolan, Siri, and Morocco, which carry the respective resistance genes *Rha1*, *Rha2+* and *Rha3+*, were determined to be

resistant. On the other hand, reproduction was fully expressed on Emir, which has the resistance gene *RhaE*.

Based on the reaction of four differential barleys, and especially on the resistance of the cultivar Ortolan, and according to the scheme established by Andersen and Andersen (1982b) and revised by Rivoal & Cook (1993), the tested populations were classified as members of *H. avenae* Group 1. The wheat cultivars AUS 10894 and Loros, each of which is a carrier of the resistance gene *Cre1*, prevented multiplication of both populations whereas Capa was an excellent host, particularly for the population from Tiaret. The oat cultivars *A. sterilis* I.376 and Nidar II were highly resistant to both populations. We had anticipated that Nidar II would be susceptible based upon an earlier assignment of the Tiaret population as *H. avenae* Group 1 (Bossis and Rivoal, 1996) or Group 3 (Mokabli et al., 2002). Similar reactions were reported for a Chinese population of *H. avenae* (Peng and Cook, 1996). Indeed, oats appear to be a poor host of *H. avenae* in the Mediterranean countries, contrary to some countries in Northern Europe where oats are considered as preferential hosts (Nicol, 2002; Ireholm, 1994).

If we consider the behavior of the populations from Tiaret and Oued Smar on the totality of the tested differential cultivars, they can be considered as two identical physiological entities in spite of their diverse geographical origin. According to the matrix updated by Smiley et al. (2011), these populations could belong to the pathotypes Ha21, Ha31, or Ha81. The latter pathotype was described by Sanchez & Zancada (1987) in the Spanish regions of Toledo and Sevilla. Our results differ from those of Bossis & Rivoal (1996), who reported that the Algerian population from Tiaret (Sidi Hosni) had the characteristics of the Southern pathotype Ha41. In our studies, *H. avenae* from both locations failed to reproduce on Siri and Nidar II, which would exclude it from being assigned as Ha41. While many pathotyping studies are performed with more than 20 differentials, the nine differentials we used were sufficient to determine that the pathotype for each population in our study was restricted to Ha21, Ha31, or Ha81. Respectively, these pathotypes were originally described in northern Europe, India, and southern Spain (Andersen and Andersen, 1982; Sanchez and Zancada, 1987). Even if we had included the full set of international differentials in this test, the only differential that may have provided additional distinction among these pathotypes would have been the barley cv. Herta, which could have distinguished between pathotypes Ha21 and Ha31. However, the complete set of differentials cannot distinguish between Ha21 and Ha81, or between Ha31 and Ha81 (Sanchez and Zancada, 1987; Smiley et al., 2011).

The pathotype concept for *H. avenae* was established to distinguish among virulence reactions of populations that had been characterized nearly four decades ago (Cook and Rivoal, 1998; Cook and Noel, 2002; Smiley et al., 2011). These authors indicate that the pathotype matrix, even in its updated form, is incomplete for defining virulence phenotypes that have been examined more recently in other regions. Up to 30 virulence phenotypes were suggested from only 69 *H. avenae* populations reported globally (Cook and Rivoal, 1998), and additional virulence phenotypes continue to be identified without a formal designation of pathotype, as was summarized by Smiley et al. (2011). It is now clear that the International Test Assortment underestimates the global polymorphism now known to occur for this species, and there is a shift from emphasis on designating a specific pathotypes to emphasis on examining local populations to identify sources of resistance that have the potential to control local *H. avenae* populations (Cook and Noel, 2002; Smiley and Nicol, 2009). In the present study it was clear that wheat genotypes with the *Cre1* resistance gene will provide value to wheat growers in the Tiaret and Oued Smar production areas of Algeria. Likewise, barley cultivars carrying the *Rha1*, *Rha2+*, and *Rha3+* genes should assist in reducing *H. avenae* densities where barley is produced in these regions.

Our description of the same pathotype in two different bioclimatic regions does not exclude the possible existence of a mixture of pathotypes within each region, as is known to occur within

local populations in several countries (Yuan et al., 2010; Holgado et al., 2009). For instance, our finding that the Tiaret population exhibited characteristics of Ha21, Ha31, or Ha 81 should be interpreted as complementary to findings of Bossis and Rivoal (1996) who identified pathotype Ha41 in the Tiaret region, and of Mokabli et al. (2002) who identified a Group 3 pathotype in that region. Mixtures of *H. avenae* pathotypes and of *Heterodera* species occur commonly in other regions of the world. It was also informative that our two populations were resistant to Ortolan, Siri and Nidar II, excluding the possibility that they could be pathotype Ha23 or Ha33 (Rivoal and Cook, 1993), each of which are now considered to be *H. filipjevi* (Subbotin et al., 2003). Our results provided further confirmation that our two isolates were *H. avenae*, as reported to us by INRA-France on the basis of examinations of specimens using morphological and PCR-RFLP methods.

Hatching tests showed that these populations exhibited biological characteristics identical to those of the Southern ecotypes (Mokabli et al., 2001) in that they have a summer diapause and an embryonic activity during the winter, coinciding with the sensitive stages of cereal development in Algeria.

While the field and in vitro experiments were not individually repeated they were well replicated and provided complementary and precise results. These results should be expanded using assays with a wider range of cultivars and a much larger collection of populations from fields particularly in the Tiaret region. Reactions on more cultivars of oats would be of particular interest to determine if the classification of pathotypes can be refined. It would also be desirable to determine the virulence of these *H. avenae* populations on local cereal cultivars and to investigate the wild grasses to reveal possible sources of resistance that could be integrated into the cultural management systems.

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Table1: *Heterodera avenae* pathotypes stemming from the International Test Assortment of the Definition of Pathotypes of Cyst Cereal Nematode in its updated version (Smiley et al., 2011) and reaction of some differential cultivars towards two Algerian populations (Tiaret and Oued Smar) of *H. avenae* under two experimental conditions; an outdoor test in potted soil and an *in vitro* test in a controlled-environment incubator.

	Pathotypes of *H. avenae*											Pot test		*In vitro* test		
	Group 1								Group 2		Group 3	Tiaret	Oued Smar	Tiaret	Oued Smar	
Cultivar differentials	Ha 11	Ha 21	Ha 31	Ha 41	Ha 51	Ha 61	Ha 71	Ha 81	Ha 12	Ha 22	Ha 13	cysts/plant[1]		White females/plant[2]		Cultivar reaction[3]
Barley																
Ortolan (*Rha* 1)	R	R	R	R	R	R	R	R	S	S	S	0	0	0	0	R
Siri (*Rha* 2+)	R	R	R	S	S	S	(S)	R	R	R	S	0	0	0.3 ± 0.6	0	R
Morocco (*Rha* 3+)	R	R	R	R	R	R	S	R	R	R	R	0	0	0	0	R
Emir (*Rha* E) [4]	S	S	-	S	-	R		S	S	S	S	45.9 ± 1.6	137.1 ± 1.5	3.7 ± 0.6	4.8 ± 1.5	S
Oats																
Nidar II [4]	S	-	-	(S)	-	S	R	R	S	R	S	0	0	0	0	R
A. sterilis I.376	R	R	-	R	R	R	R	R	R	R	R	0	0	0	0	R
Wheat																
AUS 10894 (*Cre* 1)	R	-	-	R	-	R	R	R	R	S	(R)	0	0	0	0	R
Loros (*Cre* 1)	R	R	-	R	-	(R)	R	R	R	R	(R)	0	0	0	0	R
Capa [4]	S	S	-	S	-	S	S	S	S	S	S	161.1 ± 1.7	22.9 ± 1.6	5.2 ± 0.6	3.1 ± 1.0	S

[1] Mean number of cysts/plant and standard error of the mean; n = 8.

[2] Mean number of swollen white females/root and standard error of the mean; n = 3.

[3] Cultivar reaction: R = resistant, S = susceptible; R is defined as means of fewer than 5% of the number of cysts/plant in the susceptible control differential for the pot test (Lucke, 1976), and as fewer than one swollen white female per root for the in vitro test (Bekal et al., 1998).

[4] Presumed susceptible controls for each cereal species. Note that Nidar II was considered the susceptible control for oat but was determined to be resistant to both populations of *H. avenae* examined in this study.