DOI: http://doi.org/10.1590/1678-992X-2021-0027

ISSN 1678-992X

SCIENTIA AGRICOLA

Research Article

Screening of the hatching control of root-knot nematodes using extract concentrations from oat genotypes

Cláudia Fernanda Carraro-Lemes[1]*, José Luis Trevizan Chiomento[2], Carolina Cardoso Deuner[1], Simone Meredith Scheffer-Basso[3]

[1]Universidade de Passo Fundo – Depto. de Fitopatologia, km 285 – 99052-900 – Passo Fundo, RS – Brasil.
[2]Universidade de Passo Fundo – Depto. de Olericultura – Passo Fundo, RS – Brasil.
[3]Universidade de Passo Fundo – Depto. de Botânica – Passo Fundo, RS – Brasil.
*Corresponding author <claudinhafcl@gmail.com>

Edited by: Alberto Soares Corrêa

Received March 02, 2021
Accepted September 05, 2021

ABSTRACT: Even though oats (*Avena* spp.) have the capacity to produce numerous compounds with the potential to act antagonistically against plant pathogens, studies on the genotypic effect of this crop focusing on their nematicidal activity are limited. The objective of this study was to verify the effect of the aqueous extracts prepared with the biomass of oat genotypes, on the hatching of second-stage juveniles of root-knot nematodes (*Meloidogyne javanica* and *Meloidogyne incognita*). The bioassays were carried out in a completely randomized design with four replications. Eighteen extracts were evaluated, consisting of a combination of six oat genotypes Agro Quaraí, Agro Esteio, Embrapa 139, AF 12202, UPFPS Farroupilha, and AF 1345 Ucraniana, and three extract concentrations (5 %, 10 %, and 20 % w/v). Three additional treatments were added to the study (distilled water, chemical nematicides abamectin, and imidacloprid + thiodicarb). The treatments and the suspension containing nematode eggs were placed in Petri dishes and incubated in a growth chamber for ten days. At the 5 % and 10 % w/v concentration levels, a genotype effect was observed in the hatching of juveniles for both nematode species. For the control of *M. javanica* the extracts of Embrapa 139 had a better performance, while the extracts of Agro Quaraí and AF1345 Ucraniana performed better when under the control of *M. incognita*. Thus, oat biomass formation might have the ability to suppress the nematode population in the soil, and could therefore, be used for the management of root-knot nematodes.

Keywords: *Avena* spp., *Meloidogyne javanica*, *Meloidogyne incognita*, cultural and biological practices, disease management

Introduction

White oat (*Avena sativa* L.) and black oat (*Avena strigosa* Schreb.) are grown in numerous regions around the world as forage or cover crops, on account of their suitability for the intense production of dry matter for mulching. The formation of straw on the soil surface, as a crop residue, providing the gradual decomposition and accumulation of organic material in the soil profile, serves as an alternative for disease and pest control (Franzluebbers et al., 2007).

A list of the main pests in agriculture would include root-knot nematodes (RKN) [*Meloidogyne javanica* (Treub) Chitwood and *M. incognita* (Kofoid & White) Chitwood]. These nematode species can cause severe damage to various agricultural crops worldwide (Karuri et al., 2017). Infection of nematodes in the host's roots begins with second-stage juveniles and can lead to the formation of galls due to hyperplasia, which can result in reductions in water and nutrient uptake by the host plant. The infection results in underdeveloped plants with deficient production and in several cases they become totally unproductive (Escobar et al., 2015). Thus, the search for measures to control RKN is considered a matter of urgency.

The use of crops such as oats that provide biomass formation and have an antagonistic effect on nematodes by inhibiting the hatching of second-stage juveniles, could be an alternative for the control of these pathogens. In addition, this practice is an economically and environmentally viable alternative that can be applied, with additional management, to the use of synthetic nematicides (Niro et al., 2016).

The antagonistic and nematicidal effect of the effluents of oats can be attributed to the chemical compounds they produce (Fay and Duke, 1977; Lacerda et al., 2017). However, studies on the genotypic effect of *Avena* spp. with regard to their nematicidal activity are limited.

Taking into consideration the possible existence of differences between oat genotypes, in terms of nematicide potential, we believe that the nematicidal activity of *Avena* spp. depends on the genotype and the extract concentration level. Herein, we investigate whether the aqueous extracts prepared with the aerial part of the white oat and black oat genotypes, at increasing concentrations, differ in their effect on the hatching of second-stage juveniles of *M. javanica* and *M. incognita*.

Materials and Methods

Plant material

The plant material used for the preparation of the extracts consisted of the aerial part of six oat genotypes at the 'full bloom' growth stage. The plants were simultaneously cultivated during the 2018 crop season in a soil classified as Ferritic Humic Ferralsol, according to the World Reference Base (IUSS Working Group WRB 2015), located in Passo Fundo (28°15′ 46″ S, 52°24′24″ W, altitude of 692 m), in the state of Rio Grande do Sul, Brazil. The aerial part of the plants was harvested manually.

Experimental design

The experiment was carried out in a two-factor model (6 × 3) consisting of the combination of six oat genotypes and three extract concentration levels (5, 10 and 20 % w/v). The experiment included the negative control treatment (distilled water only) and two positive controls, the synthetic nematicides abamectin (chemical group avermectin), and imidacloprid + thiodicarb (oxime methylcarbamate chemical group), making a total of 21 treatments. The genotypes included three commercial black oat cultivars (Agro Quaraí, Agro Esteio, Embrapa 139), one black oat line (AF 12202), one commercial white oat cultivar (UPFPS Farroupilha), and one white oat line (AF 1345 Ucraniana). The experimental design was completely randomized with four replications. The experimental units consisted of 100 × 90 mm Petri dishes.

Preparation of extracts

The aerial parts of the oat plants were minced into pieces approximately 1 cm in size, then dried in an oven, with forced air ventilation at 45 °C for 96 h, to prepare the extracts. This procedure simulated how the dry mass of the aerial part remained in the soil. The dried material was ground in a laboratory mill, and then stored in a refrigerator at 4 °C until needed for use. The extracts were prepared in accordance with the static maceration method, by immersing the plant material in distilled water, followed by resting for 24 h at room temperature, protected from any light (Carraro-Lemes et al., 2019).

To obtain the concentrations to be tested in the experiment, 5, 10, and 20 g of the dried material was mixed in 100 mL of distilled water, corresponding to the concentrations of 5 %, 10 %, and 20 % w/v, respectively. Each extract concentration was similar to the straw density formed by the dry mass of the oat genotypes. After the resting period, the extracts were filtered through 0.45 µm membrane filter paper and the pH was determined using a universal indicator paper. The pH ranged from 6.0 to 7.5, which was considered ideal for *in vitro* bioassays (Carraro-Lemes et al., 2019).

Commercial products that consisted of abamectin and imidacloprid + thiodicarb were diluted at the doses recommended by the manufacturers. These products were chosen because they were efficient in controlling the hatching of juveniles of *M. javanica* and *M. incognita* (Shi et al., 2019). Abamectin was prepared by diluting 125 mL of the commercial product in 500 mL of water and 700 mL of the commercial product, imidacloprid + thiodicarb, was diluted in 500 mL of water. These doses were in accordance with the manufacturers' recommendations, and were adapted to the corresponding volume of Petri dishes.

Obtaining RKN isolates and evaluation

The *M. javanica* isolate was collected from the pathogen-infected soybean [*Glycine max* (L.) Merrill] roots from the municipality of Almirante Tamandaré do Sul (28°6'9" S, 52°55'7" W, altitude of 568 m), in the state of Rio Grande do Sul, Brazil. The *M. incognita* race three isolate was collected from infected tomato roots (*Solanum lycopersicum* L.), from Barreiras (12° 8'54" S, 44°59'33" W, altitude of 454 m), in the state of Bahia, Brazil. The nematode species were identified following the perineal pattern of females (Taylor and Sasser, 1978).

The isolates of the two nematode species were multiplied in the tomato 'Santa Clara' cultivars, which were kept in a growth chamber at 27 ± 3 °C, with a photoperiod of 12 h. The inoculum was prepared by grinding the root tissue in a blender with 0.5 % sodium hypochlorite solution, following the methodology described by Bonetti and Ferraz (1981). The egg count in the suspension was determined with the aid of a Peters chamber under an optical microscope. To perform the bioassays, the suspension was adjusted to 3,000 *M. javanica* eggs mL^{-1} and 3,400 *M. incognita* eggs mL^{-1}.

Initially, 20 mL of the treatment (oat extracts, distilled water or nematicides) was placed in a 100 × 90 mm Petri dish to which 1 mL of suspension containing the nematode eggs was added. The plates were then sealed with a plastic film and kept in a biochemical oxygen demand incubator in the dark at 27 ± 1 °C. After ten days, the contents of the plates were collected in a 25 mm aperture 500 mesh sieve and transferred to test tubes. The number of hatched juveniles and remaining eggs were counted under an optical microscope, in order to obtain the hatching percentage (H %) that was calculated according to the equation (Eq. 1) proposed by Dias-Arieira et al. (2003):

$$H\% = \frac{J2}{J2 + eggs} \times 100 \quad (1)$$

where: J2 represents the number of hatched juveniles; eggs, represent the number of eggs remaining. Number of eggs and J2 are based on the mean of the four replicate values. The percentage of hatching of the juveniles (H %) *for M. javanica* and *M. incognita* was calculated according to equation 1, since this is the nematodes' infective stage with the potential for infecting the hosting plants.

Statistical analysis

The hatching percentage data of second-stage juveniles of *M. javanica* and *M. incognita* of the factorial model *Avena* spp. genotypes × extract concentration (5, 10 and 20 % w/v) were first compared by orthogonal contrast analysis due to the presence of control treatments considered as additional treatments (distilled water, chemical nematicide abamectin and chemical nematicide imidacloprid + thiodicarb). The means of the treatments were compared by the Tukey test at $p = 0.05$.

Next, the hatching percentage data of second-stage juveniles of *M. javanica* and *M. incognita* in a two-factor model (oat genotype × extract concentration)

was calculated from the total number of eggs of the nematodes quantified at the end of the experiment, and additionally,from the number of hatched juveniles. The hatching percentage data of second-stage juveniles of *M. javanica* and *M. incognita* were submitted to analysis of variance and the means were compared by the Tukey test at $p = 0.05$

Statistical procedures were conducted using EXPDES in R (R Core Team, version 2.15.2).

Results

Hatching percentage (H %) of second-stage juveniles of *M. javanica*

The 18 plant extracts reduced the hatching of the second-stage juveniles of *M. javanica*. This was attested by comparison with the additional treatments of the controls (distilled water and chemical nematicides, abamectinand and imidacloprid + thiodicarb), according to the orthogonal contrast analysis. All the extracts were more efficient than the chemical nematicides (Table 1).

All extracts at 5 % w/v concentration exhibited lower efficiency in controlling the hatching of *M. javanica* juveniles, when compared to the three extract concentrations (Table 2). All extracts at the 5 % w/v concentration level differed statistically from the 10 % and 20 % w/v concentrations (Table 2). However, the efficiency in controlling the hatching of *M. javanica* was proven by the Embrapa 139 genotype, which showed no statistical differences across all three extract concentrations (Table 2). In addition, there was no statistical difference in the control of *M. javanica* hatching for UPFPS Farroupilha genotype at either the 5 % or 10 % w/v concentration levels, showing efficiency in both extract concentrations for this genotype (Table 2).

Table 1 – Contrast of the means of the factorial model *Avena* spp. genotypes × extract concentration (5, 10 and 20 % w/v) compared with the means of the additional treatment (distilled water, abamectin and imidacloprid + thiodicarb) on the hatching percentage (H %) of *Meloidogyne javanica* and *M. incognita* juveniles.

Treatments	H (%) of *Meloidogyne javanica* juveniles	H (%) of *Meloidogyne incognita* juveniles
Avena spp. genotypes × Extract concentration (%)	11.33 b	8.84 b
distilled water[1]	78.15 a	65.77 a
Avena spp. genotypes × Extract concentration (%)	11.33 b	8.84[ns]
abamectin[2]	24.13 a	8.20[ns]
Avena spp. genotypes × Extract concentration (%)	11.33 b	8.84 b
imidacloprid + thiodicarb[3]	14.18 a	13.85 a

Means of four replications. Additional treatments: [1]Distilledwater; chemical nematicides [2]abamectinand and [3]imidacloprid + thiodicarb; [ns]=Not significant ($p > 0.05$).

Table 2 – Hatching percentage (H %) of *Meloidogyne javanica* juveniles using aqueous extracts of oat genotypes in three concentrations.

Avena spp. genotypes	Hatching percentage (H %) of *Meloidogyne javanica* juveniles		
	5 % (w/v)[1]	10 % (w/v)	20 % (w/v)
Agro Quaraí	21.00 cA	6.86 cB	0.65 aC
Agro Esteio	39.53 aA	18.47 aB	0.83 aC
Embrapa 139	5.36 dA	2.85 dA	0.15 aA
AF 12202	34.32 aA	15.95 aB	0.23 aC
UPFPS Farroupilha	10.41 dA	6.26 cdA	0.37 aB
AF1345 Ucraniana	27.65 bA	11.31 bcB	1.86 aC

Means of four replications. Means followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test ($p > 0.05$); [1]Extract concentration.

At the 5 % w/v concentration level, the Embrapa 139 and UPFPS Farroupilha extracts stood out in terms of inhibiting the hatching of *M. javanica* juveniles (Table 2). There was no statistical difference between the means of these genotypes at 5 % w/v, which showed the greatest efficiency in inhibiting the hatching of juvenile nematodes (Table 2). The combination of Agro Esteio and AF 12202 extracts at the 5 % w/v concentration level had the lowest efficiency in inhibiting hatching of *M. javanica* juveniles, and the means of these genotypes presented no statistical differences (Table 2). The Agro Quarai and AF 1345 Ucraniana genotypes showed intermediate efficiency values in inhibiting the hatching of *M. javanica* juveniles (Table 2).

The degree of efficiency of the lowest concentration extracts in controlling *M. javanica* followed the order: Embrapa 139 = UPFPS Farroupilha > Agro Quaraí > AF 1345 Ucraniana > AF 12202 = Agro Esteio (Table 2).

Overall, in the concentration 10 % w/v, the extracts showed higher efficiency in controlling the hatching of *M. incognita* juveniles when compared to the concentration 5 % w/v, but were less efficient when compared to the concentration 20 % w/v (Table 2). Out of the 10 % w/v extract concentration level group, the genotypes Embrapa 139 and UPFPS Farroupilha were the most efficient in controlling the hatching of *M. javanica* juveniles (Table 2). Both genotypes did not differ statistically at either the 5 % nor the 10 % w/v extract concentration levels compared to the efficiency in controlling the hatching of the juvenile nematodes.

At the 10 % w/v concentration level, the extracts of the Agro Esteio and AF 12202 showed no differences and were less efficient in inhibiting the hatching of *M. javanica* juveniles (Table 2). The means of these genotypes differed from AF 1345 Ucraniana and Agro Quarai ($p < 0.05$) which had intermediate efficiency in inhibiting the hatching of *M. javanica* juveniles (Table 2).

At the 10 % w/v concentration level, the degree of efficiency of the extracts in controlling *M. javanica* followed the order: Embrapa 139 = UPFPS Farroupilha > Agro Quaraí = AF 1345 Ucraniana > AF 12202 = Agro Esteio (Table 2).

At the highest extract concentration level (20 % w/v), the efficiency in inhibiting the hatching of *M. javanica* juveniles was higher than in the other concentrations, and no statistical difference was detected between the extracts of oat genotypes (Table 2).

Hatching percentage (H %) of the second-stage juveniles of *M. incognita*

The 18 plant extracts reduced the hatching of second-stage juveniles of *M. incognita*. This was attested by comparison with the additional treatment control (distilled water, chemical nematicide abamectin, and imidacloprid + thiodicarb) according to the orthogonal contrast analysis. However, there was no difference ($p > 0.05$) between the three extract concentrations when compared with the chemical nematicide abamectin (Table 1).

All extracts at the 5 % w/v concentration level exhibited low efficiency in controlling the hatching of *M. incognita* juveniles, differing from the 10 and 20 % w/v concentration levels (Table 3). A difference was observed regarding the performance of each extract at the 5 % w/v concentration level (Table 3). At this concentration level, the extracts Agro Quaraí and AF 1345 Ucraniana stood out as the most efficient inhibitors of hatching of *M. incognita* juveniles,with no difference between the means of these genotypes (Table 3). The extract Embrapa 139 extract at the 5 % w/v concentration level had the lowest efficiency in inhibiting the hatching of nematode juveniles (Table 3). The extracts of Agro Esteio, AF 12202 and UPFPS Farroupilha showed intermediate efficiency in inhibiting the hatching of *M. incognita* (Table 3).

At the 5 % w/v concentration level, the efficiency of the extracts in reducing the hatching of *M. incognita* juveniles was low and were observed in the following order: Agro Quarai = AF 1345 Ucraniana > Agro Esteio = AF 12202 > AF 12202 = UPFPS Farroupilha > Embrapa 139. (Table 3).

At the 10 % w/v concentration level, the extracts presented higher efficiency in controlling the hatching of *M. incognita* juveniles compared to the 5% w/v extract concentration level, but they were less efficient when compared to the 20 % w/v extract concentration level (Table 3). At the 10 % w/v concentration level, the extracts of Agro Quaraí and AF 1345 Ucraniana fully inhibited the hatching of *M. incognita* juveniles and were the most efficient genotypes in this concentration, with no statistical differences from each other (Table 3). At the same concentration level, the extracts of Agro Esteio, AF 12202 and Embrapa 139 differed from Agro Quaraí and AF 1345 Ucraniana, but did not differ from each other, presenting the lowest efficiency in inhibiting the hatching of *M. incognita* juveniles (Table 3). The extracts of the genotype UPFPS Farroupilha showed intermediate average efficiency (Table 3). At 10 % w/v concentration, the efficiency of the extracts in reducing the hatching of nematode juveniles presented the following order: Agro Quarai = AF 1345 Ucraniana > UPFPS Farroupilha > Agro Esteio = AF 12202 = Embrapa 139.

The efficiency in inhibiting the hatching of juveniles of *M. incognita* was higher in the highest extract concentration level (20 % w/v) than in the other concentrations, and no statistical difference was detected between the extracts of oat genotypes (Table 3). The extracts of Agro Quarai and AF 1345 Ucraniana did not show any difference at either the 10 or the 20 % w/v concentration levels, when the hatching of the nematode juveniles was totally inhibited (Table 3). At the 5 % w/v concentration level, the extracts of these genotypes also had better performance in controlling the hatching of *M. incognita* juveniles, and they are considered the most efficient genotypes (Table 3).

Table 3 – Hatching percentage (H %) of *Meloidogyne incognita* juveniles using aqueous extracts of oat genotypes at three concentrations.

Avena spp. genotypes	Hatching percentage (H %) of *Meloidogyne incognita* juveniles		
	5 % (w/v)[1]	10 % (w/v)	20 % (w/v)
Agro Quaraí	8.24 dA	0.00 cB	0.00 aB
Agro Esteio	24.10 bA	13.67 aB	0.13 aC
Embrapa 139	30.79 aA	14.26 aB	0.00 aC
AF 12202	21.60 bcA	11.41 aB	0.00 aC
UPFPS Farroupilha	18.20 cA	5.32 bB	0.71 aC
AF1345 Ucraniana	10.74 dA	0.00 cB	0.00 aB

Means of four replications. Means followed by the same lowercase letter in the column and uppercase in the row do not differ statistically from each other by the Tukey test ($p > 0.05$). [1]Extract concentration.

Discussion

The nematicidal activity of *Avena* spp. was genotype-dependent. In the most concentrated extracts there was a lower percentage of hatching of juveniles of both species of nematodes. The greater or lesser effect of the extracts depended on the nematode. This fact was evidenced by the action of the extract of the Embrapa 139 cultivar, which was more efficient in controlling the hatching of second-stage juveniles of *M. javanica*. However, for controlling the hatching of the *M. incognita* juveniles the best extracts were from Agro Quaraí and AF 1345 Ucraniana, different from the observations made for the control of *M. javanica*. Therefore, there are oat cultivars with higher nematicidal activity on *M. javanica* and others that have higher suppressive power on *M. incognita* in the field.

The nematicidal activity of the oat extracts was confirmed by the difference compared to the control (distilled water) as well as in the efficiency of the hatching control, compared to the nematicides. Extracts and nematicides have an inhibitory nematotoxic action on the hatching of second-stage juveniles of both nematode species when compared to distilled water.

Oat genotypes at the three extract concentrations and the chemical nematicide abamectin and imidacloprid + thiodicarb inhibited the hatching of juveniles of both

nematode species when compared to distilled water. The variation among genotypes as regards the efficiency in hatching control for both nematode species was observed in the 5 % and 10 % w/v extract concentrations.

The efficiency of oat extracts to control hatching increased as their concentration increased. At the 20 % w/v concentration level, the efficiency of the extracts was more pronounced and all genotypes showed higher hatching control efficiency than chemical nematicides. The positive effect of extracts made from dry leaves of *Clerodendron enermi* L. in the hatching control of *M. javanica* and *M. incognita* was reported by Patel et al. (1987). Furthermore, antagonistic plants which have the potential to form straw and mulch can be promising in controlling the hatching of second-stage juveniles of *M. javanica* and *M. incognita*.

The hatching of juveniles of nematode species can be influenced by several factors, including the substances produced and released by plants (Dias-Arieira et al., 2008). Exudates released by plants, when they have an inhibitory effect on the hatching of second-stage juveniles of *M. javanica* and *M. incognita*, cause disintegration of the vitelline layer of eggs, allowing toxins to pass from the environment into the eggs, thereby inhibiting hatching (Stirling, 1993). Enzyme production by nematodes becomes deficient, as does the action of enzymes on the hydrolysis of lipids bound to the egg's lipoprotein layer; these are stored as body energy reserves in the nematodes.

At the maximum concentration of the extract, (20 % w/v) the longer the juvenile takes to hatch after exposure to the exudate, the greater the consumption of lipids, which compromise their survival as a result of energy reserves in lipid form being required for locomotion, infectivity, reproduction, and survival of the nematode due to the antagonist compounds released into the environment by volatilization, leaching, decomposing plant tissues, or exudation of the root system (Dias-Arieira et al., 2008).

Oats have the ability to exude scopoletin that can be attributed to nematicidal activity and are rich in phenolic compounds such as ferulic and p-coumaric acid, present in the cell walls of white oats and black oats, which may be involved in the nematicidal effect (Escobedo-Flores et al., 2018). Moreover, lignified cells and intracellular spaces filled with phenols are present in white oats demonstrating a plant defense response to RKN attack (Marini et al., 2016). These substances may also be related to plant nematicidal activity as lectins present in oats. Lectins are glycoproteins that block nematode chemoreceptors, making it difficult to locate the host plant, disrupting nematode parasitism (Lacerda et al., 2017).

The influence of plant exudates on the hatching of second-stage juveniles may vary according to the phenological stage at which the plant is found. Therefore, the use of plant material from oat plants in full bloom is suitable for research purposes since the concentration of antagonist substances in oats, such as, phenolic compounds and antioxidants, is higher during the grain development phase (Alfieri and Redaelli, 2015). This emphasizes the potential antagonism of oat genotypes resulting from the accumulation of chemicals that will be released into the soil, including the straw that is formed. The nematicidal activity of the evaluated genotypes may also be related to the stage of development at which the genotypes are harvested, which is full flowering.

Both the nematode species under study differed in hatching percentage when exposed to oat extracts, even though all the extracts exerted harmful effects on individuals. This is because nematode species originate from different populations and environmental conditions, and show variability in the pattern of response to exudate inflows. This variability is influenced by genetic differences between individuals, which reflect different natural hatching mechanisms, different adaptive responses, and life cycles.

Pathogenicity factors such as the production of proteins and enzymes secreted by nematodes, to establish the site of infection and feeding on susceptible plants also have variable responses. These factors directly reflect the response pattern of individuals of different nematode species when in contact with nematotoxic plant extract (Castagnone-Sereno et al., 2013). Thus, RKN management of both species can be exercised with the use of oat cultivars that can reduce the pest population density for inhibiting their hatching, and consequently their parasitism.

Although the effect of plant extracts on the hatching of juveniles of *M. javanica* and *M. incognita* is recognized, the information on the acting biomolecules and their mechanism of action is scarce. The use of dry extracts by laboratory tests is a procedure employed to prospect the bioactivity of plants on a given organism, prospecting the action of chemical compounds (Arul et al., 2020). The results obtained in this study confirm the nematotoxic action of the extracts regarding the inhibition of the hatching of juvenile nematodes. The inhibitory effect increases when the concentration of the extract is increased resulting in greater accumulation of antagonist compounds, responsible for inhibiting the hatching of juveniles of both nematode species.

There is inter- and intra-specific variability in *Avena* spp. regarding the efficiency in the hatching control of *M. javanica* and *M. incognita*, accessed by the application of aqueous extracts of the aerial part of white oat and black oat strains and cultivars. As the concentration of the extracts increases, there is an increase in the hatching control efficiency of both nematode species, which suggests an increase in the amount of phytopathogen-inhibiting chemicals.

Regardless of the concentration, the extract of the Embrapa 139 genotype had a greater inhibitory nematotoxic action on the hatching of *M. javanica*. On the other hand, the extracts of the Agro Quaraí and Af 1345 Ucraniana had a greater inhibitory nematotoxic action on the hatching of *M. incognita*. These findings presuppose the possibility of the choice of genotypes of *Avena* spp.,

potentially inhibitory of the hatching of second-stage juveniles of *M. javanica* and *M. incognita,* which support the continuity of studies with field trials. Thus, crop rotation or succession with nematicidal oat cultivars is a management strategy aimed at suppressing the RKN population in the subsequent culture.

Knowledge of the substances responsible for nematicidal action is an essential step in the prospecting of bioactive molecules for the control of phytopathogenic nematodes. Thus, future studies should: i) identify and isolate substances with nematicidal action from oats; ii) understand the mechanisms of action of these biomolecules; and iii) develop field trials for the applicability of bio-nematicides in line with the sustainability of cultivation of agro-ecosystems.

Acknowledgments

The authors are grateful to the Coordination for the Improvement of Higher Level Personnel (CAPES), for the scholarship and to the Brazilian National Council for Scientific and Technological Development (CNPq), for the Productivity Scholarship.

Authors' Contributions

Conceptualization: Carraro-Lemes, C.F.; Chiomento, J.L.T.; Deuner, C.C.; Scheffer-Basso, S.M. **Data acquisition**: Carraro-Lemes, C.F.; Chiomento, J.L.T. **Data analysis**: Carraro-Lemes, C.F.; Chiomento, J.L.T.; Deuner, C.C.; Scheffer-Basso, S.M. **Design of methodology**: Carraro-Lemes, C.F.; Chiomento, J.L.T.; Deuner, C.C.; Scheffer-Basso, S.M. **Writing and editing**: Carraro-Lemes, C.F. Chiomento, J.L.T.; Deuner, C.C.; Scheffer-Basso, S.M.

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