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Plant Parasitic Nematodes Associated with Quinoa Genotypes and their Effects on the Yield under Field Conditions

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ABSTRACT

Quinoa plant is a new crop in Egypt and have recently gained global and local attention, especially for its ability to grow under various biotic and abiotic stresses. Currently, there are no studies related to the reaction of the nematodes on quinoa in Egypt and only few studies worldwide. The present study aimed to determine the distribution and prevalence of plant parasitic nematodes associated with quinoa and to evaluate their reaction on plants health and yield of different quinoa genotypes grown in Egypt. An investigation was carried out in Ismailia Governorate during two growing seasons 2020/2021 and 2021/2022. The results revealed the presence of four plant parasitic nematode genera which were *Meloidogyne, Pratylenchus, Xiphinema* and *Longidorus*. It has been observed that *Xiphinema* spp. was the most predominant species in the soil, followed by *Meloidogyne* spp. and *Pratylenchus* spp., respectively. The reproduction factors of nematodes (RF) highlighted differential responses among the tested quinoa genotypes ranging from immune to sensitive. The results showed that yield injury (YI) as a result of nematode infection ranged from 12.61 to 28.05%. According to both yield injury and nematode tolerance index (NTI), the tested quinoa genotypes can be divided into three groups under nematode infestation conditions compared to normal conditions, represented by a high resistance group which includes the genotypes G1, G50 and G2, a medium resistance group including the genotypes G29, G44, G78 and G105, and a low resistance group which include the genotypes G23, G49 and G111.

***Keywords*:** quinoa, genotypes, nematodes, resistance, susceptibility, yield injury.

INTRODUCTION

Quinoa is a new crop in Egypt and have recently gained global and local attention, especially for its ability to grow under various biotic and abiotic stresses such as soil salinity, drought, frost, and others, as well as its stability under different conditions (Adolf et al., 2012; Ruiz et al., 2014; Algosaibi et al., 2017; Badran et al., 2019 and Badran, 2022). Quinoa (*Chenopodium quinoa* Willd.), an Andean grain, is one such resilient crop that can potentially contribute to the development of marginal areas (Alandia et al., 2020; Rodriguez et al., 2020; Tabatabaei et al., 2022). Improving the standard of living and sustaining the livelihoods of local poor farmers in the desert regions of Egypt (Shin et al., 2022; Mansour et al., 2023). Moreover, quinoa seed has an outstanding nutritional value **(**Vega-Gálvez et al., 2010 and Tabatabaei et al., 2022). and it is a multipurpose grain (food, feed, cosmetics usages) (Bhargava et al., 2006). Repo-Carrasco-Valencia et al. (2010) reported that quinoa grains have a high-quality protein i.e., sulfur rich amino acids 14.8 to 15.7%, oil with essential fatty acids as linoleic acid and g-linolenic acids and natural antioxidants (tocopherol and g-tocopherol), along with a wide range of minerals and vitamins (Kumar et al., 2006). Its composition has attracted the attention of many scientists owing to its high nutritional value and presence of proteins, lipids, fibers,

vitamins, minerals, and essential amino acids; gluten free nature (Navruz-Varli and Sanlier, 2016; Filho et al., 2017; Almadini et al., 2019; Tabatabaei et al., 2022), tocopherols and organic acids as well as isoflavones and interesting antioxidant functional properties (Pereira et al., 2019, 2020). All these components contribute to food security (Nowak et al., 2016).

Quinoa is an important crop not only because of its high nutritional value but as well for its high tolerance to external biotic and abiotic stresses (Jarvis et al., 2008; Novak et al., 2016; Hinojosa et al., 2018) and its adaptation to diverse agroecological zones (Tabatabaei et al., 2022). Although the quinoa grains are known for their bitterness due to the saponins which need to be removed before grain consumption, this characteristic confer to the crop other potential uses (Otterbach et al., 2021). The saponin waste is used as a novel bioproduct with their potential biological roles, from antifungal and anti-herbivory activity to their impact on germination and stress tolerance. Quinoa is an emerging crop around the globe, with great potential to contribute to Africa's food and nutrition security (Ruiz et al., 2014). No crop other than quinoa can resist the combination of adverse factors, and therefore, a national campaign to expand the cultivation of quinoa has been launched by the Egyptian Ministry of Agriculture (El-Sayed, 2018) due to its adaptability to adverse climate and soil conditions (Schlick and Bubenheim, 1993).

The most economic pests attacking quinoa crop are; the kona-kona (*Eurysacca quinoa* Povolny), the cutworms (*Copitarsia turbata* Herrich and Schäffer), chinch bugs (*Epitrix subcrinita* Lec.*)*, the green aphid *(Macrosiphum euphorbiae* Thomas), mildew (*Peronospora farinose* Fries), and plant parasitic nematodes (Mendoza-Lima et al., 2020 and León et al., 2018). The genera of nematodes associated with quinoa crop that has been identified by the researchers are *Meloidogyne, Nacobbus, Pratylenchus, Helicotylenchus, Mesocriconema, Xiphinema, Dorylaimus, Hemiciclyophora*, and *Globodera* (Franco, 2003 and Lima-Medina et al., 2019). A recent study by Mendoza-Lima et al. (2020) stated that the majority of the quinoa cultivars tested by the researchers in an area in Peru were susceptible to the root-knot nematode *M. incognita* and resistant to *M. arenaria* and *M. hapla.*
Plant parasitic nematodes (PPNs) are one of the most hidden destructive enemies that infect economic and non-economic plants all over the world. They represent one of the major biotic constraints in agriculture. More than 4100 species susceptible to PPNs were registered (Decraemer and Hunt, 2006). Global yield losses caused by PPNs were estimated to be US$ 70 billion in 1987 (Sasser and Freckman, 1987) and have been reported to be US$ 80 billion per year in 2011 (Nicol et al., 2011). PPNs were reported as highly destructive plant pathogens causing worldwide losses exceeding in some years US$ 125 billion per year (Chitwood, 2003; Mokrini et al., 2018). It has been reported by previous studies the existence of 54 genera and 160 species of phytoparasitic nematodes in Egypt and associated with different type of plants (Oteifa et al., 1997; Ibrahim et al., 2000; Ibrahim and El-Sharkawy, 2001; AbdelRazek and Balah, 2023). Many of these nematodes fell under the - order Tylenchida (*Meloidogyne* spp., *Pratylenchus* spp., *Rotylenchulus reniformis*, and *Tylenchulus semipenetrans*) and they were reported as limiting factor to the production of the host plants (Oteifa et al., 1997; Ibrahim et al., 2000; Ibrahim and El-Sharkawy, 2001). Root-knot nematodes (*Meloidogyne* spp.) represent one of the most common pathogenic nematodes in Egypt, as they are widespread in the majority of Egyptian soils (Oteifa et al., 1997; Ibrahim et al., 2000; Korayem et al., 2011).

Presently, in Egypt, there are no reports about plant parasitic nematodes attacking quinoa plants and the susceptibility of grown genotypes therefore, the current study aimed to determine the prevalence of plant parasitic nematodes associated with quinoa plants and to evaluate the response of the different quinoa genotypes grown under Egyptian conditions.

MATERIALS AND METHODS

Experimental procedure

This study was conducted on a private farm in Ismailia Governorate during the growing seasons 2020/2021 and 2021/ 2022, Soil samples were taken from the wet rhizosphere at three periods where soil samples were collected during the initial survey of the field before preparation for cultivation (field investigation process), conducted again after plowing and field preparation, and the third time soil samples were taken after three months before harvest during the first and the second growing season. in order to monitor the numbers of nematode species during growing season. Each sample was kept in a polyethylene bag and sent immediately to the laboratory for nematode isolation and examination. The first season was investigation, 10 genotypes obtained from International Center Biosaline of Agriculture (ICBA) where they were grown under normal conditions in a randomized complete block design with three replicates. Each genotype was planted in a plot of 6.6 m^2 (2.2m × 3 m). Based on observation of the nematode's infestations, 10 quinoa genotypes were selected to be evaluated in the second season as follows: G1(C4R-2-19-6), G2 (CHEN-193), G23 (Ames-13738), G29 (CHEN-128), G44(CO-KA-1880), G49 (CO-KA-1936), G50 (CO-KA-1950), G78 (D-12065), G105 (Ames-19046), and G111 (BO-40). During the second season, the 10 selected quinoa genotypes were arranged in a randomized complete block design with three replicates. Each genotype was planted in a plot of 10.5 m^2 (3m × 3.5 m) where the distance between the rows was 30 cm; while the distance between the holes was 20 cm, 6:7 seeds were placed in each hole, and after germination, only two plants were left in the hill.

Extraction of nematodes from soil

The extracted nematodes were counted in Hawksley slide and identified nematodes in soil were extracted by sieving and decanting method (Byrd et al.,1996). Each soil sample was carefully mixed, and an aliquot of 200 g was processed for nematode isolation according to methods described by Christie and Perry (1951) and Southey (1970). as follows: About 300-400 ml of water were added to the soil in a glass beaker (1000 ml) and the mixture was agitated by glass stalk for few seconds. The suspension was poured onto a 60 mesh-sieve and passing suspension was collected in another clean glass beaker. Residual caught on the 60 mesh-sieve was discarded, while the collected suspension was then poured onto a 200 mesh-sieve. The remaining material on the sieve was thoroughly washed by a gentle stream of water into a 200 ml beaker. The resulting suspension containing nematodes was then, transferred to a modified Baermann funnel, after that nematodes were identified under light microscope according to the description of Mai and Lyon (1975). The reproduction factor (RF) was determined according to the methodology described by Oostenbrink (1996). The reaction of the nematode's species (RE) are considered I= immune (RF = 0), S = Susceptible (RF ≥ 1) and R = Resistant (RF ≤ 1).

Yield injury and tolerance index

Indices of stress tolerance (salinity tolerance index, yield injury, superiority measure, and relative performance) can be reliable parameters to evaluate quinoa crop under environmental stress conditions to determine the degree of resistance of tested genotypes, as indicated by Badran et al. (2019). Tolerance and sensitivity parameters of the tested genotypes to the nematode's species were calculated based on the weight of grain per plant as follows:

Nematode tolerance index (NTI): NTI= $(Yn)\times(Yi)/(\acute{Y}n)^2$ according to Fernandez, (1992)

Yield injury % (YI): YI = (Yn-Yi)/Yn × 100 according to Blum (1983) where, Yn = yield/plant of genotype under non-infected conditions; Yt= yield/plant of genotype under injury conditions; Ýn=Mean yield of all tested genotypes under normal conditions

Statistical analysis

Data were subjected to the analysis of variance test (ANOVA) and Duncan's Multiple Range test was used at 5% level to compare the means using MSTATC program, version 2018.

RESULTS

Identification and quantification of nematodes during field investigation process

The examination of soil samples collected during farm investigation (before planting preparations) showed that soil contains four genera of nematodes: *Xiphinema., Meloidogyne, Pratylenchus* and *Longidorus.* The quantification of the nematodes indicated that there are clear significant differences between the numbers of nematodes genera/200g soil.

Table 1: Examination of soil samples collected from the farm at the investigation stage.

	Number of nematode juveniles per 200 g soil			
	Before planting preparations			
Genera	***Xiphinema***	***Meloidogyne***	***Pratylenchus***	***Longidorus***
Number	800 [a]	250 [d]	350[b]	260 [c]

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

The examination of the nematodes showed that the genus *Xiphinema* recorded the highest value of the nematode juveniles in the soil, followed by *Pratylenchus, Longidorus* and *Meloidogyne,* respectively (Table 1).

Effect of the plowing operations on the nematodes

The soil samples taken after plowing and land preparation during the first season showed that the number of plant parasitic nematodes were decreased for all genera due to field preparation activities (Table 2). The results indicate that the genus *Longidorus* was the least affected with a decrease of -19% compared with the soil samples examined at the investigation stage. The soil samples taken after plowing process and field preparation for the second season cultivation indicated that the genus *Xiphinema* recorded the highest population of the nematode juveniles in the soil with an increase of +12.5% compared to the soil samples collected during investigation and an increase of +50% compared to the soil collected after field preparation in the first season. A similar increase was recorded for the genus *Longidorus* where an increase of +8% and +33% of the nematode juveniles in the soil were recorded, compared to the investigation stage and the first season, respectively. However, the population of the genus *Meloidogyne* showed a slight decrease of -8% when compared with the soil collected during investigation stage and a significant increase of +27% compared with the samples collected after field preparation for the first season. On the other hand, the population of the genus *Pratylenchus* spp. was the most affected with a decrease of -57% when compared with the soil samples collected during investigation and -40% when compared with soil samples collected after field preparation for the first season (Table 3).

Table 2: Examination of nematode samples from the farm after plowing operations and field preparation for the first season.

	Number of nematode juveniles 200 g-soil			
	After field preparation, Season 1			
Genera	***Xiphinema***	***Meloidogyne***	***Pratylenchus***	***Longidorus***
Number	600 [a]	180 [d]	250 [b]	210 [c]

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Table 3: Examination of nematode samples from the farm after plowing operations and field preparation for the second season.

	Number of nematodes juveniles /200g soil			
	After field preparation, Season 2			
Genera	***Xiphinema***	***Meloidogyne***	***Pratylenchus***	***Longidorus***
Number	900 [a]	230 [c]	150 [d]	280 [b]

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Interaction between nematodes genera and quinoa genotypes during first growing season

Based on observations during first growing season, 10 quinoa genotypes were selected for examination of the nematodes' infestation. Samples were collected from the rhizosphere of the 10 selected quinoa genotypes and evaluated in the laboratory. The obtained results showed the existence of the initially identified 4 genera of the plant parasitic nematodes i.e. *Xiphinema*., *Pratylenchus, Longidorus* and *Meloidogyne*. The results revealed as well that *Xiphinema* spp., was prevalent in small numbers in the tested quinoa genotypes G2, G1, G50, G29 and G78, respectively (Table 4) suggesting that these genotypes are less infected and have a relative resistance to nematodes with RF <1 (Table 5).

The data presented in Table (5) highlight that the plant nematode reproduction factor (RF) for *Xiphinema* spp. was low in the genotypes G1 and G2 with RF = 0.31 and 0.30, respectively (Table 5), which classify those two genotypes as the most resistant (R). On the other hand, the genotype G49 had the highest population of *Xiphinema* spp. (6285 juveniles/200g), followed by G23 (2755Js), G105 (2454 Js), G111 (2200 Js) and G44 with 2176 counted J (Table 4), which classify this group as highly sensitive with a reproduction factor RF > 1 (Table 5).

Furthermore, the reproduction factor of *Meloidogyne* spp. was high in the genotypes G105, G111, G23, G44, G78, G50, G29 and G49, therefore they were classified as susceptible with RF≥1 according to Oostenbrink (1966). Most of quinoa genotypes were not infected by *Pratylenchus* spp. where genotypes G2, G23, G50, G78, G105 and G111 recorded RF=0, and classified as immune. However, the genotypes G1, G29, G44 and G49 were classified as resistant with RF<1. In the other hand, the reproduction factor of plant nematode, *Longidorus* spp. was low in most of the quinoa genotypes and classified as resistant except the genotypes G23, G44, G105 and G111 which were classified as susceptible with RF>1 (Table 5).

Table 4: Numbers of plant parasitic nematodes associated with soil samples of quinoa genotypes in the first season.

Genotype	Number of nematode juveniles/ 200g soil				Mean
	***Xiphinema* spp.**	***Meloidogyne* spp.**	***Pratylenchus* spp.**	***Longidorus* spp.**	
G1	188 ^{kl}	166 ^{lm}	110 ^{m}	144 ^{lm}	152.00 ^{G}
G2	192 ^{kl}	177^{kl}	0.0 ^{n}	192 ^{kl}	140.25 ^{G}
G23	2755 ^{b}	530 ^{h}	0.0 ^{n}	630 ^{g}	978.75 ^{B}
G29	200 ^{kl}	228 ^{jk}	198 ^{kl}	170 ^{l}	199.00 ^{F}
G44	2176 ^{d}	400 ^{i}	200 ^{kl}	280 ^{j}	764.00 ^{D}
G49	6285 ^{a}	200 ^{kl}	192 ^{kl}	180 ^{kl}	1714.2^{A}
G50	195 ^{kl}	280 ^{j}	0.0 ^{n}	170 ^{l}	161.25 ^{G}
G78	400 ^{i}	400 ^{i}	0.0 ^{n}	200 ^{kl}	250.00 ^{E}
G105	2454 ^{c}	880 ^{e}	0.0 ^{n}	510 ^{h}	961.00^{B}
G111	2200 ^{d}	800 ^{f}	0.0 ^{n}	350 ^{i}	837.50^{C}
Mean	1704.5 ^{A}	405.9 ^{D}	70.0 ^{C}	282.6 ^{B}	

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Interaction between nematode species and quinoa genotypes during second growing season

At the second season, the tested genotypes were cultivated in two sectors. The first sector as a control group (free from nematodes). This sector was selected based on the examination of the soil samples during the investigation stage where the sector showed absence of any nematodes genera. The second sector was cultivated in the site contained the same nematodes genera identified in the first season (*Xiphinema*, *Meloidogyne*, *Pratylenchus* and *Longidorus*.). The examination of the rhizosphere soil samples collected during the second growing season from the nematodes infested sector showed that the interaction between the nematodes genera and the quinoa genotypes was varied based on the nematode genus (Table 6).

The data in Table (6) indicate that there are significant differences between nematodes genera, and there are significant differences in the response of the different genotypes of quinoa to the infection with these genera. The interaction between nematode genera and quinoa genotypes showed significant differences. The examination of the soil samples collected from the quinoa genotypes rhizosphere showed that the genotypes G2, G1 and G50 were less infected with an average number of nematode juveniles equal to 137.50, 162.75 and 186.00, respectively (Table 6). These results are consistent with the calculated data of the reproduction factor (RF) and reaction (RE) of nematodes/200g soil (Table 7). On the other hand, the results in Table (6) revealed that, the two genotypes G49 and G105 are the most infected with nematodes as 1947.50 and 1074.50 Js, respectively. These results are in line with the calculated reproduction factor (RF) and reaction (RE) of nematodes/200g soil for the two genotypes (G49 and G105) which showed averages of RF equal to 2.86 and 2.28, respectively (Table 7).

Table 5: Reproduction factor (RF) of nematodes/200g soil and reaction (RE) of different quinoa genotypes to the different nematodes' genera during the first season.

Genotype	Reproduction factor (RF) of nematodes/200g soil and reaction (RE) of quinoa genotypes								RF Mean
	Xiphinema spp.		*Meloidogyne* spp.		*Pratylenchus* spp.		*Longidorus* spp.		
	RF	RE	RF	RE	RF	RE	RF	RE	
G1	0.31 ^{t}	R	0.92 ^{mno}	R	0.44 ^{s}	R	0.69 ^{qr}	R	0.59 ^{I}
G2	0.30 ^{t}	R	0.98 ^{m}	R	0.00 ^{u}	I	0.91^{mo}	R	0.55 ^{I}
G23	4.59 ^{c}	S	2.94 ^{g}	S	0.00 ^{u}	I	3.00 ^{g}	S	2.63 ^{C}
G29	0.33 st	R	1.27 ^{k}	S	0.79 ^{opq}	R	0.81 ^{op}	R	0.80 ^{G}
G44	3.62 ^{f}	S	2.22 ^{i}	S	0.80 ^{opq}	R	1.33 ^{k}	S	1.99 ^{E}
G49	10.47 ^{a}	S	1.11 ^{l}	S	0.77 ^{pqr}	R	0.85^{nop}	R	3.30 ^{A}
G50	0.32 st	R	1.55 ^{j}	S	0.00 ^{u}	I	0.81 ^{op}	R	0.67 ^{H}
G78	0.66 ^{r}	R	2.22 ^{i}	S	0.00 ^{u}	I	0.95 ^{mn}	R	0.96 ^{F}
G105	4.09 ^{e}	S	4.88 ^{b}	S	0.00 ^{u}	I	2.42 ^{h}	S	2.85 ^{B}
G111	3.66 ^{f}	S	4.44 ^{d}	S	0.00 ^{u}	I	1.66 ^{j}	S	2.44 ^{D}
Mean	2.84 ^{A}		2.25 ^{B}		0.28 ^{D}		1.34 ^{C}		

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test). RF= Reproduction factor (final population/initial population); RE= Reaction: I= immune (RF = 0), R= Resistant (RF ≤ 1) and S= Susceptible (RF ≥ 1) Oostenbrink, 1966). Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Regarding the reproduction factor of *Xiphinema* spp., it remained low during the second season in the same tested genotypes G1, G2, G29, G50 and G78 indicating that these genotypes are less infected. On the contrary, the tested genotypes G49, G23, G105, G111 and G44 had the highest population of *Xiphinema* spp., and classified as sensitive where RF > 1. In the other hand, *Meloidogyne* spp. showed low reproduction factor for the genotypes G2 and G1 with RF= 0.75 and 0.77, respectively (Table 7), and classified as resistant; while the reproduction factor was high for the genotypes G105, G111, G23, G44, G78, G50, G49 and G29 and classified as sensitive genotypes (RF ≥ 1).

Concerning *Pratylenchus* spp., the reproduction factor differed in the second season compared to the first one. The calculation of RF showed higher figures (FR>1) for the genotypes G29, G44 and G49 (RF= 1.46, 1.40 and 1.33, respectively), therefore they were classified as susceptible genotypes during the second growing season. The examination of *Longidorus* spp. revealed that the reproduction factor remained similar to that of the first seasons for all of the quinoa genotypes except the genotype G49 where the reproduction factor increased (RF= 1.03) and therefore the genotype G49 is classified as susceptible during the second season as RF>1. For the quinoa genotypes G1, G2, G29, G50 and G78, the reproduction factor remained below 1 and classified as resistant Similar to first season the genotypes G23, G44, G105 and G111 were classified as susceptible to *Longidorus* spp. with RF > 1.

Table 6: Number of plant parasitic nematodes associated with soil samples of quinoa genotypes in the second season**.**

Genotype	Number of nematode juveniles/200 g soil				Mean
	***Xiphinema* spp.**	***Meloidogyne* spp.**	***Pratylenchus* spp.**	***Longidorus* spp.**	
G1	200 $^{n-q}$	179 ^{pqr}	122 ^{s}	150 ^{rs}	162.75 ^{I}
G2	198 $^{n-q}$	174 ^{qr}	0.0 ^{t}	178 ^{pqr}	137.50 ^{J}
G23	1800 ^{d}	600 ^{h}	0.0 ^{t}	700 ^{g}	775.00 ^{D}
G29	420 ^{l}	230 ^{n}	220 ^{no}	192 ^{opq}	265.50 ^{G}
G44	1800 ^{d}	430 ^{kl}	210 ^{nop}	300 ^{m}	685.00 ^{E}
G49	7000 ^{a}	300 ^{m}	200 $^{n-q}$	290 ^{m}	1947.5^{A}
G50	230 ^{n}	294 ^{m}	0.0 ^{t}	220 ^{no}	186.00 ^{H}
G78	460 ^{jk}	480 ^{j}	0.0 ^{t}	230 ^{n}	292.50 ^{F}
G105	2822 ^{b}	933 ^{e}	0.0 ^{t}	543 ^{i}	1074.5^{B}
G111	2608 ^{c}	830 ^{f}	0.0 ^{t}	400 ^{l}	959.50 ^{C}
Mean	1753.80 ^{A}	445.00 ^{B}	75.20 ^{D}	320.30 ^{C}	

Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Table 7: Reproduction factor (RF) of nematodes/200g soil and reaction (RE) of different quinoa genotypes to the different nematodes' genera in the second season**.**

Genotype	Reproduction factor (RF) of nematodes juveniles /200 g soil and reaction (RE) of quinoa genotypes								RF Mean
	***Xiphinema* spp.**		***Meloidogyne* spp.**		***Pratylenchus* spp.**		***Longidorus* spp.**		
	RF	**RE**	**RF**	**RE**	**RF**	**RE**	**RF**	**RE**	
G1	0.22 ^{u}	R	0.77 ^{pq}	R	0.81 ^{p}	R	0.55 st	R	0.59 ^{G}
G2	0.22 ^{u}	R	0.75 ^{pq}	R	0.0 ^{v}	I	0.63 ^{rs}	R	0.40 ^{H}
G23	2.00 ^{hi}	S	2.60 ^{f}	S	0.0 ^{v}	I	2.50 ^{g}	S	1.78 ^{D}
G29	0.46 ^{t}	R	1. 00 ^{o}	S	1.46 ^{k}	S	0.68 ^{qr}	R	0.87 ^{F}
G44	2.00 ^{hi}	S	1.86 ^{j}	S	1.40 ^{klm}	R	1.07 ^{o}	S	1.58 ^{E}
G49	7.77 ^{a}	S	1.30 ^{mn}	S	1.33 ^{lmn}	S	1.03 ^{o}	S	2.86 ^{A}
G50	0.25 ^{u}	R	1.27 ^{n}	S	0.0 ^{v}	I	0.78 ^{pq}	R	0.51 ^{G}
G78	0.51 ^{t}	R	2.08 ^{h}	S	0.0 ^{v}	I	0.82 ^{p}	R	0.86 ^{F}
G105	3.13 ^{d}	S	4.05 ^{b}	S	0.0 ^{v}	I	1.93 ^{ij}	S	2.28 ^{B}
G111	2.89 ^{e}	S	3.60 ^{c}	S	0.0 ^{v}	I	1.42 ^{kl}	S	1.98 ^{C}
Mean	1.95 ^{A}		1.93 ^{A}		0.50 ^{C}		1.18 ^{B}		

RF= Reproduction factor (final population/initial population); RE= Reaction: I= immune (RF = 0), R= Resistant (RF ≤ 1) and S= Susceptible (RF ≥ 1) Oostenbrink, 1966). Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

Effect of plant parasitic nematodes on the crop yield of the quinoa genotypes

Results in Table (8) showed that there were significant differences in the grain yield among the tested genotypes, whether exposed to infection with the four nematode genera or free from infection (control), with the highest grain yield for genotype G44 (24.6 g/plant). While the results of yield injury (YI) in the grain yield as a result of infection with nematodes revealed that the percentage were ranged from 12.61 (genotype G2) to 28.05% (genotype G44). Only five quinoa genotypes recorded a yield injury (YI) below the general average (19.45%), and were classified as infection-resistant genotypes (G2, G29, G1, G50 and G78, respectively). Regarding to nematode tolerance index (NTI), there are relatively agreement with the yield injury (YI) rate, with genotypes G1, G50, and G2 being recorded, respectively, as nematode-tolerant genotypes.

Table 8: Average grain yield of quinoa genotypes under nematodes-infested condition and nematodes-free sectors, yield injury and nematode tolerance index.

Genotype	Yield / plant (g) under control (free nematode)	Yield / plant (g) under nematodes infestation	(YI)	(NTI)
G1	23.4 ^{ab}	19.9 ^{a}	14.96 ^{f}	1.158 ^{a}
G2	22.2 ^{b}	19.4 ^{a}	12.61 ^{g}	1.071 ^{a}
G23	18.1 ^{de}	13.9 ^{d}	23.20 ^{c}	0.626 ^{d}
G29	15.3 ^{f}	13.1 ^{de}	14.38 ^{f}	0.500 ^{e}
G44	24.6 ^{a}	17.7 ^{b}	28.05 ^{a}	1.083 ^{a}
G49	16.2 ^{ef}	12.6 ^{e}	22.22 ^{cd}	0.508 ^{e}
G50	22.6 ^{ab}	19.1 ^{a}	15.49 ^{f}	1.073 ^{a}
G78	16.8 ^{ef}	13.9 ^{d}	17.26 ^{e}	0.581 ^{de}
G105	21.5 ^{bc}	16.1 ^{c}	25.12 ^{b}	0.861 ^{b}
G111	19.8 ^{cd}	15.6 ^{c}	21.21 ^{d}	0.768 ^{c}
Mean	20.05	16.13	19.45	0.823
Standard Error	0.713	0.400	0.468	0.032

NTI= nematodes tolerance index, YI= yield injury. Different letters correspond to significantly different values at a 0.05 probability level (Duncan's Multiple Range test).

DISCUSSION

Microscopic examination of soil samples revealed the presence of four genera of phytoparasitic nematodes, and have been reported as harmful for the agriculture in Egypt and might cause dangerous losses in the quality and quantity of various plants (Ibrahim, 1994; Ibrahim and El-Sharkawy, 2001; Korayem and Mohamed, 2010; Korayem et al., 2014). Although some research in Egypt were carried out to study the relationship between phytoparasitic nematodes with certain crops (Aboul-Eid and Ghorab, 1974, 1981), the economic effects and the degree of damage that they may cause to their hosts are still scientifically uncertain probably due to the combination with predominant environmental conditions which play an important role in its distribution and dissemination.

The main genera of phytoparasitic nematodes identified in the main production areas of cultivated quinoa of the Puno region in Peru were *Meloidogyne* spp., *Mesocriconema* spp., *Xiphinema* spp., *Dorylaimus* spp., *Hemiciclyophora* spp., *Globodera* spp., and *Pratylenchus* spp., and they were reported causing significant yield losses (Franco, 2003; Lima-Medina et al., 2019). The revealed root-knot nematodes (*Meloidogyne* spp.) represent one of the most common pathogenic nematodes in Egypt, as they are widespread in the majority of Egyptian soils (Ibrahim et al., 2000; Korayem et al., 2011) and the results of current study run at Ismailia confirm the high reproduction factor of this genus in the Egyptian study area.

Recent studies highlighted that root-knot nematode causes huge decrease in yield of many field crops and the amount of damage depends on nematode population density, predominant environmental conditions and type of host plant (Korayem, 2008; Youssef and Korayem, 2008; Korayem et al., 2008; 2009; 2012 and Korayem and Bondok, 2013). Phytoparasites such as nematodes attack plants without giving signs of symptoms, as they can prevent the passage of nutrients and the normal growth of quinoa plant according to Lima-Medina et al. (2019). The results of the field investigation showed the differences between population densities and frequencies of the root-knot nematode *Meloidogyne* spp. occurrence in the surveyed locations. The data showed as well that *Meloidogyne* spp. is associated with the majority of examined plants and these results agree with others (Anwar et al.,1991; Bakr et al., 2011; Bakr 2014). They revealed that infection and highest distribution of *Meloidogyne* spp. occurred in sandy soil especially in the newly reclaimed lands and depend on the kind of cultivated crops and temperature. The continuous growing of local cultivars and constant cropping practice may favor survival and rapid build-up of nematode populations in the soil.

The virus-transmitted nematodes, (*Longidorus* spp. and *Xiphinema* spp.) that were detected in the examined soil samples of our study area in Ismailia has been reported as nematodes that transmit some plant viruses causing viral diseases to crop in Europe (Brown et al., 2004). However, their economic importance as vectors of plant viruses in Egypt requires more investigation studies. The other plant parasitic nematode (*Pratylenchus* spp.) detected in the examined samples of our study area is a lesion nematode. The obtained results agree with those obtained by Lima-Medina et al. (2019). in Peru and Ashoub (2010) in North Sinai governorate. who reported that *Pratylenchus* spp. feed on cell sap of infected plants causing damage to plants. However, the economic effects and the degree of damage by nematodes is causing have not gained the required attention. Still, more studies are needed to determine the amount of damage caused by these nematodes.

Results of the current study agree with some studies carried on quinoa reaction to nematodes (Asmus et al., 2001; 2005; Mendoza-Lima et al., 2020). They reported that the quinoa crop had the highest multiplication of *M. javanica* and that its cultivation in infested areas can increase the probability of infection, Recently, results reported by Mendoza-Lima et al. (2020). indicated as well that all tested quinoa cultivars were susceptible to *M. incognita,* and some were susceptible to other species of *Meloidogyne*.

Regarding the comparison of the reaction quinoa genotypes' reaction nematodes infection, the tolerance index of tested genotypes was calculated based on the yield injury comparing the average grain yield under no-infestation conditions (control) compared to the average grain yield of the genotypes tested under nematodes infection conditions. Generally, the results revealed that the quinoa genotypes can be divided into three groups based on their reaction to nematodes infection: high resistance (G1, G50 and G2), medium resistance (G105, G29, G78 and G44), and low resistance (G23, G49 and G111). These results are similar to the results reported by Fernandez (1992) and Badran 2022) who classified quinoa genotypes into four groups according to their performance under the environmental stress conditions.

CONCLUSION

The most important results out of the current study are that the quinoa crop can be considered as one of the important crops with a high ability to resist nematodes, compared to many other locally cultivated crops that are clearly affected by nematodes. It also showed that *Xiphinema* spp. recorded the largest number of the nematode stage juveniles J2 in soil cultivated by quinoa compared to other existing plant-parasitic nematode genera. Some of the tested quinoa genotypes, namely G2, G1 and G50, can be considered as promising genotypes with regard to their resistance to nematode infection and can be recommended to growers in Egypt.

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DECLARATION

The authors declare that they do not have any actual or potential conflict of interest.

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الملخص العربي

النيماتودا المتطفلة نباتيا المرتبطة بالتراكيب الوراثية للكينوا وتأثيرها على المحصول تحت الظروف الحقلية

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يعد نبات الكينوا محصولًا جديدًا في مصر وقد اكتسب مؤخرًا اهتمامًا عالميًا ومحليًا، خاصة لقدرته على النمو تحت مختلف الضغوط الحيوية واللاحيوية. لا توجد حاليًا دراسات تتعلق بتفاعل الافات النيماتودية على الكينوا في مصر، فقط هناك دراسات قليلة على مستوى العالم. تهدف الدراسة الحالية إلى تحديد توزيع انتشار الافات النيماتودية المصاحبة للكينوا وتقييم تأثيرها على صحة النباتات وإنتاجية التراكيب الوراثية المختلفة للكينوا المزروعة في مصر. تم إجراءالدراسة بمحافظة الإسماعيلية خلال موسمى النمو ٢٠٢٠/٢٠٢١ و ٢٠٢١/٢٠٢٢. أظهرت النتائج وجود أربعة اجناس من النيماتودا المتطفلة نباتيا وهي نيماتودا تعقد الجذور *Meloidogyne* ، نيماتودا التقرح *Pratylenchus*. ، النيماتودا الخنجرية *Xiphinema*. والنيماتودا الابرية *Longidorus* وقد لوحظ أن *Xiphinema* كان الجنس الأكثر انتشارًا في التربة، يليه *Meloidogyne* و*Pratylenchus* ، على التوالي. أبرزت عوامل تكاثر الاقات النيماتودية (RF) استجابات تفاضلية بين الأنماط الجينية للكينوا التي تم اختبارها والتي تتراوح بين المنيع والحساس للإصابة.. أظهرت النتائج أن نسبة فقد المحصول (YI) نتيجة الإصابة بالنيماتودا تراوحت بين ١٢,٦١ إلى ٢٨,٠٥%. وفقا لكل من مؤشر إصابة المحصول ومؤشر تحمل النيماتودا(NTI) ، يمكن تقسيم التراكيب الوراثية التي تم اختبارها في الكينوا إلى ثلاث مجموعات تحت الظروف الحقلية للإصابة بالنيماتودا مقارنة بالظروف ذات التربة الحقلية غير الملوثة بالنيماتودا، وهي تشمل مجموعة عالية المقاومة و الممثلة بالأنماط الجينية G1 ، G50، G2، ومجموعة متوسطة المقاومة وتشمل التراكيب الجينيG29 ، G44، G78 وG105، ومجموعة المقاومة المنخفضة وتشمل التراكيب الجينية G23، G49 و G111