Occurrence of Potato Cyst Nematode (*Globodera* spp.) as a Threat to the Potato Crop in Yemen

J.K. Showkat and M.R.M. Saeed*
Department of Plant Protection, Faculty of Agriculture, Food and Environment, Sana'a University, Yemen.
*Email address of the corresponding author: pro.m.raweh@gmail.com

Abstract

Showkat, J.K. and M.R.M. Saeed. 2026. Occurrence of Potato Cyst Nematode (*Globodera* spp.) as a Threat to the Potato Crop in Yemen. Arab Journal of Plant Protection, 44(2):173-182. https://doi.org/10.22268/AJPP-001384

The potato cyst nematode (PCN) (*Globodera* spp.) was previously regarded as the most detrimental pest to potatoes, causing serious crop losses worldwide. Despite the significance of PCNs, there is currently no data available on their prevalence or the extent of their impact on Yemeni potato cultivation. Therefore, this investigation was conducted to investigate the distribution and population density of this pest in the major potato production regions in Yemen and assess potato yield loss caused by it. During the 2023 production season, a total of 455 soil samples were collected from 145 fields located in 30 regions in Amran, Dhamar, and Ibb governorates. Cysts were extracted using the Fenwick can technique. The results obtained showed that PCNs were detected in all surveyed regions, except for the Daaf region in the Dhamar governorate. This nematode was recovered from 121 fields (83.4%) with densities ranging from 3 to 1,340 cysts/200 g of soil. The highest mean frequency of occurrence (100%), population density, cyst viability, and soil infestation level (SI) were recorded in the Ibb governorate, whereas the lowest mean frequency of occurrence (21.8%), population density, and soil infestation level were recorded in Dhamar governorate. The results obtained also showed significant variation in the mean SI levels of PCN across most of the surveyed fields within regions, in addition to their differences between regions within the governorates. Mean SI levels ranged from 1.4 to 190.3 eggs and juveniles/g soil, resulting in an estimated average yield loss ranging from 0.2 to 26.2 t/ha. The results of soil infestation levels with potato cyst nematodes recorded at seven sites in Ibb Governorate and one site in Amran Governorate revealed levels far exceeding the economic damage threshold, leading to severe yield losses and the failure of potato cultivation in these areas. Thus, there is an urgent need to provide farmers with an appropriate strategy for PCN management.

Keywords: *Globodera*, PCNs, distribution, density, yield loss.

Introduction

Potato is one of the important crops that people in developing countries depend on as a primary source of food (FAO, 2018). Potatoes are rich in potassium, phosphorus, magnesium, vitamin C, and dietary antioxidants. The cultivation of potatoes as a food crop has the potential to fulfill the four essential criteria for food security: availability, quality, accessibility, and stability (Ahmadu *et al*., 2021). Potatoes are considered one of the most promising crops in the fight against hunger and poverty (Thomas & Sansonetti, 2009). It is grown in around 140 countries, with more than 100 of them located in tropical and subtropical regions (FAOSTAT, 2022).

In Yemen, potato is an important vegetable crop and are considered one of the most essential crops for nutrition security, in addition to being an important source of income. In 2021, potatoes were cultivated on more than 17018 hectares, yielding approximately 347377 metric tons. The crop was initially planted in the Taiz and Ibb governorates in the southern regions of Yemen, before spreading to other highland zones located at 1,000 and 2,800 meters above sea level (Al Rahomy & El Girshi, 1986). Amran, Dhamar, and Ibb governorates produced more than 82.6% of total production, with 9.3, 41.0 and 32.3%, respectively (Anonymous, 2021). Recently, farmers have increasingly expressed concerns about declining potato production in the main potato production areas in Yemen. The decline was attributed to a high incidence of PCN infection, which has led to a complete failure of potato production in some regions.

More than 4100 plant parasitic nematodes species (PPNs) have been described (Decraemer & Hunt, 2006), and they are reported to cause an annual crop loss of around 80-118 billion dollars worldwide (Nicol *et al*., 2011; Sasser & Freckman, 1987). Jensen *et al*. (1979) documented the existence of approximately seventy PPN species belonging to twenty-four genera that are associated with the potato crop. Several of them are significant factors restricting potato production and tuber quality in several potato-producing regions, while others may cause minor injuries and have local importance (Imren, 2018; Lima *et al*., 2018; Maleita *et al*., 2018; Orlando *et al*., 2020). Two of those species, the pale cyst nematode *Globodera pallida* (Stone, 1973) and the golden cyst nematode *G. rostochiensis* (Wollenweber, 1923), cause significant yield loss to potatoes (CABI/EPPO 2020a; CABI/EPPO 2020b; Turner & Evans, 1998). Both species originated from south America's Andean mountains, where they coevolved with their solanaceous host plants (Evans & Stone, 1977). They were introduced into Europe around 1850 as collections of potato tubers brought to breed for resistance to potato late blight caused by *Phytophthora infestans* (Evans *et al*., 1975; Jones, 1970; Mai, 1977). According to Evans & Stone (1977), PCNs are likely to spread from Europe to other nations via transported seed tubers or breeding materials. Currently, they are prevalent in all European potato-growing

https://doi.org/10.22268/AJPP-001384

regions, particularly on the Balkan peninsula (Oro, 2011). Both PCN species are classified as quarantined pests in over 100 countries and are subjected to harsh regulatory procedures when detected (EPPO, 2017). PCNs have been documented in potato-growing regions across Europe, South America, and parts of Asia, North America, Oceania, and Africa (EPPO, 2020).

In the Middle East, both species are found in Algeria, Cyprus, Iran, Pakistan, and Tunisia. *G. rostochiensis* is found in Egypt, Lebanon, Libya, Oman and Türkiye, whereas *G. pallida* is exclusively found in Morocco (EPPO, 2020). In Algeria, PCNs have been recorded for the first time in 1953 and it was established into many regions of this country (Frezal, 1954; Scotto La Massese, 1961). Since that period, PCNs have spread quickly to become a major limiting factor to potato production in several important potato production localities (Mezerket *et al*. 2018; Tirchi *et al*., 2016). In Tunisia, PCNs were first detected in the northern area in 1977 (Mai, 1977). A study conducted by Hlaoua *et al*. (2008) revealed that PCNs were found in 37.28% of fields surveyed across several locations. According to Hajjaji *et al*. (2021), *Globodera pallida* was detected with low prevalence in Berkane in the east and Gharb and Doukkala in the west of Morocco. The golden cyst nematode *G. rostochiensis* was detected on potatoes in El-Nobarria, El-Behera governorate in northern Egypt. The frequency of occurrence was 44%, with an average density of 284 cyst nematode 2nd stage juveniles/250 cm^3 ml of soil (Ibrahim *et al*., 2017). PCN was recorded for the first time in Rayak, Lebanon, in 2000 (Ibrahim *et al*., 2000). An extensive survey was conducted to study the distribution of PCN in different regions of Bekaa Valley, Lebanon. The results showed that cysts were found in 76.25% of the samples collectedwith egg counts ranging from 0 to 5.3 eggs/g soil (Kachacha *et al*., 2020). In the Republic of Yemen, a recent study presented a new record of PCN species in the major potato-growing regions of Amran, Dhamar, and Ibb governorates (Saeed & Showkat, Data not published). In addition, there are few studies on nematodes associated with some other crops, such as grapes and garlic (Saeed, 2009; Saeed, 2015).

Numerous studies that have been carried out to estimate the losses of potatoes due to PCNs are documented in the literature. For example, Brown & Sykes (1983) estimated that for every 20 viable eggs/g of soil, about 2.75 t/ha of potatoes are lost. Yield losses caused by PCNs range from minor to major crop failure, depending on the infestation level (Blacket *et al*., 2019; Lima *et al*., 2018; Turner & Subbotin, 2013).

In Yemen, there is no information on the prevalence of PCNs or their losses in potatoes. As a result, the purpose of this study was to investigate the distribution and intensity of PCNs in the major potato production regions, as well as estimate potato yield losses.

Materials and Methods

Sample collection

An extensive survey was carried out to determine ct the presence and prevalence of PCNs (*Globodera* species) that attacked potatoes in the governorates of Amran, Dhamar, and Ibb. Major potato production regions were chosen as sampling sites (Figure 1). During the 2023 potato production season, a total of 455 soil samples were collected from 145 fields owned by 95 farmers (Table 1).

The number of fields sampled in each region was selected based on the potato crops present during the pre-flowering and flowering stages. The following soil samples were collected: 94 samples from seven regions in the Amran governorate, 61 samples from four regions in Dhamar governorate, and 300 samples from nineteen regions in Ibb governorate. Typically, two to four samples were collected from a field, depending on its size. The collected samples were taken from various directions in the field. Soil samples were collected from the rhizosphere of actively developing plants by digging with a garden spade to a depth of 10-20 cm at various random sites in the field (Barker, 1985). The soil samples from each field were stored in polyethylene bags and shielded from sunlight.

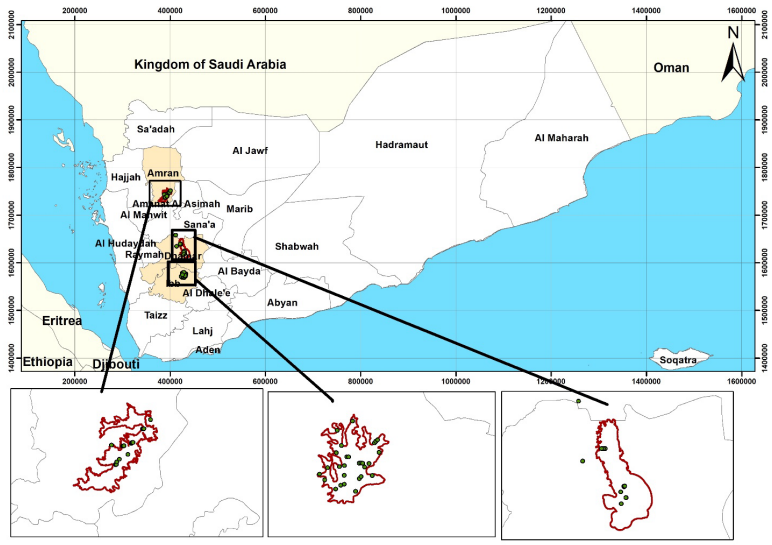

Figure 1. A map of the Republic of Yemen showing the locations of potato cyst nematodes (PCNs) collection sites in the main potato growing area.

Table 1. Potato cyst nematodes distribution and incidence (%) in potato production regions of Amran, Dhamar, and Ibb governorates.

Region	No. of farmers	No. of soil samples	No. of fields surveyed	No. of infested fields	Prevalence (%)
Amran					
Al Duper	4.0	12.0	6.0	4.0	66.7
Badaa	4.0	32.0	8.0	5.0	62.5
Jenah	2.0	4.0	2.0	2.0	100.0
Joop Al-Sufla	5.0	20.0	10.0	4.0	40.0
Qeenah	3.0	12.0	6.0	3.0	50.0
Raydah	2.0	6.0	3.0	2.0	66.7
Russa'a Shban	2.0	8.0	4.0	3.0	75.0
Total	**22.0**	**94.0**	**39.0**	**23.0**	**59.0**
Dhamar					
Daaf	4.0	15.0	4.0	0.0	0.0
Qa`wan	3.0	16.0	3.0	2.0	66.7
Risabah	3.0	15.0	4.0	3.0	75.0
Wasitah	3.0	15.0	3.0	1.0	33.3
Total	**13.0**	**61.0**	**14.0**	**6.0**	**42.9**
Ibb					
Ad Darbah	5.0	17.0	5.0	5.0	100.0
Al Breek	1.0	5.0	1.0	1.0	100.0
Al Habeel	1.0	5.0	1.0	1.0	100.0
Al Husayn	1.0	5.0	2.0	2.0	100.0
Al Jarda`a	1.0	5.0	1.0	1.0	100.0
Al Jarjarah	7.0	30.0	15.0	15.0	100.0
Al Jbaleeh	1.0	5.0	2.0	2.0	100.0
Al Jurayn	5.0	18.0	6.0	6.0	100.0
Al Jurf	1.0	5.0	1.0	1.0	100.0
Al Kadeemah	1.0	6.0	3.0	3.0	100.0
Al Krabah	1.0	5.0	3.0	3.0	100.0
Al Manzel Aljadeed	7.0	44.0	15.0	15.0	100.0
Al Manzel Alqadeem	3.0	9.0	4.0	4.0	100.0
Aras	2.0	21.0	4.0	4.0	100.0
Dakhlat Uwaydin	1.0	5.0	3.0	3.0	100.0
Dhalman	1.0	10.0	2.0	2.0	100.0
Dhmran	2.0	5.0	2.0	2.0	100.0
Kitab	7.0	26.0	10.0	10.0	100.0
Ribat Al Qala`ah	12.0	74.0	12.0	12.0	100.0
Total	**60.0**	**300.0**	**92.0**	**92.0**	**100.0**

Prevalence (%) = (Number of infested fields/ Number of fields surveyed) × 100

Cyst extraction and potato yield loss assessment

The collected samples were appropriately labeled and brought to the Plant Protection Laboratory, Faculty of Agriculture, Food, and Environment, Sana'a University for analysis and PCN detection. Each soil sample was subsampled using 200 g of sieved and dried soil. Cysts were extracted from this sub-sample using a modified container based on the Fenwick can technique (Fenwick, 1940). The cysts were collected through a 250 µm sieve, labeled, and dried on filter paper, and then picked and counted manually with a dissecting needle under a stereo-binocular microscope (Cambridge Instruments, Z 30 E) at 10 × magnification. In addition, a viability test was performed by randomly selecting 10 cysts from each field soil samples and placed them in a modified 1.5 ml Eppendorf tube with the end cut off and a nylon mesh attached over the bottom. The tubes' ends were soaked in a 0.01% Nile blue stain solution in a 10 ml beaker and thereafter incubated in the dark for 48 hours at room temperature. After the incubation period, the stain was completely washed and substituted with sterile distilled water. Individual cysts were then picked, placed on a glass slide, and carefully cut open to release eggs and juveniles (Faggian *et al*., 2012). The released eggs and juveniles were then counted using a stereoscopic microscope in order to determine the mean number of eggs per cyst.

Data analysis

The population density of cysts in soil was determined by calculating the average number of cysts per 200 g of soil recovered from all the fields visited, and the population range was recorded as the minimum and maximum densities of cysts per 200 g of soil. The prevalence (%) was determined

by dividing the number of cyst-positive samples by the total number of samples collected and then multiplied by 100. The mean number of full and empty cysts was calculated by randomly selecting 10 cysts per soil sample from each field and cutting them open to reveal their contents. Cyst viability rate (CV%) was determined as the total number of viable eggs and juveniles divided by the total number of viable and non-viable eggs and juveniles. The infestation level of viable eggs/g of soil was calculated by multiplying the average number of viable eggs and juveniles per cyst by the average number of cysts extracted per 200 g of soil, then divided by 200. The assessment of potato production loss (in tons per hectar) in each region was conducted using Brown & Sykes (1983) regression line. This regression line shows that for every 20 viable eggs per gram of soil, there is a loss of 2.75 tons per hectare of potato due to PCN. The yield loss data were statistically analyzed using the SPSS software (2022), and the average yield losses were compared using $LSD_{0.05}$.

Results

Nematode sampling and occurrence of PCNs

During the survey period (2023), 455 soil samples were collected from 145 fields owned by 95 farmers in Yemen's major potato-producing regions of Amran, Dhamar, and Ibb governorates. The cysts of PCNs were recovered from 121 fields (83.4%) with densities ranging from 3 to 1,340 cysts/200 g of soil (Tables 1 and 2). PCNs were detected in all surveyed regions except the Daaf region, Dhamar governorate.

Table 2. Occurrence and density levels of *Globodera* spp. in the surveyed regions of Amran, Dhamar and Ibb governorate.

Region	No. of samples collected	No. of samples with cyst	Frequency (%)	No. of cysts/200 g soil		
				Full	Empty	Total mean (range)
Amran						
Al Duper	12.0	4.0	33.3	95.3	89.0	184.3 (67-310)
Badaa	32.0	4.0	12.5	39.0	28.3	67.3 (14-101)
Jenah	4.0	2.0	50.0	30.5	21.5	52 (47-57)
Joop Al-Sufla	20.0	5.0	25.0	49.7	38.6	88.3 (27-246)
Qeenah	6.0	5.0	83.3	53.7	40.8	94.5 (30-313)
Raydah	12.0	4.0	33.3	57.3	50.5	107.8 (11-247)
Russa'a Shban	8.0	5.0	62.5	72.6	61.8	134.4 (15-284)
Average	**13.4**	**4.1**	**42.9**	**56.9**	**47.2**	**104.1**
Dhamar						
Daaf	15.0	0.0	0.0	0.0	0.0	0.0
Qa`wan	16.0	3.0	18.8	29.2	24.2	53.4 (30-125)
Risabah	15.0	4.0	26.7	19.1	10.4	29.5 (3-127)
Wasitah	15.0	3.0	20.0	33.0	17.0	50.0 (26-84)
Average	**15.3**	**3.3**	**21.8**	**27.1**	**17.2**	**44.3**
Ibb						
Ad Darbah	17.0	17.0	100.0	81.8	76.0	157.8 (39-605)
Al Breek	5.0	5.0	100.0	43.0	11.4	54.40 (22-77)
Al Habeel	5.0	5.0	100.0	15.7	9.5	25.20(18-40)
Al Husayn	5.0	5.0	100.0	70.4	53.6	124.0 (100-134)
Al Jarda`a	5.0	5.0	100.0	24.4	27.0	51.40 (8-111)
Al Jarjarah	30.0	30.0	100.0	131.1	86.4	217.5 (27-273)
Al Jbaleeh	5.0	5.0	100.0	7.6	6.4	14.00 (5-22)
Al Jurayn	18.0	18.0	100.0	69.7	52.1	121.70 (21-340)
Al Jurf	5.0	5.0	100.0	11.6	11.4	23.00 (13-32)
Al Kadeemah	6.0	6.0	100.0	84.3	88.0	172.30 (57-406)
Al Krabah	5.0	5.0	100.0	24.6	13.0	37.60 (24-50)
Al Manzel Aljadeed	44.0	44.0	100.0	193.2	159.5	352.70 (62-1114)
Al Manzel Alqadeem	9.0	9.0	100.0	340.4	217.3	557.80 (206-1340)
Aras	21.0	21.0	100.0	63.8	53.3	117.10 (15-397)
Dakhlat Uwaydin	5.0	5.0	100.0	25.0	27.8	52.80 (22-121)
Dhalman	10.0	10.0	100.0	45.9	41.4	87.30 (55-138)
Dhmran	5.0	5.0	100.0	22.4	24.2	46.60 (23-78)
Kitab	26.0	26.0	100.0	247.2	204.1	451.4 (133-1280)
Ribat al Qala`ah	74.0	74.0	100.0	164.1	129.9	294.0 (50-800)
Average	**15.8**	**15.8**	**100.0**	**87.7**	**68.0**	

Frequency (%) = (Number of samples with potato cyst/Number of samples collected) × 100.

In Amran governorate, out of 39 fields surveyed, 23 were positive for the presence of PCN (Table 1 and Figure 2). PCNs were detected in 29 out of 94 samples collected from seven regions, viz., Al-Duper, Badaa, Jenah, Joop Al-Sufla, Qeenah, Raydah, and Russa'a Shban (Table 2). The mean population density ranged from 52 to 184.3 cysts per 200 g of soil, with the mean frequency of occurrence ranging from 12.5 to 83.3%. The highest mean density was recorded in the Al-Duper region with 184.3 cysts (67–310 cysts/200 g soil), followed by Russa'a Shban, Raydah, Qeenah, and Joop Al-Sufla with 134.4, 107.8, 94.5, and 88.3 cysts/200 g soil, respectively. Conversely, the lowest mean density was in Jenah and Badaa with 52 (47–57 cysts/200 g soil) and 67.3 (14–101 cysts/200 g soil), respectively (Table 2).

In the Dhamar governorate, a total of 61 soil samples were collected from 14 fields located in four regions, namely Daaf, Qa`wan, Risabah, and Wasitah (Table 1 and Figure 3). PCNs were detected in 10 soil samples distributed in 6 fields (42.9%) located in the Qa`wan, Risabah, and Wasitah regions. The mean frequency of occurrence ranged from 18.8 to 26.7%, with the mean densities ranged from 29.5 to 53.4 cysts per 200 g of soil (Table 2). The Qa'wan region had the highest mean density, with 53.4 cysts (30–125 cysts/200 g soil). This was closely followed by Wasitah, with 50 cysts (26–84 cysts/200 g soil). The lowest mean density was observed in Risabah with 29.5 cysts (3–127 cysts/200 g soil). In contrast, PCNs were not detected in the surveyed fields of the Daaf region.

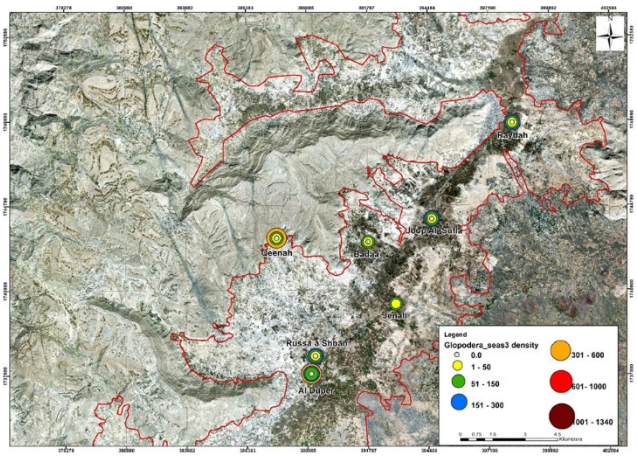

Figure 2. A map of the Amran governorate showing the distribution pattern of potato cyst nematodes (PCNs) in potato fields distributed in the surveyed regions.

Ibb governorate had the highest number of surveyed regions, with a total of 19, as well as the highest number of collected samples, amounting to 300 (Table 1 and Figure 4). PCNs were detected in all soil samples collected from each field. The frequency of occurrence was 100%, with a mean density ranging from 14 to 557.8 cysts per 200 g of soil. The highest mean density was recorded in the Almanzel Al Qadeem region with 557.8 cysts (206–1340 cysts/200 g soil), followed by Kitab, Almanzel Aljadeed, Rebat Al Qalah, and Al Jrjarah with 451.4, 352.7, 294, and 217.5 cysts/200 g soil, respectively. Conversely, the lowest mean density was observed in Al Jbaleeh, with 14 cysts (5-22 cysts/200 g soil). In the remaining regions, with mean density ranged from 23 to 172 cysts per 200 g of soil (Table 2).

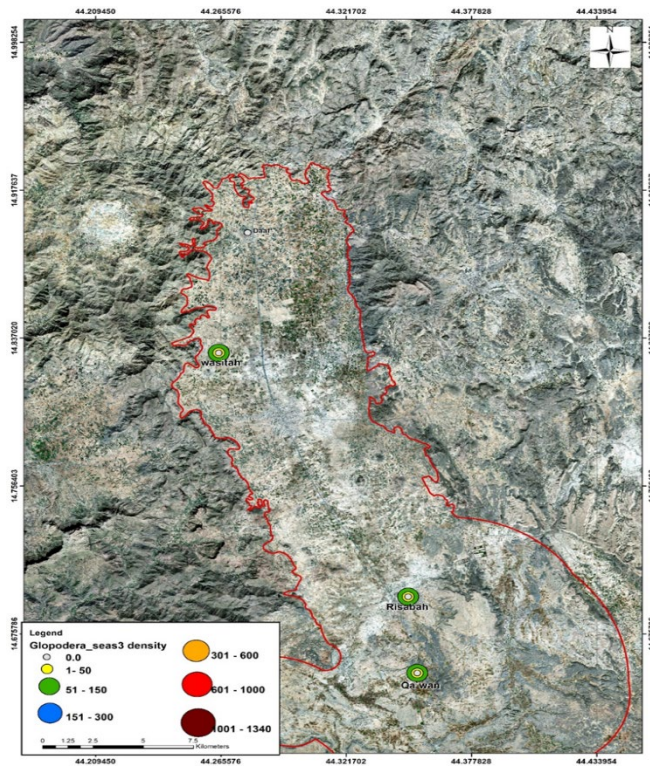

Figure 3. A map of the Dhamar governorate showing the distribution pattern of potato cyst nematodes (PCNs) in potato fields distributed in the surveyed regions.

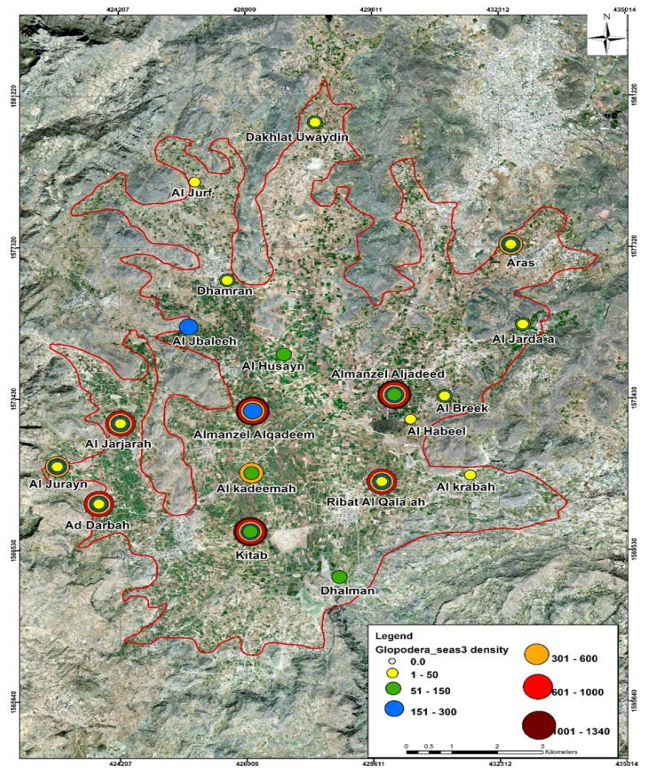

Figure 4. A map of the Ibb governorate showing the distribution pattern of potato cyst nematodes (PCNs) in potato fields distributed in the surveyed regions.

Potato cyst nematode infestation and yield loss assessment

Results obtained indicated that all PCN-positive samples showed cysts containing viable eggs. The mean cyst viability percentage (CV%) in all surveyed regions ranged from 58.1 to 86.9%. Cyst infestation levels varied in the surveyed fields within regions, in addition to their differences between regions within the governorates (Table 3).

Results obtained indicated that 17% of the field samples had infestation levels of 1 to 50 cysts per 200 g of soil. Additionally, 18%, 14%, 17%, 3%, and 1% of the field samples were found between infestation levels of 51 to 150, 151 to 300, 301 to 600, 601 to 1000, and 1001 to 1340 cysts per 200 g of soil, respectively. In contrast, 30% of the field samples were found to be negative for PCNs. The presence of these empty field samples was detected in the Amran and Dhamar governorates (Figure 5).

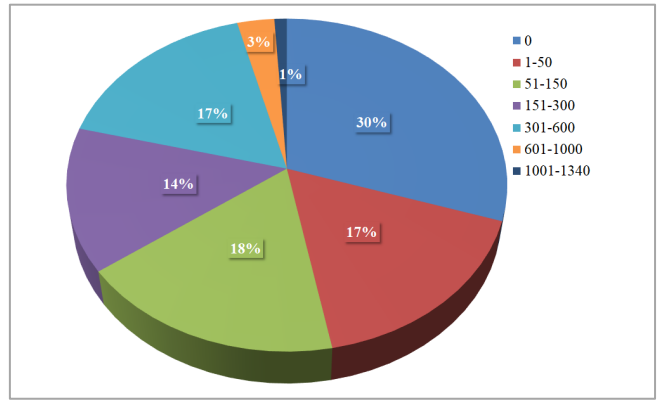

Figure 5. Infestation rates (%) of potato cyst nematodes (PCNs) in the potato fields surveyed in the Amran, Dhamar, and Ibb governorates.

Table 3. *Globodera* spp. infestation and estimated potato yield losses in the surveyed regions of Amran, Dhamar and Ibb governorates.

Region	No. of full cysts/200 g soil	No. of eggs/cyst (Fertility)			Cyst viability (CV%)	Mean soil infectivity (viable egg/g soil)	Estimated mean yield loss (t/ha)
		Viable	Non-viable	Total			
Amran							
Al Duper	95.3	64.2	21.9	86.1	74.6	30.6	4.2
Badaa	39.0	33.1	11.7	44.7	73.9	6.5	0.9
Jenah	30.5	24.5	17.7	42.2	58.1	3.7	0.5
Joop Al-Sufla	49.7	45.4	20.4	65.8	69.0	11.3	1.6
Qeenah	53.7	57.7	22.2	79.9	72.2	15.5	2.1
Raydah	57.3	49.0	19.8	68.8	71.2	14.0	1.9
Russa'a Shban	72.6	51.8	20.2	72.0	71.9	18.8	2.6
Average	**56.9**	**46.5**	**19.1**	**65.7**	**70.9**	**14.3**	**2.0**
Dhamar							
Daaf	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Qa`wan	29.2	60.0	30.8	90.8	66.1	8.8	1.2
Risabah	19.1	53.5	13.0	66.5	80.4	5.1	0.7
Wasitah	33.0	63.3	15.7	79.0	80.1	10.4	1.4
Average	**27.1**	**58.9**	**19.8**	**78.8**	**74.8**	**8.1**	**1.1**
Ibb							
Ad Darbah	81.8	90.5	20.9	111.5	81.2	37.0	5.1
Al Breek	43.0	55.0	12.7	67.7	81.3	11.8	1.6
Al Habeel	15.7	135.0	20.3	155.3	86.9	10.6	1.5
Al Husayn	70.4	58.0	14.3	72.3	80.2	20.4	2.8
Al Jarda`a	24.4	77.3	28.7	106.0	73.0	9.4	1.3
Al Jarjarah	131.1	68.8	15.3	84.1	81.8	45.1	6.2
Al Jbaleeh	7.6	36.7	22.0	58.7	62.5	1.4	0.2
Al Jurayn	69.7	65.0	14.3	79.3	82.0	22.6	3.1
Al Jurf	11.6	36.3	15.3	51.7	70.3	2.1	0.3
Al Kadeemah	84.3	119.0	20.3	139.3	85.4	50.2	6.9
Al Krabah	24.6	34.0	17.3	51.3	66.2	4.2	0.6
Al Manzel Aljadeed	193.2	147.1	22.7	169.8	86.7	142.2	19.5
Al Manzel Alqadeem	340.4	111.8	43.8	155.5	71.9	190.3	26.2
Aras	63.8	72.7	14.7	87.4	83.2	23.2	3.2
Dakhlat Uwaydin	25.0	40.0	18.0	58.0	69.0	5.0	0.7
Dhalman	45.9	104.7	23.9	128.6	81.4	24.0	3.3
Dhmran	22.4	37.0	12.3	49.3	75.0	4.1	0.6
Kitab	247.2	102.8	18.1	120.9	85.0	127.0	17.5
Ribat al Qala`ah	164.1	109.6	20.3	130.0	84.4	89.9	12.4
Average	**87.7**	**79.0**	**19.7**	**98.8**	**78.3**	**43.2**	**5.9**

$LSD_{0.05}$= 1.96

In Amran governorate, the mean cyst fertility varied between 42.2 and 86.1 eggs per cyst, with an average viability of 70.9% (ranging from 58.1 to 74.6%) (Table 3). The Al Duper region had the highest average soil infestation levels (SI), with 30.6 eggs and juveniles per gram of soil, resulting in an estimated average yield loss of 4.2 t/ha. In contrast, the Jenah region had the lowest average SI levels, with 3.7 eggs and juveniles per gram of soil, resulting in an estimated average yield loss of 0.5 t/ha. In the remaining regions, the mean SI levels ranged from 6.5 to 18.8 eggs and juveniles/g of soil, resulting in an estimated mean yield loss ranging from 0.9 to 2.6 t/ha.

In Dhamar governorate, results obtained showed that the mean number of full cysts was the lowest, measuring 27.1 cysts/200 g of soil (Table 3). The mean cyst fertility ranged from 66.5 to 90.8 eggs/cyst, whereas the average viability was 74.8%, ranging from 66.1 to 80.4%. PCNs were recorded in Wasitah, Qa'wan, and Risabah regions with mean SI levels of 10.4, 8.8, and 5.1 eggs and juveniles/g soil, respectively. The estimated mean yield loss in these regions was 1.4, 1.2, and 0.7 t/ha, respectively. Conversely, all soil samples collected from the surveyed fields in the Daaf region were uninfested with PCN cysts.

In the Ibb governorate, about 47.4% of cysts were found to contain more than 100 eggs/cyst, with an average viability rate exceeding 81%. The highest mean cyst fertility was recorded in the Al Manzel Aljadeed region at 169.8 eggs/cyst, with a mean CV rate of 86.7%. In contrast, the lowest mean fertility was recorded in the Dhmran region at 49.3 eggs/cyst, with a mean CV rate of 75%. Mean SI levels ranged from 1.4 to 190.3 eggs and juveniles/g soil, with an estimated mean yield loss ranging from 0.2 to 26.2 t/ha. The highest mean SI levels were detected in the Al Manzel Alqadeem region, with 190.3 eggs and juveniles/g soil and an estimated mean yield loss of 26.2 t/ha, followed by the Al Manzel Aljadeed, Kitab, and Ribat Al Qala`ah regions with 142.2, 127, and 89.9 eggs and juveniles/g soil, respectively. In contrast, the lowest mean SI levels were detected in the Al Jbaleeh region, measuring 1.4 eggs and juveniles/g soil, with an estimated mean yield loss of 0.2 t/ha. This was followed by Al Jurf, Dhmran, Al Krabah, and Dakhlat Uwaydin regions with 2.1, 4.1, 4.2, and 5 eggs and juveniles/g soil, respectively. In the remaining regions, the mean SI levels ranged from 9.4 to 50.2 eggs and juveniles/g soil.

The results reported in Table 3 indicated that the Ibb governorate had the highest average SI level (43.2 eggs and juveniles/g of soil), resulting in an estimated average yield loss of 5.9 t/ha. In Amran governorate, the average soil infestation level was modest, with 14.3 eggs and juveniles/g of soil. This resulted in an estimated average yield loss of 2 t/ha. On the other hand, Dhamar governorate had the lowest average soil infestation level, with 8.1 eggs and juveniles/g of soil, resulting in an estimated average yield loss of 1.1 t/ha. Generally, the estimated average yield loss due to nematode infestation varied significantly according to the surveyed regions. The regions of Al Manzel Aljadeed, Al Manzel Alqadeem, Kitab, Ribat Al Qala'ah, and Al Kadeemah in Ibb Governorate recorded the highest average yield losses, with significant differences between each other. The crop losses in these regions exhibited significant differences when compared to those in the other regions. It was also noted that there were no significant differences among the fifteen regions that recorded average yield losses ranging from 0 to 2.1 tons/ha.

Discussion

Potato cyst nematode is considered the most destructive pest of potatoes, causing substantial yield losses worldwide. This pest was first reported to infect potato and cause serious losses in Yemen only recently (Saeed & Showkat, Data not published). Due to the weak quarantine and agricultural extension services in Yemen, these nematodes had spread to most potato production regions. This study is the first study to investigate the distribution, frequency of occurrence, and population density of PPNs, as well as to assess the potato yield loss caused by their presence in Yemen. The results obtained showed that PCNs are widespread in 96.7% of the studied regions, with densities ranging from 3 to 1,340 cysts/200 g of soil. Consequentially, this causes severe yield losses, particularly in regions with high cyst density (Tables 2 and 3). It was found that PCNs were more prevalent and had a higher population density than those in other Middle Eastern countries such as Algeria, Tunisia, Morocco, Egypt, and Lebanon (Hlaoua *et al*., 2008; Ibrahim *et al*., 2000; Kachacha *et al*., 2020; Mezerket *et al*., 2018; Tirchi *et al*., 2016).

Ibb governorate had the highest mean frequency of occurrence (100%), population density, cyst viability, and soil infestation level. This may be related to the continuous cultivation of susceptible potatoes, potato residue, soil type, and other suitable environmental conditions (Anwar *et al*., 2007; Carrión & Rojas, 2013; Hlaoua *et al*., 2008; Prasad, 2008; Starr *et al*., 1993). The cyst population density varied between different regions, with values ranging from 3 to 1340 cysts/200 g of soil. Many regions showed low population densities, which may be related to practicing non-host crop rotations by growing a barley or wheat crop in a 1 to 2 years rotation and using certified potato seed.

Dhamar governorate had the lowest mean frequency of occurrence (21.8%), population density, and soil infestation level. This may be attributed to the limited number of samples collected, resistant potato cultivars used, soil type, and several other environmental factors. The presence of PCN was not confirmed in soil samples collected from the Daff region of the Dhamar governorate. The absence of PCN in this region may be attributed to the fact that this nematode was not introduced into the fields of this region, in addition to the unsuitable environmental conditions.

PCN yield losses were estimated based on the soil infestation damage threshold reported by Brown & Sykes (1983). This extrapolation is considered a realistic indicator of the extent of PCN damage to potato production in the studied regions of Yemen. Our results showed variation in mean SI levels of PCN across most of the potato regions surveyed. These levels ranged from 1.4 to 190.3 eggs and juveniles/g soil, with an estimated mean yield loss ranging from 0.2 to 26.2 t/ha. PCNs cause economic losses to the potato crop in the presence of 10 eggs/g of soil (Phillips *et al*., 1991). According to this study, the soil infestation level exceeded 10 eggs and juveniles/g soil in 65.52% of the

regions surveyed, causing economic losses to the potato crop. Soil infestation levels in seven regions of Ibb governorate (Al Manzel Aljadeed, Al Manzel Alqadeem, Kitab, Ribat Al Qala`ah, Al Kadeemah, Al Jarjarah, and Ad Darbah) and Al Duper region in Amran governorate were very much higher than the economic damage threshold. Therefore, the average yield losses in each of these regions were significantly higher than those in the other regions. Unfortunately, this led to severe yield losses and the failure of potato cultivation in those regions.

PCNs are mostly transmitted by infested tubers, soil, farm machinery, and equipment contaminated with cysts, water, animals, and wind from infested areas to non-infested ones (Dandurand *et al*., 2019; Evans & Stone, 1977; Henrique, 2012; Jatala & Bridge, 1990; Turner & Evans, 1998). Many potato farmers moved from their PCN-infested regions to new un-infested areas in the Al-Jawf and Marib Governorates. Understanding PCN distribution and population density, as well as knowledge of various agricultural practices represent the necessary background for preventing pest spread into un-infested regions and developing integrated nematode management programs to reduce population densities in infested regions. These integrated management programs include the use of certified seed and PCN-resistant potato varieties, as well as other practices such as crop rotation, solarization, trap cropping, biofumigation and selected nematicides.

الملخص

شوكت، جمان خالد ومحمد راوح محمد سعيد. 2026. ظهور نيماتودا حوصلات البطاطا/البطاطس (*Globodera* spp.) كتهديد لمحصول البطاطس/البطاطا في اليمن. مجلة وقاية النبات العربية، 44(2):173−182. https://doi.org/10.22268/AJPP-001384

تعدّ نيماتودا حوصلات البطاطا/البطاطس (*Globodera* spp.) من أكثر الآفات ضرراً لمحصول البطاطا/البطاطس، مسببةً خسائر كبيرة في المحصول في جميع أنحاء العالم. وعلى الرغم من أهميتها، لا توجد أي بيانات متوفرة حالياً عن انتشارها أو مدى تأثيرها على زراعة البطاطا/البطاطس في اليمن. لذلك، جرى هذه البحث لدراسة الانتشار والكثافة العددية لهذه الآفة في مناطق إنتاج البطاطا/البطاطس الرئيسية، إضافة إلى تقدير الخسائر التي تسببها لمحصول البطاطا/البطاطس في اليمن. جمعت 455 عينة تربة أثناء موسم إنتاج البطاطا/البطاطس 2023 من 145 حقلاً في 30 موقعاً تابعة لمحافظات عمران وذمار وإب. استخلصت الحوصلات من التربة باستخدام تقنية جهاز فينويك. أظهرت النتائج وجود نيماتودا حوصلات البطاطا/البطاطس في جميع المناطق التي شملها المسح، باستثناء منطقة ضاف في محافظة ذمار. وجدت الحوصلات في تربة 121 حقلاً (83.4%) بكثافة عددية تراوحت بين 3 إلى 1340 حوصلة/200 غرام تربة. سجلت محافظة إب أعلى متوسط لمعدل وجود الحوصلات (100%)، والكثافة العددية، ونسبة حيوية الحوصلات، ومستوى تلوث التربة (SI) بالبيوض واليرقات، في حين سُجل أقل متوسط للوجود (21.8%)، والكثافة العددية، ومستوى تلوث التربة بالبيوض في محافظة ذمار. أظهرت النتائج تبايناً في متوسط مستويات تلوث التربة بالبيوض لمعظم الحقول التي تمّ مسحها داخل المواقع، بالإضافة إلى اختلافاتها بين المواقع داخل المحافظات. تراوح متوسط مستويات تلوث التربة بالبيوض من 1.4 إلى 190.3 بيضة وطور يرقي ثاني/غ تربة، مسبباً متوسط خسارة في الغلة تراوحت بين 0.2 إلى 26.2 طن/هكتار. سجلت نتائج مستويات تلوث التربة بالبيوض في سبعة مواقع بمحافظة إب وموقع واحد في محافظة عمران مستويات أعلى بكثير من مستوى الضرر الاقتصادي، مما تسبب في خسائر فادحة في الإنتاج وفشل زراعة البطاطا/البطاطس في تلك المناطق. لذلك، ثمّة حاجة ملحة لتزويد المزارعين باستراتيجية مناسبة لإدارة نيماتودا حوصلات البطاطا/البطاطس في اليمن.

كلمات مفتاحية: نيماتودا حوصلات البطاطا/البطاطس، البطاطا/البطاطس، انتشار، كثافة، خسارة المحصول، Glodobera.

عناوين الباحثين: جمان خالد شوكت ومحمد راوح محمد سعيد*، قسم وقاية النبات، كلية الزراعة والأغذية والبيئة، جامعة صنعاء، اليمن. *البريد الإلكتروني للباحث المراسل: m.saeid@su.edu.ye

References

Ahmadu, T., A. Abdullahi and K. Ahmad. 2021. The role of crop protection in sustainable potato (*Solanum tuberosum* L.) production to alleviate global starvation problem: an overview. Pp. 19-51. *In*: Solanum tuberosum – A Promising Crop for Starvation Problem. M. Yildiz and Y. Özgen (eds.). IntechOpen, UK. https://doi.org/10.5772/intechopen.100058

Al Rahomy, A.A. and A.A.H. El Girshi. 1986. Report presented at Germplasm Management Course. Turkey. September 22-October 2, 1986.

Anonymous. 2021. Annual Agricultural Statistics Book 2021. Ministry of Agriculture and Irrigation, Republic of Yemen.

Anwar, S.A., A. Zia, M. Hussain and M. Kamran. 2007. Host suitability of selected plants to *Meloidogyne incognita* in the Punjab, Pakistan. International Journal of Nematology, 17(2):144-150.

Barker, K.R. 1985. Nematode extraction and bioassays. Pp. 19-35. *In*: An Advanced Treatise on Meloidogyne. Vol. II. Methodology. K.R. Barker, C.C. Carter and J.N. Sasser (eds.). North Carolina State University Graphics, Raleigh, NC, USA.

Blacket, M.J., A. Agarwal, J. Wainer, M.D. Triska, M. Renton and J. Edwards. 2019. Molecular assessment of the introduction and spread of potato cyst nematode, *Globodera rostochiensis*, in Victoria, Australia. Phytopathology, 109(4):659-669. https://doi.org/10.1094/PHYTO-06-18-0206-R

Brown, E.B. and G.B. Sykes. 1983. Assessment of the losses caused to potatoes by the potato cyst nematodes,

Globodera rostochiensis and *G. pallida*. Annals of Applied Biology, 103(2):271-276.

CABI/EPPO. 2020a. *Globodera rostochiensis*. Invasive Species Compendium. CAB International, Wallingford, UK. Available at CABI.

CABI/EPPO. 2020b. *Globodera pallida*. Invasive Species Compendium. CAB International, Wallingford, UK. Available at CABI.

Carrión, Y. and D. Rojas. 2013. Distribución poblacional del nemátodo quiste de la papa (*Globodera* spp.) en dos zonas productoras de los Municipios de Tausa (Cundinamarca) y Ventaquemada (Boyacá). Licenciatura thesis, Corporación Universitaria Minuto de Dios, Bogotá, Colombia. 56 pp.

Dandurand, L.-M., I.A. Zasada, X. Wang, B. Mimee, W. de Jong, R. Novy, J. Whitworth and J.C. Kuhl. 2019. Current status of potato cyst nematodes in North America. Annual Review of Phytopathology, 57:117-133. https://doi.org/10.1146/annurev-phyto-082718-100254

Decraemer, W. and D.J. Hunt. 2006. Structure and classification. Pp. 3-32. *In:* Plant Nematology. R.N. Perry and M. Moens (eds.). CAB International, Wallingford, UK. https://doi.org/10.1079/9781845930561.0003

EPPO. 2017. EPPO Standard PM 7/40 (4) *Globodera rostochiensis* and *Globodera pallida*. EPPO Bulletin, 47(2):174–197.

EPPO. 2020. EPPO Global Database: *Globodera pallida*. European and Mediterranean Plant Protection Organization. Available at EPPO Global Database.

Evans, K. and A.R. Stone. 1977. A review of the distribution and biology of the potato cyst-nematodes *Globodera rostochiensis* and *G. pallida*. PANS, 23(2):178-189. https://doi.org/10.1080/09670877709412426

Evans, K., J. Franco and M.M. Descurrah. 1975. Distribution of species of potato cyst nematodes in South America. Nematologica, 21(3):365-369.

Faggian, R., A. Powell and A.T. Slater. 2012. Screening for resistance to potato cyst nematode in Australian potato cultivars and alternative solanaceous hosts. Australasian Plant Pathology, 41(5):453-461.

FAO. 2018. FAOSTAT. Food and Agriculture Organization of the United Nations, Rome, Italy. Available at FAOSTAT.

FAOSTAT. 2022. World Food and Agriculture – Statistical Yearbook 2022. Food and Agriculture Organization of the United Nations, Rome, Italy. https://doi.org/10.4060/cc2211en

Fenwick, D.W. 1940. Methods for the recovery and counting of cysts of *Heterodera schachtii* from soil. Journal of Helminthology, 18(4):155–172. https://doi.org/10.1017/S0022149X00031485

Frézal, P. 1954. Importance et répercussions de la contamination de l'Algérie par le nématode doré (*Heterodera rostochiensis* Woll.). Comptes Rendus des Séances de l'Académie d'Agriculture de France, 40:71-74.

Hajjaji, A., R.A. Mhand, N. Rhallabi and F. Mellouki. 2021. First report of morphological and molecular characterization of Moroccan populations of potato cyst nematodes. Journal of Nematology, 53(1):e2021-18.

Henriques, L. 2012. Nemátodos de quisto da batateira – *Globodera rostochiensis* e *G. pallida*. Boletim Técnico BT/12. Instituto Nacional de Investigação Agrária, Unidade de Investigação de Protecção de Plantas.

Hlaoua, W., N. Horrigue-Raouani, D. Fouville and D. Mugniéry. 2008. Morphological and molecular characterization of potato cyst nematode populations from Tunisia and survey of their probable geographical origin. Biotechnology, 7(4):651-659. https://doi.org/10.3923/biotech.2008.651.659

Ibrahim, S.K., A.T. Saad, P.P.J. Haydock and Y. Al-Masri. 2000. Occurrence of the potato cyst nematode *Globodera rostochiensis* in Lebanon. Nematology, 2(2):125-128.

Ibrahim, S.K., M. Mama, A. Israel and L. Ibrahim. 2017. The occurrence, distribution and control of potato cyst nematodes in Lebanon. American Journal of Agricultural Science, 4(3):51-57.

İmren, M. 2018. Determination of plant parasitic nematodes in potato growing areas in Bolu Province. International Journal of Agriculture, Environment and Food Sciences, 2(1):26-32. https://doi.org/10.24180/ijaws.404959

Jatala, P. and J. Bridge. 1990. Nematode parasites of root and tuber crops. Pp. 137-180. *In*: Plant Parasitic Nematodes in Tropical and Subtropical Agriculture. M. Luc, R.A. Sikora and J. Bridge (eds.). CAB International, Wallingford, UK.

Jensen, H.J., J. Armstrong and P. Jatala. 1979. Annotated Bibliography of Nematode Pests of Potato. International Potato Center, Lima, Peru, and Oregon State University Agricultural Experiment Station, Corvallis, OR, USA. 315 pp.

Jones, F.G.W. 1970. The control of the potato cyst nematodes. Journal of the Royal Society of Arts, 118:179-199.

Kachacha, S., S.K. Ibrahim, G. Kachacha, L. Ibrahim, F. Jreijiri, T. Elbeaino and E. Choueiri. 2020. Potato cyst nematodes *Globodera* spp. in the Bekaa Valley, Lebanon. Lebanese Science Journal, 21(1):54-63.

Lima, F.S.O., V.S. Mattos, E.S. Silva, M.A.S. Carvalho, R.A. Teixeira, J.C. Silva and V.R. Corrêa. 2018. Nematodes affecting potato and sustainable practices for their management. Pp. 1-18. *In*: Potato – From Incas to All Over the World. IntechOpen, UK. https://doi.org/10.5772/intechopen.73056

Mai, W.F. 1977. Worldwide distribution of potato-cyst nematodes and their importance in crop production. Journal of Nematology, 9(1):30-34.

Maleita, C., I. Esteves, J.M.S. Cardoso, M.J. Cunha, R.M.D.G. Carneiro and I. Abrantes. 2018. *Meloidogyne luci*, a new root-knot nematode parasitizing potato in Portugal. Plant Pathology, 67(2):366-376. https://doi.org/10.1111/ppa.12755

Mezerket, A., M. Hammache, C. Cantalapiedra-Navarrete, P. Castillo and J.E. Palomares-Rius. 2018. Prevalence, identification, and molecular variability of potato cyst nematodes in Algeria. Journal

of Agricultural Science and Technology, 20(6):1293-1305.

Nicol, J., S. Hockland, T. Prior, D. Turner and Z. Maafi. 2011. Current nematode threats to world agriculture. Pp. 21-43. *In*: Genomics and Molecular Genetics of Plant-Nematode Interactions. J. Jones, G. Gheysen and C. Fenoll (eds.). Springer, Dordrecht, The Netherlands. https://doi.org/10.1007/978-94-007-0434-3_2

Orlando, V., I.G. Grove, S.G. Edwards, T. Prior, D. Roberts, R. Neilson and M. Back. 2020. Root-lesion nematodes of potato: current status of diagnostics, pathogenicity and management. Plant Pathology, 69(3):405-417. https://doi.org/10.1111/ppa.13144

Oro, V. 2011. New records of *Globodera rostochiensis* in Serbia. Zaštita bilja, 62(4):233-241.

Phillips, M.S., C.A. Hackett and D.L. Trudgill. 1991. The relationship between the initial and final population densities of the potato cyst nematode *Globodera pallida* for partially resistant potatoes. Journal of Applied Ecology, 28(1):109-119. https://doi.org/10.2307/2404118

Prasad, P.V.V., S.A. Staggenborg and Z. Ristic. 2008. Impacts of drought and/or heat stress on physiological, developmental, growth, and yield processes of crop plants. Pp. 301-355. *In*: Response of Crops to Limited Water: Understanding and Modeling Water Stress Effects on Plant Growth Processes. A.R. Ahuja, V.R. Reddy, S.A. Saseendran and Q. Yu (eds.). American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI, USA.

Saeed, M.R. 2009. Plant-parasitic nematodes associated with grapevine in Sana'a and Sa'dah governorates of Yemen. Journal of Agricultural Sciences, Mansoura University, 34(2):1339-1345.

Saeed, M.R. 2015. Plant-parasitic nematodes associated with garlic in Yemen. Egyptian Journal of Agronematology, 14(1):37-44.

Sasser, J.N. and D.W. Freckman. 1987. A world perspective on nematology: the role of the Society. Pp. 7-14. *In:* Vistas on Nematology. J.A. Veech and D.W. Dickson (eds.). Society of Nematologists, Hyattsville, MD, USA.

Scotto La Massese, C. 1961. Aperçu sur les problèmes posés par les nématodes phytoparasites en Algérie. Journée d'Étude et d'Information. Association de Coordination Technique Agricole, F.N.G.P.C., Paris, France. 27 pp.

SPSS Inc. 2022. SPSS Base 26 for Windows User's Guide. SPSS Inc., Chicago, IL, USA.

Starr, J.L., C.M. Heald, A.F. Robinson, R.G. Smith and J.P. Krausz. 1993. *Meloidogyne incognita* and *Rotylenchulus reniformis* associated with soil textures from some cotton production areas of Texas. Journal of Nematology, 25(4S):895-899.

Stone, A.R. 1973. *Heterodera pallida* n. sp. (Nematoda: Heteroderidae), a second species of potato cyst nematode. Nematologica, 18:591-606.

Thomas, G. and G. Sansonetti. 2009. New Light on a Hidden Treasure: International Year of the Potato 2008, an End-of-Year Review. Food and Agriculture Organization of the United Nations, Rome, Italy.

Tirchi, N., A. Troccoli, E. Fanelli, A. Mokabli, F. Mouhouche and F. De Luca. 2016. Morphological and molecular identification of potato and cereal cyst nematode isolates from Algeria and their phylogenetic relationships with other populations from distant geographical areas. European Journal of Plant Pathology, 146(4):861-880. https://doi.org/10.1007/s10658-016-0965-z

Turner, S.J. and K. Evans. 1998. The origins, global distribution and biology of potato cyst nematodes (*Globodera rostochiensis* (Woll.) and *Globodera pallida* Stone). Pp. 7-26. *In:* Potato Cyst Nematodes: Biology, Distribution and Control. R.J. Marks and B.B. Brodie (eds.). CAB International, Wallingford, UK.

Turner, S.J. and S.A. Subbotin. 2013. Cyst nematodes. Pp. 109-141. *In:* Plant Nematology. 2nd edition. R.N. Perry and M. Moens (eds.). CAB International, Wallingford, UK.

Wollenweber, H.W. 1923. Krankheiten und Beschädigungen der Kartoffel. Arbeiten der Forschungsinstitut für Kartoffelbau, 7:1-56.

Received: September 18, 2024; Accepted: November 14, 2024

تاريخ الاستلام: 2024/9/18؛ تاريخ الموافقة على النشر: 2024/11/14