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The yam nematode (*Scutellonema bradys*), a potential threat to potato (*Solanum tuberosum*) production in West Africa

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Potato (*Solanum tuberosum*) production in Africa is rapidly expanding and becoming increasingly important. As its geographical production range broadens, so does its potential to host new pests and diseases. Following the discovery that potato can be affected by *Scutellonema bradys*, further studies were undertaken to assess its potential pathogenicity on potato under screenhouse and field conditions, and on marketed tubers. Potato plants inoculated with *S. bradys* produced tubers with substantial cracking and evident tuber rot, compared with tubers from uninoculated plants. Symptoms of nematode infection on tubers included a scaly appearance, surface cracking as well as deeper tissue cracks, distortions, and darkened surface patches. In most cases these patches were related to sub-surface rot. Nematodes were recovered from the soil, roots and tubers of inoculated plants. Eight weeks after inoculation, the reproduction factor of the nematode was greatest (2·0) at the lowest inoculation rate assessed (1000 nematodes per 2·5-L pot) and least (0·4) at the highest inoculation rate (5000 nematodes per pot). In the screenhouse, potato tuber weights were low and mostly unaffected by nematode inoculation rate, except at 5000 nematodes per pot. In the field, non-inoculated plants yielded over nine times more tubers than plants inoculated with 2000 *S. bradys*. Low densities of *S. bradys* were also recovered from 10 of 15 (67%) samples collected from market stalls, indicating field infection. This study confirms that potato can host and be damaged by *S. bradys*, raising its prospect as a likely significant biotic constraint to the crop.

Keywords: pathogenicity, plant parasitic nematode, *Pratylenchus*, tuber rot, yield loss

Introduction

Globally, potato (*Solanum tuberosum*) is the most economically important root crop with an estimated global annual production of 329·6 million tonnes in 2008 (FAOstat, 2010). Although developing countries are net importers in the international potato trade, which in 2005 was estimated to be worth US$6 billion (FAO, 2008), production is steadily shifting away from wealthier countries towards lower-income areas of the world (FAOstat, 2010). In the less developed countries, potato is largely cultivated by small-holder producers on a subsistence basis, nevertheless it remains a key staple crop for millions of people. Introduced into Africa in the early 1900s, potato currently constitutes a key staple food crop across many parts of Africa. Production is rapidly expanding, with the area cultivated in Africa having doubled over the last decade from 877 604 ha in 1997 to 1·87 million ha in 2009 and a 10-fold increase in production since 1960 to a record of 20·2 million tonnes (FAOstat, 2010). Consequently, potato cultivation is increasingly encroaching into new areas, under more intensive conditions or in rotation with crops previously not commonly associated with potato systems. Besides the elevated inoculum pressure from existing pests and diseases, this is also increasing the potential for new pest and disease problems.

Plant parasitic nematodes are economically important threats to potato production, particularly the cyst nematodes *Globodera rostochienensis* and *G. pallida* (Scurrah *et al.*, 2005; Defra, 2010). In Africa, the cyst nematodes have been recorded mostly from South Africa and North African countries (Kleynhans, 1998), while *Pratylenchus* spp., and especially *Meloidogyne* spp., are the main documented nematode pests of potato in sub-Saharan Africa (Scurrah *et al.*, 2005). Although knowledge on nematode pests of potato in Africa remains limited, they are likely responsible for significant damage to production and quality, with *Meloidogyne* spp. probably responsible for the greater proportion of damage. Several species attack potato, with *M. incognita*, *M. javanica* and *M. arenaria* the most commonly encountered in warm temperate, tropical and subtropical regions of the world. Tolerance

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limits for fresh shoot weight and shoot height of cv. Spunta plants infected with *M. javanica* were established as 0·50 and 0·64 eggs and J2s per cm^3 soil, respectively (Volvas *et al.*, 2005). Thus, soil infestations at planting, even in small numbers, can induce damage to potato over just a few crop cycles with susceptible hosts.

In West Africa, yam (*Dioscorea* spp.) is a major staple crop, cultivated traditionally in the wetter equatorial ecologies, but increasingly in the savannahs and towards the drier Sahelian ecologies, where potato has more traditionally been produced (Dumont *et al.*, 2006). A major economic pest of yam is *Scutellonema bradys,* known as the yam nematode and casual agent of yam dry rot. This nematode occurs mostly in West Africa, where yam is its principal host, but is also recorded on yam from parts of South and Central America and Asia (Bridge *et al.*, 2005). The nematode affects all the main cultivated yam species and cultivars in West Africa (Kwoseh, 2000; Coyne *et al.*, 2006), mainly on mature tubers and during storage (Bridge, 1973). Nematodes feed intracellularly in tuber tissue, rupturing cell walls and resulting in necrotic lesions (Fig. 1). Population multiplication up to 14-fold over a 5–6 month storage period has been recorded (Bridge, 1973). In recent surveys in West and Central Africa, *S. bradys* was found associated with root necrosis of cassava and sweet potato (D.L. Coyne, IITA, Nigeria, personal observations). Also a preliminary investigation in Nigeria revealed the association of *S. bradys* with potato tuber cracking and distortion (Coyne & Claudius-Cole, 2009). Therefore, investigations were undertaken to assess the host status of potato for *S. bradys*, the damage potential of the nematode to potato, and the presence of the nematode in marketed potatoes.

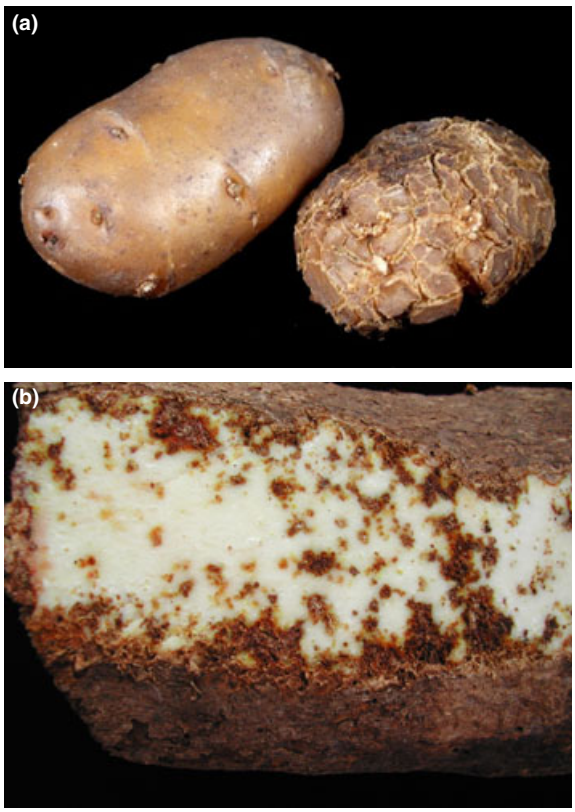


Figure 1 (a) Healthy potato tuber (left) from the control treatment compared with a cracked and deformed tuber from a plant inoculated with *Scutellonema bradys* (right); and (b) a yam tuber showing sub-surface necrosis caused by the nematode.

Materials and methods

Experimental site and details

Three separate experiments were conducted, two in a screenhouse and one in the field. White-skinned unblemished potato tubers of unknown cultivar, sourced locally in Ibadan, were used throughout the study. Additionally, potato tubers collected from Nigerian markets were assessed for natural infection. All experiments were conducted at the International Institute of Tropical Agriculture (IITA) station, Ibadan, Nigeria, located in the derived savannah zone of Nigeria (7·30°N, 3·54°E; altitude 243 m a.s.l.), 120 km north of Lagos. Ibadan experiences average air temperatures ranging from 25 to 27°C and relative humidity of 78 to 89%.

Tubers were first rinsed in water to remove any soil debris, set aside to dry and then sprouted in sterile sawdust seeding beds. Three weeks later, sprouts were transplanted singly into steam sterilized sandy loam soil in 2·5 L potting bags (pots). This permitted uniformly sprouted tubers to be selected for transplanting and reduce variability between sprouts. Potting bags were maintained in a screenhouse, misted uniformly with water for 30 min at 1 h intervals, between 08·00 and16·00 hours for the duration of the experiment, to stimulate rooting of the sprouts and to facilitate crop establishment. No hormones were used to stimulate rooting. In all experiments, pots were inoculated with *S. bradys* using infected yam peel from yam tubers collected locally. Yam tubers were peeled and peels cut into approximately 2 cm long pieces and 10 5-g subsamples removed from the bulked yam peel. Nematodes were extracted from these sub-samples using a modified Baermann technique over two days (Coyne *et al.*, 2007), counted and then peel weights were calculated to obtain the desired inoculation levels. Nematodes were identified as *S. bradys* according to diagnostic criteria and confirmed by A. Swart (ARC, Biosystematics, Pretoria, South Africa). Only *S. bradys* was present in peel used for inoculation. Control pots were treated with an equivalent amount of peel weight following sterilization by autoclaving. *Scutellonema bradys* was inoculated two weeks after transplanting of potato seedlings. Soil at approximately 3·5 cm distance from the plant stem was gently scraped back to approximately 5 cm depth to expose roots where the yam peel was evenly distributed and then covered with soil. One group of pots remained in the screenhouse, while another group was transferred to the

field one week after inoculation. All experiments were terminated 8 weeks after inoculation when haulms began to senesce.

In the first screenhouse experiment 20 pots were each inoculated with 2000 specimens of *S. bradys* (equivalent to 0·8 nematodes cm^{-3} of soil) and 20 were not inoculated, serving as controls. The experiment was repeated once. In the second experiment, potato plants were inoculated with 0, 1000, 2500 or 5000 *S. bradys* (equivalent to 0·4, 1·0 and 2·0 nematodes cm^{-3} of soil) using 10 replicates per treatment. In both experiments a randomized complete block design (RCBD) was used. No nematodes other than *S. bradys* were recovered from potatoes in the screenhouse.

For the field experiment, the soil was ploughed twice and harrowed. Prior to planting, five soil samples per plot were removed from approximately 5–25 cm depth using a hand trowel, bulked and used to assess pre-plant soil nematode densities, as described above, from 100 mL sub-samples per plot. The potted plants were transferred from the screenhouse into two-row plots with plants spaced at 0·3 m within rows and 1 m between rows. Plants were carefully removed from the potting bags and placed in shallow holes before covering with soil. Treatments included inoculation with 2000 specimens of *S. bradys* and non-inoculated control, with four replicated plots, each of 20 plants, arranged in a RCBD. A 1 m border separated replicate blocks, along rows only, and a 2-row potato border was planted around the site. The control plots were pre-treated with 10 g per plant of the nematicide Rugby® 10G (cadusaphos) one day before planting, by mixing into the planting hole soil. Plots were maintained weed-free by hand, as necessary. Plots were rainfed and received no fertilizer, irrigation or additional maintenance.

Assessment of nematodes in marketed potatoes

Potatoes were collected from eight markets in Nigeria, taking samples from different source locations at the same market, where possible. For each sample, the production site was confirmed as being grown locally by the vendor. From each sample, five potatoes were peeled and the peel cut into approximately 2 cm pieces, before extracting nematodes from a 5-g sub-sample from each tuber, as above, and mean nematode densities per site calculated.

Observations

At harvest root, tuber and peel fresh weights were recorded, tuber and root health assessed and nematode densities determined. Tubers were visually observed and scored for tuber cracks and rot; percentage healthy roots and tubers were also recorded. All tubers were scored for tuber surface cracks and rot based on a scale of 0–4 where 0 = clean tuber, 1 = mild symptoms (1–25% of potato exterior damage), 2 = moderate symptoms (26–50%), 3 = severe symptoms (51–75%), 4 = highly severe symptoms (76–100%) (Baimey *et al.*, 2009). Root and tuber health was determined based upon presence of necrosis, lesions, rot or cracks on roots or tubers and percentage healthy (unblemished) calculated. Nematode densities were determined in 5-g sub-samples of chopped potato tuber peel and roots per plant, as above. Soil nematode densities were assessed from 100 mL sub-samples removed after thoroughly mixing the pot soil, or from a bulk sample per field plot, comprising soil from five potato plant locations per plot. At harvest total root and tuber nematode densities were calculated for all experiments together with the nematode reproduction factor from the screenhouse pots.

Statistical analysis

Data were subjected to analysis of variance according to the general linear model procedure using the SAS (SAS Institute Inc., 1997) statistical package. Data of nematode density and rot were ($\log_{10}$ $(X + 1)$) transformed prior to analysis to attain normal distribution among treatments. Treatment means were compared using the Least Significant Difference test (LSD) at $P \leq 0{\cdot}05$.

Results

In the sterilized soil in the screenhouse, inoculation of *S. bradys* caused severe damage to potatoes (Tables 1 & 2).

Table 1 Effect of *Scutellonema bradys* (2000 specimens per pot, equivalent to 0·4 nematodes cm^{-3} of soil) on potato plants 8 weeks after inoculation in 2·5 L pots in the screenhouse[a]; $n = 20$

Treatment	Tuber fresh weight per plant (g)		Root fresh weight per plant (g)		Tuber crack[b] score		Tuber rot score[b]		Healthy tuber[c] (%)		Healthy root[c] (%)	
Control	41·4	20·8	1·1	1·3	0·0	0·0	–	0·4	69·2	75·6	78·3	86·3
Inoculated	34·6	20·2	0·8	1·5	2·6	3·0	–	2·2	59·5	60·0	42·7	40·0
LSD	15·1	2·3	0·5	1·0	0·4	0·6	–	0·6	18·74	27·7	9·3	10·9

[a]Two columns per parameter correspond to mean data from the repeated experiments; tuber rot score recorded only in the repeated experiment.
[b]Tubers were scored for cracking and rot based on a scale of 0–4 where 0 = clean tuber, 1 = mild symptoms (1–25% damage), 2 = moderate symptoms (26–50%), 3 = severe symptoms (51–75%), 4 = highly severe symptoms (76–100%).
[c]Percentage health based on presence or absence of damage (necrosis, lesions, rot, cracks, etc.).

Table 2 Effect of inoculum level of *Scutellonema bradys* on potato plants 8 weeks after inoculation in 2·5 L pots in the screenhouse; $n = 10$

Inoculum level (specimens per pot)	Tuber fresh weight per plant (g)	Root fresh weight per plant (g)	Healthy root[a] (%)	Healthy tuber[a] (%)	Tuber crack score[b]	Tuber rot score[b]
Control	11·2	4·1	84	97	0	0·6
1000	7·0	1·7	49	66	1·6	1·5
2500	6·6	0·6	47	65	2·3	2·1
5000	2·8	1·0	21	14	1·5	3·2
LSD	7·6	1·4	20·3	16·7	1·1	0·8

[a]Percentage health based on presence or absence of damage (necrosis, lesions, rot, cracks, etc.).
[b]Tubers were scored for cracking and rot based on a scale of 0–4 where 0 = clean tuber, 1 = mild symptoms (1–25% damage), 2 = moderate symptoms (26–50%), 3 = severe symptoms (51–75%), 4 = highly severe symptoms (76–100%).

The nematode infected both roots and tubers, resulting in substantial surface cracking of tubers, and root and tuber rot, 8 weeks after inoculation with 1000–5000 specimens of *S. bradys,* compared with the nearly healthy tubers from non-inoculated plants (Fig. 1). Symptoms of the nematode infection also included scaly appearance, deep tissue cracks and distortions, and darkened surface patches, in most cases associated with sub-surface rot. Root fresh weight was affected ($P < 0·05$) at all inoculation levels of *S. bradys*, while tuber fresh weight was reduced ($P < 0·05$) only following inoculation with 5000 specimens. Increasing levels of root and tuber damage reflected increasing inoculation levels. The nematode population density was greatest (2-fold) ($P < 0·05$) in pots inoculated with the lowest inoculum level (1000 specimens per pot, equivalent to 0·4 nematodes cm^{-3} of soil), remained nearly the same (1·1-fold) at the intermediate inoculum level (2500 specimens per pot, equivalent to 1·0 nematodes cm^{-3} of soil) and declined in pots inoculated with the highest inoculum level (5000 *S. bradys* per pot, equivalent to 2·0 nematodes cm^{-3} of soil) (Table 3).

In the field soil, no *S. bradys* was recovered before planting, while trace numbers of nematodes within the genera *Meloidogyne* and *Pratylenchus* were detected, and *Helicotylenchus* spp. were present in low densities (<30 specimens 100 mL^{-1} soil). Although tuber weights from the field experiment were generally relatively low, those from non-inoculated plants were more than nine times greater ($P < 0·05$) than those from plants inoculated with 2000 *S. bradys* (Table 4), and the tubers also appeared relatively healthier. Plants inoculated with *S. bradys* also became infected with *Pratylenchus* spp., while those from the controls were not (Table 5). A small number of *S. bradys* were, however, recovered from non-inoculated plants.

Of the tubers collected from market stalls, specimens of *S. bradys* were recovered from 10 (66·7%) locations, although at relatively low tuber peel density (1 per g of tuber peel), along with low densities of *Pratylenchus* spp. and a few *Meloidogyne* spp. (Table 6).

Discussion

This study gives strong evidence of the pest potential of *S. bradys* on potato, supporting the initial report of its occurrence on the crop (Coyne & Claudius-Cole, 2009). At low densities, the nematode was recovered from the majority of tubers sampled from northern Nigeria, indicating that the nematode can reproduce in potato in the

Table 3 *Scutellonema bradys* densities on root, tuber peel and soil from potato plants inoculated with different inoculum levels of the nematode, 8 weeks after inoculation in 2·5 L pots in the screenhouse

Experiment										
Inoculum level (specimens per pot)	Total in the tubers		Total in the roots		Total in the soil		Total per pot		Reproductive factor	
$n = 20$[a]										
Control	0	0	0	0	0	0	0	0	0	0
2000	99	952	17	676	1425	537	1541	2165	0·77	1·1
$n = 10$										
Control	0		0		0		0		0·0	
1000	820		494		651		1966		2·0	
2500	1227		886		723		2836		1·1	
5000	448		1080		404		1933		0·4	
LSD	604		805		487		142		0·8	

[a]Two columns per parameter correspond to data from repeated experiments when using a single inoculum level of 2000 specimens per pot; analysis of nematode data undertaken on $\log_{10}(X + 1)$ transformed; back-transformed means presented.

Table 4 Effect of inoculation of 2000 specimens of *Scutellonema bradys* on potato plants transplanted in the field plots; $n = 80$

Treatment	Tuber fresh weight (g)	Root fresh weight (g)	Healthy root[a] (%)	Healthy tuber[a] (%)	Tuber cracks[b]	Tuber rot[b]
Control	65·8	0·7	77·1	80·7	1·2	1·3
Inoculated	7·2	2·3	47·9	61·9	2·2	2·6
LSD	22·1	1·5	12·7	19·4	0·7	0·9

[a]Percentage health based on absence of damage (necrosis, lesions, rot, cracks, etc.).
[b]Tubers were scored for cracking and rot based on a scale of 0–4 where 0 = clean tuber, 1 = mild symptoms (1–25% damage), 2 = moderate symptoms (26–50%), 3 = severe symptoms (51–75%), 4 = highly severe symptoms (76–100%).

Table 5 Nematode densities in potato plants inoculated with 2000 specimens of *Scutellonema bradys* and transplanted in the field plots

	Scutellonema bradys			*Pratylenchus* spp.		
Treatment	Total tuber	Total root	Soil (100 mL)	Total tuber	Total root	Soil (100 mL)
Control	13·2[a]	8·6	4	0	0	4
Inoculated	387	482	456	12	214	354
LSD	277	294	268	15	265	407

[a]Analysis of nematode data undertaken on $\log_{10}(X + 1)$ transformed; back-transformed means presented.

Table 6 Nematode population density (5 g peel) in potatoes collected from local markets in Nigeria; $n = 5$ per site

State	Market location	*Scutellonema bradys*	*Meloidogyne* spp.	*Pratylenchus* spp.
Abuja	Kubwa	6	2	0
Abuja	Airport express rd	22	8	1
Abuja	Giri junction	0	2	0
Niger	Dikko Junction 1	12	2	8
Niger	Dikko Junction 2	6	2	4
Niger	Dikko Junction 3	6	4	1
Niger	Suleja	5	5	0
Kaduna	Bakin Gida 1	0	0	4
Kaduna	Bakin Gida 2	2	4	24
Kaduna	Zaria metro 1	2	0	8
Kaduna	Zaria metro 2	2	0	6
Kaduna	Gada jere	0	0	0
Kaduna	Mando	0	0	0
Zaria	Kwangila	10	3	0
Zaria	Kwangila	0	0	0

field conditions prevailing there, and that it can be spread with infected tubers. However, natural infection levels are expected to be higher than those observed in this study, as infected and damaged tubers are less likely to appear in the market and more likely to be consumed or retained by farmers for subsequent planting, as commonly occurs with other tuber crops such as yam (Coyne *et al.*, 2006). Therefore, the risk of spreading the nematode might be higher than infection levels in marketed potatoes would indicate. Plants inoculated with *S. bradys* produced tubers with substantial cracking and evident tuber rot. Although the experiments were conducted under controlled conditions, the severity of the damage to tubers was surprising, especially given the relatively short 8 week duration. It is possible that damage is occurring at the farm level, but this needs to be determined by a study more comprehensive than those undertaken to date. At present there is only limited information on nematode pests of potato in Africa, especially for West Africa (Scurrah *et al.*, 2005). In this study *Pratylenchus* spp. (*P.* cf. *brachyurus*) were also extracted from plants in inoculated field plots. The nematicide cadusaphos used in the control plots may have helped reduce other pests, including *Pratylenchus* spp. However, damage symptoms of inoculated plants were entirely consistent with the potted plants, with no other obvious problem observed.

In this study, the lowest inoculum level led to the greatest reproductive rate (2·0), which, over 8 weeks may not be particularly high but constitutes a significant increase in the nematode density. However, how well *S. bradys* is sustained on potato needs to be determined, especially as Ibadan is not the most suitable location for potato production (Dumont *et al.*, 2006) and is why a misted screenhouse was necessary in the current study.

Therefore, the assessment of the nematode impact on potato under a variety of environmental conditions, using *S. bradys* of both potato and yam origin, is desirable. Similarly, there is a need to determine the host status of the potato cultivars most broadly used in the region.

This study confirms that potato is a suitable host for *S. bradys* and a likely important biotic constraint to the crop. Under more intensified cropping conditions it is likely that the nematode will become increasingly prominent on potato, especially as potato is becoming increasingly cultivated in association with the nematode's main host, yam (Dumont *et al.*, 2006). As *S. bradys* has been shown to exhibit a relatively high degree of polymorphism (Coyne *et al.*, 2006; Baimey *et al.*, 2009; Humphreys, 2010) the likelihood of a potato strain developing also exists. This study furthermore underscores the importance of pre-emptive action towards preventing pest and disease problems, especially on such staple crops that are rapidly increasing in importance.

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