ISSN: 2347-4688, Vol. 14, No.(1) 2026, Pg. 119-133

Current Agriculture Research Journal

www.agriculturejournal.org

Efficacy of Microbial and Biochemical Biopesticides Against Potato Cyst Nematodes (*Globodera Rostochiensis* and *Globodera Pallida*) in Kenya

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Abstract

Potato *(Solanum tuberosum L.)* is a valuable and nutritious staple food crop, driving both food security and economic growth globally. However, potato production has been limited by infection of potato cyst nematodes (PCN) causing significant yield losses. This study evaluated the efficacy of five biocontrol agents and botanical extracts in the management of PCN within production systems. Potatoes were grown in pots containing sterile soil in a screenhouse arranged in a Complete Block Design for two consecutive cycles. The pots were treated with biocontrol agents; Nemguard *(Paecilomyces lilacinus), Trichoderma viride* and botanical extract; Maytech *(polysulphides),* Pesticide (Nimbecidine), and a negative control that was not treated.The pots were then inoculated with PCN cysts. Data on cyst count, tuber yield and plant vigor were collected and analyzed using analysis of variance (ANOVA). The results indicate that Cyst reproduction index was significantly reduced in Pesticide, Trichoderma and Maytech treated pots. This was quantified as 0.83% (Maytech), 2% (Nemguard), 0.33% Pesticide and 0.83% in Trichoderma, as compared to negative control. Treatment and Cycle × Treatment were significantly differently for PCN juveniles ($p \leq 0.05$);4.95,5.5; and final potato cyst nematodes (FPCN)/ 200g of soil ($p \leq 0.001$).; 254.58, 50.55. All the biocontrols had significantly higher plant vigor than control. The Pesticide and Trichoderma treated pots resulted in high total number of marketable tubers, weight of marketable tubers, low number of final potato cyst nematode per 200g of soil and PCN juveniles. The reproductive index (r=-0.68) and FPCN/200g of soil

Article History
Received: 23 January 2026
Accepted: 10 April 2026

Keywords
Biocontrol,
Cyst;
Juveniles;
Marketable Tubers;
Nematode and Potato.

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Doi: http://dx.doi.org/10.12944/CARJ.14.1.9

(*r*=-0.28) had a negative correlation with weight of total tubers. The number of PCN juveniles increased with a decrease in weight of total tubers at the rate of 6.23 (counts). These results show the effectiveness of biocontrol and their potential in management of PCN and therefore recommend testing of Pesticide and *Trichoderma* under field conditions.

Abbreviations

PCN	(Potato cyst nematodes)
ANOVA	(Analysis of variance)
FPCN	(Final potato cyst nematodes)

Introduction

Potato *(Solanum tuberosum L.)* is the third most important non-cereal food crop globally after wheat *(Triticum aestivum)* and rice *(Oryza sativa)*, with an annual production of approximately 383.08 million metric tons.[1,2] In Kenya, potato ranks second after maize *(Zea mays)* in terms of consumption and contribution to food security. The crop is cultivated by approximately 800,000 smallholder farmers and supports over 2 million people along the value chain. In 2022, national production was estimated at 1.8 million tonnes, valued at approximately USD 394 million.[3] Potato is widely grown across diverse agro-ecological zones, with major production occurring in Nyandarua, Kirinyaga, Meru, Nakuru, and Kiambu counties.[4] Nutritionally, potato is an important source of carbohydrates (20.43%), protein (1.76%), and essential minerals, including iron, zinc, calcium, and thiamine. Increasing population growth and urbanization have contributed to rising global demand and production of potato.[5] To enhance productivity, several improved varieties, including Kenya Mpya, Shangi, Sherekea, Markies, Eldo Amani, and Unica, have been released and adopted by farmers.

Despite its significance, potato production in Kenya is constrained by poor seed quality, pests, diseases, and limited access to inputs.[4] Among the major biotic constraints are potato cyst nematodes (PCN), *Globodera rostochiensis* and *Globodera pallida*, which are among the most economically important pests of potato.[6] These nematodes are primarily disseminated through contaminated soil, infected tubers, and farm machinery. They are obligate sedentary endoparasites capable of surviving in soil for up to 3 decades in the absence of a host, posing a persistent threat to potato production. PCN infestation can result in yield losses of up to 80% due to damage to root systems, which are critical for water and nutrient uptake and tuber development.[7]

The life cycle of PCN is closely synchronized with the host plant. Juveniles hatch from eggs in response to chemical stimuli present in potato root exudates, which contain compounds that specifically induce hatching.[8] The juveniles penetrate root tissues and establish specialized feeding structures (syncytia), which serve as nutrient sources for their development. Following several developmental stages, the nematodes reproduce, and females form cysts that protect eggs in the soil, ensuring long-term survival and persistence of the pest.

Management of PCN has traditionally relied on chemical nematicides such as fosthiazate and oxamyl. Although effective, their use is increasingly restricted due to environmental concerns, potential health risks, and the development of resistance.[9,10] Consequently, there is a growing need for sustainable and environmentally friendly management strategies. Cultural practices such as crop rotation with non-host crops can reduce nematode populations; however, their effectiveness is often limited when used as a sole control measure.[11] Trap cropping, for instance using *Solanum sisymbriifolium,* stimulates nematode hatching without supporting reproduction, thereby reducing soil populations over time.[12] The use of resistant varieties also represents a sustainable approach, particularly when integrated with regular soil monitoring and appropriate crop rotation strategies.[10,13]

Biological control has emerged as a promising alternative for the management of plant-parasitic nematodes. This approach involves the use of natural antagonists, including fungi and botanical products, to suppress nematode populations and reduce reliance on synthetic pesticides.[14] For example, *Paecilomyces lilacinus* produces hydrolytic enzymes that degrade nematode eggshells, while *Trichoderma viride* enhances plant defense mechanisms and improves soil health.[15,16] Botanical products such as polysulphides and neem-based formulations (e.g., Nimbecidine) have also demonstrated efficacy in disrupting nematode development and reproduction.[10,17,18] Evaluation of these biocontrol agents under controlled conditions is essential for developing effective integrated management strategies.

Therefore, this study aimed to evaluate the effectiveness of selected biocontrol agents—Maytech, Nemguard, Nimbecidine, and *Trichoderma* in reducing PCN populations and improving potato growth and yield under screenhouse conditions. The findings are expected to contribute to the development of sustainable nematode management strategies that enhance potato productivity while minimizing environmental impacts.

Materials and Methods

Experimental Procedure

The experiment was set up in a screenhouse at Kenya Plant Health Inspectorate Service, (KEPHIS) Lanet, Nakuru County located at 0° 17''43.6'S 36° 11'' 3.7'E. Lanet is 16 km Southeast of Nakuru town and experiences a bimodal rainfall pattern with an annual mean of 800 mm. The minimum and maximum temperatures are 10 and 26 °C, respectively.[19]

Shangi variety was selected for this study due to its known to be susceptible to potato cyst nematodes (PCN) and cultivated by many farmers in potato growing regions in Kenya. Soil was sampled from an infested paddock in 2 farms in Ndundori, Nakuru County using a 10 m × 10 m grid was dug to a depth of 15 cm after removing topsoil and 10 kg was weighed. The soil was placed in a polyethylene bag in a cool box and transported to KEPHIS laboratory for cyst isolation, identification and quantification. Soil samples were air dried at 37oC for 48 hours to aid flotation of cysts which improves efficiency of recovery.[20] Cysts were then extracted from 100 g sub-samples of soil using the Fenwick Can flotation method.[21] The cysts were individually handpicked using sterile entomological forceps and counted using a Leica MZ 12.5 dissecting microscope and recorded.

At the screen house, the experiment was conducted in polythene plastic pots measuring 30 cm in diameter filled with 2 kg autoclaved soil (Sandy: Loam = 1:3). Four biocontrol agents and a control were used as treatments (Table 1). The application rate for each of the treatments followed manufacturers' recommendations.

Table 1: Treatments for the evaluation of the bio control agents

Treatments	Treatments combinations
T1	Paecilomyces lilacinus at 125g/ha (10 g/pot)/Nemguard
T2	Polysulphides (botanical extracts)8l/ha (8 g/pot)/Maytech
T3	Trichoderma viride at 125 g/ha (10 g/pot)/Trichoderma
T4	Nimbecidine at 2 kg/ha (Pesticide) (10g/pot)/Nimbecidine
T5	Untreated control

The treatments were applied as a soil drench to ensure uniformity within the pot and allowed to settle for 24 hours. One tuber of the Shangi variety, was sown in each pot, including the control (Without bio-control). The DAP fertilizer (18:46:0) was applied at planting at the rate of 25 g per 2 kg of soil. Two weeks after emergence, each pot was inoculated with 30 cysts of PCN. The pots were then arranged in a Randomized Complete Block Design (RCBD) with 3 replicates, over 2 cycles. All good agronomic practices were carried out to ensure the experiment's uniformity and minimize errors. Data was collected on growth parameters, yield and yield components. Plant height was determined by measuring the plants in the pot using a 1 m ruler from the base to the tip of the plant, number of stems were also counted and averaged, and the number of leaves at 75 days after planting was determined by counting leaves from each plant and averaged. Data on tuber yield, number, and weight were recorded at the time of harvest from each pot.

Data collection on PCN infestation symptoms was assessed visually on a scale of 1 (less severe) to 5 (high severe). The initial cyst population (pi) before planting and the final cyst population (FCP) after harvest, 90 days after planting were determined from each pot. The cysts were extracted from 100 ml soil by Fenwick can method,[21] and the nematode reproduction factor (RF) was estimated as the ratio of the final and initial nematode population.

Data Analysis

Data on the agronomic parameters was subjected to analysis of variance (ANOVA) using SAS to determine the statistical significance at P≤ 0.05 following a linear model for a completely randomized design. Mean separation was done using Fischer's least significant difference test (LSD) whenever the treatments were significant.

$$LSD = t_{\frac{\alpha}{2}} \times \sqrt{\frac{2MSE}{r}} \qquad ...(1)$$

Where α is the significance level, MSE is the mean square error, and r is the number of replicates.

Correlation coefficients will be derived using Pearson's formula to determine the relationship between potato agronomic traits and PCN severity.

$$r_p = \frac{n(\sum x_i y_i) - (\sum x_i)(\sum y_i)}{\sqrt{[n\sum x^2 (\sum x_i)^2][n\sum y_i - (\sum y_i)^2]}} \qquad ...(2)$$

Where r_p is Pearson's correlation coefficient, n is the number of samples, x is the dependable variable, and y is the independent variable. The correlation coefficients were derived using SAS version 9.2. A probability level of ≤0.05 was considered statistically significant.

The relationship between the final number of cysts, PCN reproductive index and tuber yield was determined using correlation analysis. The PCN cyst reproduction index was expressed as.[22]

$$RI = \frac{Pf}{Pi} \qquad ...(3)$$

Where; Pi=initial population density, Pf=final population density. The relative yield loss for each treatment was determined as described.[23]

$$RL(\%) = \frac{Y_{bt} - Y_{ot}}{Y_{bt}} \times 100\% \qquad ...(4)$$

Where; Y_{bt} is the mean total yield of the best experimental treatment in the experiment, Y_{ot}: is the mean yield of other experimental treatments.

Results

All the treatments were significantly different from control in terms of plant vigor. Nemguard, Nimbecidine and Trichoderma were significantly different from Maytech and control in terms of number of stems (Figure 1). Best root structure was observed in control while Trichoderma enhanced plant height although did not differ statistically from all the other treatments. Trichoderma had a significantly high number of marketable tubers but did not differ from Nimbecidine and Control.

Treatments performance on number of nonmarketable tubers and total number of tubers did not differ statistically (Figure 1). Weight of marketable tubers interestingly varied among the treatments with Nimbecidine registering highest weight while Nemguard registered the least weight but did not differ from Control. The least weight of nonmarketable tubers was observed on Control while Nimbecidine registered the highest weight of total tubers however it was not significantly different from Trichoderma.

Control = Untreated, Maytech =Polysulphides (botanical extracts) 8l/ha, Nemguard= Paecilomyces lilacinus at 125g/ha, Pesticide = Nimbecidine at 2 kg/ha, Trichoderma= Trichoderma viride at 125 g/ha

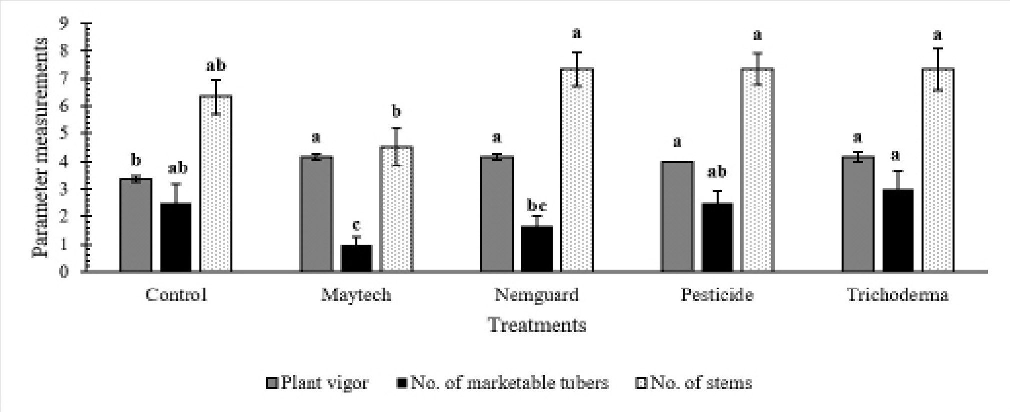

Fig. 1: Effects of biocontrol on yield and yield parameters

Effect of Biocontrol on the Weight of Total Tubers, Final PCN Count and Reproductive Index

Pesticide registered no weight loss at 0% while Nemguard had highest weight loss at 67.91% (Table 2). The differential final PCN count was exhibited by number of final PCN count in control, where Maytech, Nemguard, Pesticide and Trichoderma had 63.78%, 66.14%, 76.38 and 65.35% reduction in final PCN count as compared to the control. Further, the rate of cysts reproduction reduced significantly with application of the biocontrols. From the results, Maytech, Nemguard, Pesticide and Trichoderma resulted in 66.8%, 20%, 86.8% and 66.8%, respectively reduction in cysts reproduction (Table 2).

Table 2: Effect of biocontrol on tuber weight and PCN parameters

Biocontrols	Weight of total tubers	Relative yield loss (%)	Final PCN count/200g of soil	%change	Reproductive index	%change
Control (No Biocontrol)	0.20	43.72	21.17	0.00	0.00	0.00
Maytech (Polysulphides)	0.17	52.56	7.67	63.78	0.83	66.80
Nemguard (Paecilomyces lilacinus)	0.12	67.91	7.17	66.14	2.00	20.00
Pesticide (Nimbecidine)	0.36	0.00	5.00	76.38	0.33	86.80
Trichoderma	0.30	16.28	7.33	65.35	0.83	66.80

Control = Untreated, Maytech =Polysulphides (botanical extracts) 8l/ha, Nemguard= Paecilomyces lilacinus at 125g/ha, Pesticide= Nimbecidine at 2 kg/ha, Trichoderma= Trichoderma viride at 125 g/ha

Effect of Biocontrol on the Agronomic and Yield Parameters of Shangi Cultivar

Cycle 1 and 2 showed significance ($p \leq 0.01$, $p \leq 0.001$) in weight of marketable tubers, weight of nonmarketable tubers, total weight of tubers and PCN with juveniles (Table 3). Treatments had significant ($p \leq 0.05$, $p \leq 0.01$, $p \leq 0.001$) effects on plant vigor, number of marketable tubers and FPCN/200g of soil and PCN with juveniles. Interaction effects of Cycle x Treatment showed significant effects ($p \leq 0.05$, $p \leq 0.001$) on plant vigor, number of marketable tubers, FPCN/200g of soil and PCN with juveniles (Table 3).

Table 3: Mean squares for agronomic and yield parameters of shangi cultivar under 5 biocontrol agents

Source of variation	d.f	Vigor	Number of stems	Root structure	Plant height	No. of Marketable tubers	No. of Non-marketable tubers	Total number of tubers
Cycle	1	0.03	1.63	0.0	2.70	8.53	1.63	2.70
Replicate	2	0.01	7.03	0.01	321.03	0.63	4.8	5.83
Treatment	4	0.78***	9.13	1.11	75.95	3.78**	9.28	11.47
Cycle x Treatment	4	0.28***	1.47	0.19	239.78	3.28*	7.05	11.37
Error	18	0.036	2.29	0.04	195.84	0.74	9.99	13.43
R2		0.87	0.58	0.89	0.35	0.74	0.30	0.30
C.V		4.7	23.06	10.76	20.27	40.44	73.49	56.96

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$), respectively. R2=Coefficient of determination, CV= Coefficient of variation, df= degree of freedom.

Table 3: Cont..,

Source of variation	d.f	Weight of marketable tubers	Weight of non-marketable tubers	Total weight of tubers	FPCN/ 200g of soil	PCN with juveniles
Cycle	1	0.51***	0.03**	0.81***	4.80	24.30***
Replicate	2	0.01	0.00	0.00	2.03	0.70
Treatment	4	0.02	0.02	0.06	254.58***	4.95*
Cycle x Treatment	4	0.03	0.01	0.06	50.55***	5.55*
Error	18	0.01	0.00	0.02	3.51	1.48
R2		0.78	0.71	0.80	0.95	0.72
C.V		59.13	97.68	58.77	19.39	93.51

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$), respectively. R2=Coefficient of determination, CV= Coefficient of variation, df= degree of freedom.

Effect of Biocontrol on Potato Cyst Nematode Reproductive Index

All the biocontrol significantly inhibited cyst reproduction in comparison with the control. Pesticide (Nimbecidine) (RI=0.33) was the best but not significantly different in controlling cyst reproduction compared to Trichoderma (RI=0.83) and Maytech (RI=0.83). Interestingly, although Nemguard performed better than control they did not differ statistically (Figure 2).

Control = Untreated, Maytech =Polysulphides (botanical extracts) 8 l/ha, Nemguard= Paecilomyces lilacinus at 125g/ha, Pesticide= Nimbecidine at 2 kg/ ha, Trichoderma= Trichoderma viride at 125 g/ha

The differential final PCN count was exhibited by number of final PCN count in control, where Maytech, Nemguard, Pesticide and Trichoderma had 63.78%, 66.14%, 76.38 and 65.35% reduction in final PCN count as compared to the control.

Further, the rate of cysts reproduction reduced significantly with application of the biocontrols. From the results, Maytech, Nemguard, Pesticide and Trichoderma resulted in 66.8%, 20%, 86.8% and 66.8%, respectively reduction in cysts reproduction (Table 2). Highest FPCN was observed under the control while pesticide registered the least FPCN. Further, control had significantly the highest PCN with juveniles but did not differ from Nemguard with pesticide exhibiting the least PCN with juveniles (Figure 3; Table 4).

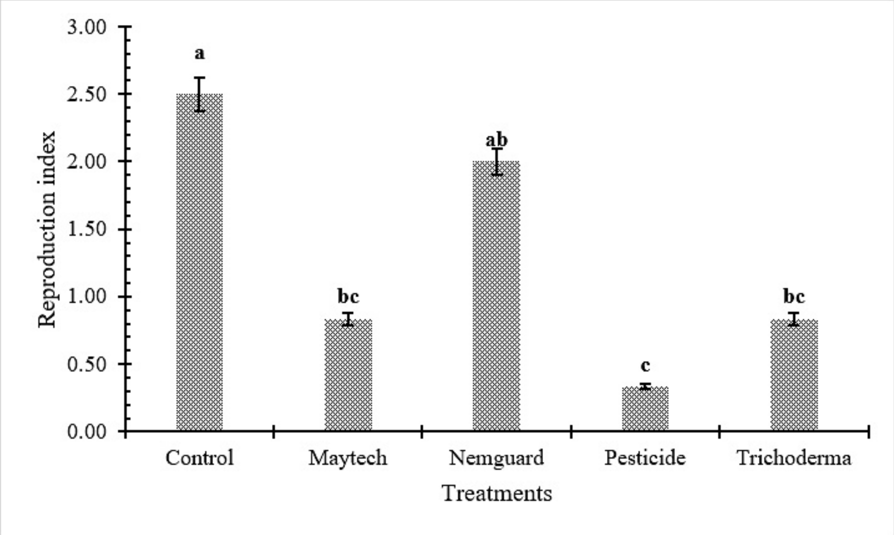

Fig. 2: Potato cyst nematode reproductive index

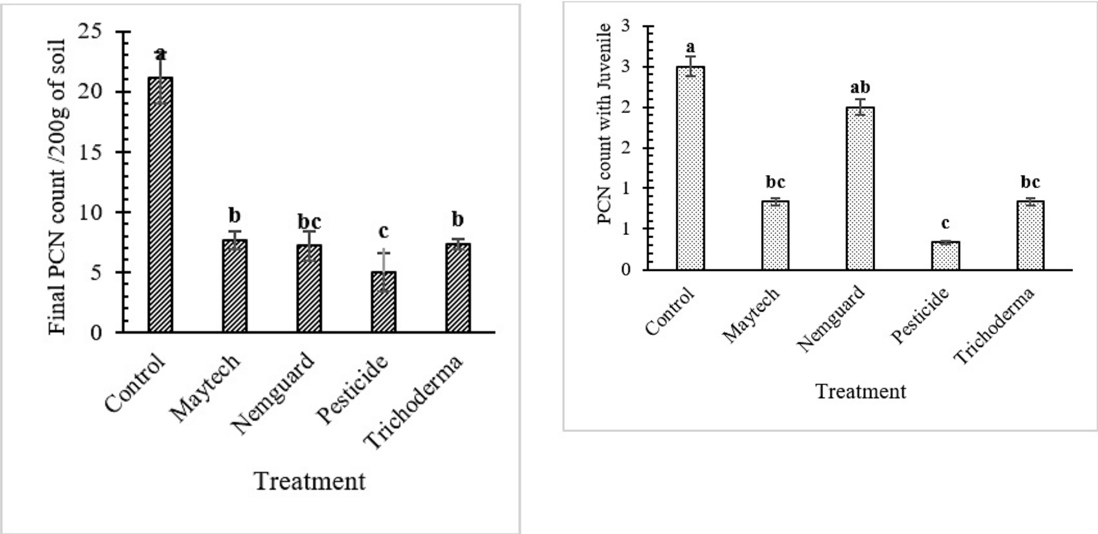

Fig. 3: Effects of biocontrol on PCN parameters

Control = Untreated, Maytech =Polysulphides (Botanical extracts) 8l/ha, Nemguard= Paecilomyces lilacinus at 125g/ha, Pesticide= Nimbecidine at 2 kg/ha, Trichoderma= Trichoderma viride at 125 g/ha.

Table 4: Means for the agronomic and yield parameters of potato varieties under 5 biocontrol agents

Treatment	Plant vigor	No. of stems	Root structure	Plant height	No. of marketable tubers	No. of nonmarketable tubers
Control	3.33 ± 0.11[b]	6.33 ± 0.61[ab]	2.50 ± 0.13[a]	67.50 ± 5.12[a]	2.50 ± 0.67[ab]	2.50 ± 0.99[a]
Maytech	4.17 ± 0.11[a]	4.50 ± 0.67[b]	1.75 ± 0.11[b]	65.83 ± 7.46[a]	1.00 ± 0.26[c]	5.33 ± 1.99[a]
Nemguard	4.17 ± 0.11[a]	7.33 ± 0.61[a]	1.42 ± 0.08[d]	75.00 ± 5.32[a]	1.67 ± 0.33[bc]	3.50 ± 0.85[a]
Pesticide	4.00 ± 0.00[a]	7.33 ± 0.56[a]	1.67 ± 0.11[bc]	67.50 ± 6.92[a]	2.50 ± 0.43[ab]	5.17 ± 1.08[a]
Trichoderma	4.17 ± 0.17[a]	7.33 ± 0.76[a]	1.50 ± 0.00[cd]	69.33 ± 3.57[a]	3.00 ± 0.63[a]	5.00 ± 0.68[a]
$LSD_{0.05}$	0.23	1.84	0.23	16.98	1.05	3.83

Means followed by the same letters down the column are not significantly different at ($p \le 0.05$).

Table 4: Cont…,

Treatment	Total number of tubers	Weight of marketable tubers	Weight of nonmarketable tubers	Weight of total tubers	FPCN/200g of soil	PCN with juveniles
Control	5.00 ± 1.39[a]	0.17 ± 0.06[ab]	0.05 ± 0.03[bc]	0.20 ± 0.08[abc]	21.17 ± 2.12[a]	2.50 ± 1.15[a]
Maytech	6.33 ± 2.22[a]	0.16 ± 0.05[ab]	0.01 ± 0.01[c]	0.17 ± 0.05[bc]	7.67 ± 0.76[b]	0.83 ± 0.48[bc]
Nemguard	5.17 ± 1.08[a]	0.11 ± 0.04[b]	0.01 ± 0.00[c]	0.12 ± 0.04[c]	7.17 ± 1.19[bc]	2.00 ± 0.82[ab]
Pesticide	7.67 ± 1.09[a]	0.26 ± 0.13[a]	0.10 ± 0.04[ab]	0.36 ± 0.16[a]	5.00 ± 1.57[c]	0.33 ± 0.21[c]
Trichoderma	8.00 ± 0.93[a]	0.18 ± 0.06[ab]	0.12 ± 0.04[a]	0.30 ± 0.10[ab]	7.33 ± 0.42[b]	0.83 ± 0.48[bc]
$LSD_{0.05}$	4.44	0.13	0.07	0.16	2.27	1.47

Means followed by the same letters down the column are not significantly different at ($p \le 0.05$).

In pearson correlation, the reproductive index had a negative relationship (*r*=-0.68) with weight of total tubers (Figure 4). Reproductive index decreased at a rate of 6.24 with increase in weight of total tubers. Final PCN count/ 200g of soil had a negative correlation with the weight of total tubers. Further, the weight of total tubers increased with decrease in Final PCN/200g of soil at a rate of 17.45. On the other hand, a negative relationship was observed between PCN with juveniles and weight of total tubers with PCN cyst count of decreasing at the rate of 6.23 with an increase in weight of total tubers (Figure 4).

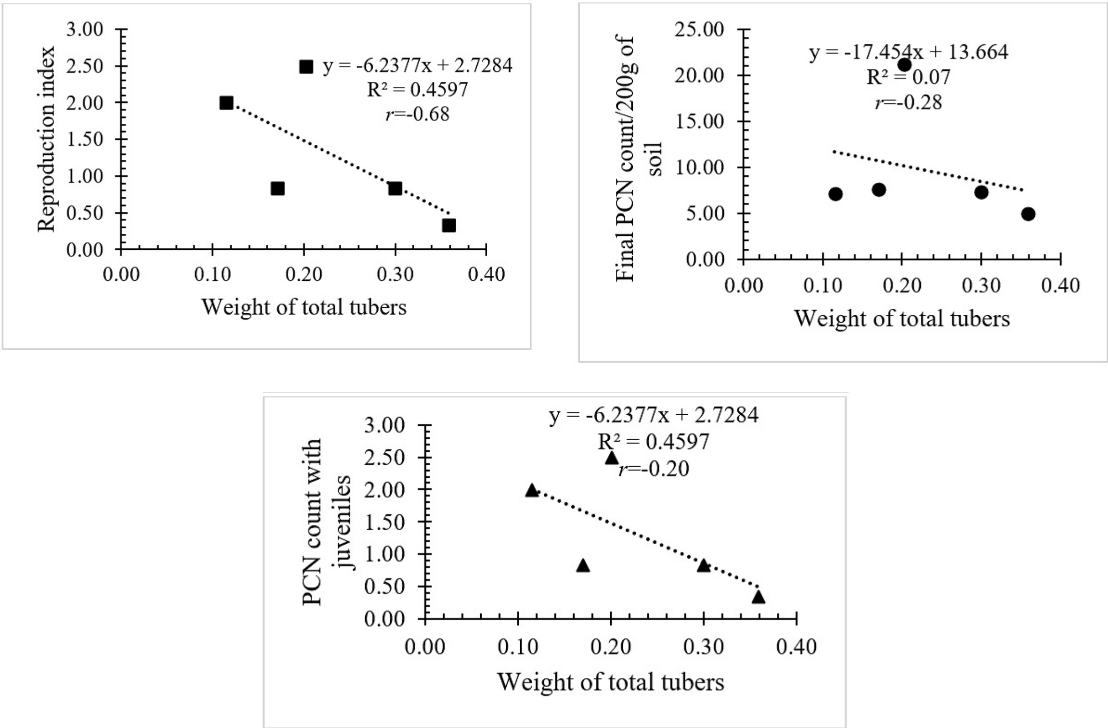

Fig. 4: Pearson correlation coefficient for PCN and potato growth and yield parameters

Plant vigor showed negative significant relationship with root structure (*r*=-0.96**) and FPCN/200g of soil (*r*=-0.93*) (Table 5). The number of stems and FPCN/200g of soil also had a negative significant (*r*=-0.18*) relationship. PCN with juveniles showed a significant negative correlation with the number of nonmarketable tubers (*r*=-0.97**) and the total number of tubers (*r*=-0.89*). Weight of total tubers showed positive significant correlation with weight of marketable tubers (*r*=0.92*) and weight of nonmarketable tubers (*r*=0.92*) (Table 5).

Table 5: Pearson Correlation coefficients for agronomic and yield parameters

Variables	Vigor	No. of stems	Root structure	Plant height	No. of marketable tubers	No. of non-marketable tubers tubers	Total number of tubers	Weight of market-able tubers	Weight of non-marketable tubers	Weight of total marketable	FPCN/200g of soil
No. of stems	0.04										
Root structure	-0.96**	-0.32									
Plant height	0.30	0.60	-0.50								
No. of marketable tubers	-0.32	0.73	0.13	0.00							
No. of nonmarketable tubers	0.75	-0.18	-0.62	-0.36	-0.13						
Total tubers Total number of tubers	0.49	0.25	-0.48	-0.33	0.45	0.82					
Weight of marketable tubers	-0.12	0.19	0.10	-0.60	0.47	0.46	0.68				
Weight of nonmarketable tubers	-0.01	0.58	-0.10	-0.23	0.89	0.33	0.81	0.71			
Weight of total tubers	0.02	0.41	-0.08	-0.43	0.70	0.50	0.85	0.92*	0.92*		
FPCN/200g of soil	-0.93*	-0.18*	0.93	-0.21	0.19	-0.82	-0.63	-0.19	-0.16	-0.28	
PCN with juveniles	-0.64	0.03	0.55	0.40	-0.04	-0.97**	-0.89*	-0.66	-0.49	-0.68	0.79

*, **, ***, significant at (p≤0.05), (p≤0.01), (p≤0.001), respectively.

Discussion

Biocontrols; Nemguard, Maytech, Trichoderma, and Trichoderma significantly influenced the reduction in rate of reproductive index for the cysts. This suggests that they were effective in PCN control. When compared to the negative control which did not have any treatment the reproductive index (RI) was significantly higher. According to researcher[24] biocontrol agents significantly reduce the reproductive index of potato cyst nematodes. Further, it reduces egg density and multiplication rates of up to 86%. Among the biocontrol agents, pesticide was the most effective with 86% reduction in RI followed by Trichoderma and Maytech (66%).[25] The biocontrols might have altered the production of exudates which are the basis for signaling of nematodes to attack the potato roots. This inhibition of cyst reproduction means reduced PCN population in the field and reduced severity on plants. This is evident in this study where biocontrol resulted in 63-76% reduction in PCN population/200g of soil.

Growth and physiology of plants is interrupted by biotic and abiotic stresses resulting in reduced production. RI increased with decrease in weight of total tubers. Similarly, the results showed that the final PCN count/ 200g of soil increased with a decrease in weight of total tubers[26] found out that, tuber weight significantly reduced 44%-87% with increased PCN population and number of PCN eggs. PCN has been a pest of importance in potato growing regions of Kenya. From the results of this study, it is evident that the effects of PCN are detrimental to potato production. PCN significantly inhibited plant vigor which is a major trait that determines production. Furthermore, the number of stems in potato growth and establishment influences tuber production. PCN significantly reduced the number of stems in the infected potato plants. Interestingly, biocontrols did not have significant effects on plant height. However, control had moderate plant height which might be due to redirection of assimilates to root structure rather than the shoot. It is worth noting that control plots had higher root density compared to the biocontrols agents. This is in line with[27] who reported higher root density in potato infested by PCN. This might be due to production of extra roots when infested as a defense response. Control had the least plant vigor, but higher root structure compared to the rest of the treatments. In disease susceptibility interactions, a cultivar might reduce plant above ground growth and invest more in root lignification or branching, improving root resilience to pests and diseases.

Trichoderma was the most effective agent in increasing the number of marketable tubers and total number of tubers. Pesticide performed better in terms of the weight of marketable tubers and total weight of marketable tubers. This is a true reflection of the effects of biocontrols in suppressing PCN. The reduction in nematode population density decreases root damage and nutrient uptake disruption, allowing better root development and higher tuber formation, which translates into more marketable tubers. It is evident from the results that biocontrols had significantly lower final PCN count/200g of soil. Similar observation was realized in the PCN count with juveniles in plots with biocontrols as compared to those without biocontrol. The plots with biocontrols registered reduced PCN juvenile population which further contributed to increased yield production.

Plant vigor correlated with increase in weight of marketable tubers and number of marketable tubers. This is in agreement with[28] who reported that potato clones with higher plant vigor have higher tuber yield. The treatment with PCN/200g of soil had significantly increased with a decrease in number of plant stems. Potato infestation in potato fields causes root damage that leads to stunted and weakened plants, which results in fewer stems per plant. Detrimental effects on plants reduce plants' ability to absorb water and nutrients efficiently which causes reduction in plant vigor and growth.[29] This is in line with the results from this study where plant vigor has a significant negative correlation with FPCN/200g of soil. Potato cysts infect feeder roots, where the females attach, feed and become sedentary. Increased number of nematodes cause plant wilting, stunted growth and poor root development.

Plant root structure was negatively correlated with the marketable tubers. This might be due to redirection of assimilates to the root structure to repair and protect the roots which are infected by the cysts. PCN juveniles induce the formation of a large, multinucleate feeding site called a syncytium by dissolving cell walls and fusing neighboring root cells.[8] This syncytium acts as a strong nutrient sink; drawing assimilates from the plant to support nematode development. The nematode manipulates host cells to maintain this feeding site, which requires continuous supply of nutrients and assimilates from the plant's photosynthate pool.[8] These trade-offs might be the reason for the negative effects observed between the two traits. Higher or dense root systems improve nitrogen, water and nutrient absorption which contribute to tuber development.

Moreover, plant vigor and root structure had negative correlation which might be due to the investment in shoot growth at the expense of root development. Strong dense root systems might grow slower, however, establish long-term resilience. This is in concurrent with[30] who reported that root mass is negatively correlated with tuber bulking implying an increase in root growth may not enhance plant vigor. Infected plants are weakened, chlorotic, premature drying and wilting of above ground vegetation. This inhibits photosynthesis, nutrients and assimilates storage and poor tuber initiation and development. Researcher[31] reported an increase in number of PCN juveniles resulted in 40%, 32%, 40%, and 70% reduction in plant height, fresh weight, dry weight and yield per plant antithesis to the control.

In this study, plant height had a negative influence on tuber yield. This might be due to the redirection of assimilates to sinks rather than structural parts of the plant. Tall plants redirect most of the resources to vegetative growth rather than tuber bulking. Further, excessive shading may reduce photosynthesis on lower plant leaves, and delayed tuber initiation. Biocontrol is a reputable and increasingly adopted approach for suppressing PCN in soils, offering environmental and sustainability benefits. However, despite the effectiveness observed in this study, several limitations of biocontrol agents should be considered to provide a balanced interpretation. Biocontrol agents such as Nemguard, Maytech, and Trichoderma typically exhibit a slower mode of action compared to chemical pesticides and may require multiple application cycles to achieve substantial suppression of PCN populations. In addition, their performance can be inconsistent across different field conditions. Environmental factors including soil moisture, temperature, solar ultraviolet radiation, and soil microbial composition strongly influence their survival, establishment, and efficacy. These constraints may result in variable outcomes under farmer field conditions and should be taken into account when recommending their use.[32,33]

Therefore, East Africa potato farmers can use the recommended biocontrols in this study by implementing them under natural field conditions and give recommendations on optimization of the timing and frequency of biocontrol agent applications.34,35 However, due to long use of biocontrol to completely eliminate the PCN in the soils, integrating biocontrol with potato friendly agro ecological practices such as crop rotation, use of trap or refugia crops, and minimized broad spectrum insecticide use farmers create more favorable habitats for natural enemies and microbial agents, thereby improving their establishment and impact on key pests such as aphids, tuber moths, and root knot nematodes.[34-36] Furthermore, farmer generated data on pest pressure, tuber yield, and input costs provide valuable on farm evidence on economic feasibility and scalability, which strengthens the applied value of the research and supports more realistic extension recommendations.[34,36]

Conclusion

Nemguard, Trichoderma, Mytech and Nemguard offer a sustainable, ecofriendly and cost-effective solution for managing potato cyst nematode. This study has shown the effectiveness of biocontrol in reducing PCN reproductive index and population. Pesticide and Trichoderma were the most effective in suppressing PCN reproduction. Biocontrol significantly suppressed PCN juvenile population which contributed to increased number and weight of marketable tubers. Managing PCN effectively requires combining multiple strategies starting with prevention, then intergrating cultural, biological and chemical controls, tailored to local conditions, alongside proper timing, application techniques, and environment management. This intergrated pest management approach maximizes efficacy while minimizing environmental impact.

Acknowledgements
We thank Kenya Plant Health Inspectorate Service for providing the screenhouse and laboratory to conduct the research.

Funding Sources
This research was supported by Erasmus+ BREEDTECH project number 101128862

Conflict of Interest
The authors do not have any conflict of interest.

Data Availability Statement
This statement does not apply to this article.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration
This research does not involve any clinical trials.

Permission to Reproduce Material from other Sources
Not Applicable.

Author Contributions
- **Miriam Karwitha Charimbu, Joseph Juma Mafurah and Milka Mbithe Kananda:** Concept--ualization, Methodology, Data collection, Analysis, Writing, and Final approval of the manuscript.

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