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13. Approaches to Control Nematode Diseases in Potato Farming

Hemlata Pant

Department of Zoology,
CMP PG. College, University of Allahabad,
Prayagraj, U.P, India

Vinny John

Department of Agriculture,
Mangalayatan University, Jabalpur,
M.P., India.

Amit Kumar Maurya

College of Agriculture Sciences,
Teerthanker Mahaveer University,
Moradabad, U.P, India.

D. K. Srivastava

Council of Science and Technology,
Lucknow, U.P, India.

Abstract:

Nematodes are a major hazard to potato crops, resulting in severe yield losses worldwide. Nematode disease management involves an integrated approach that includes cultural, biological, and chemical techniques. Recent developments in nematode control have concentrated on precision agriculture, which uses remote sensing and soil health monitoring to detect nematode infestations early. The use of resistant potato varieties, combined with crop rotation and bio-fumigation, has proven to be an effective technique for nematode population control. Biological control methods, such as nematode-trapping fungus and predatory nematodes, provide an environmentally acceptable alternative to chemical nematicides. Furthermore, the introduction of innovative nematicides with tailored activity and low environmental impact has improved control strategies. The integration of these strategies, combined with current research into worm biology and potato genetics, has the potential to improve the long-term viability and effectiveness of nematode disease management in potato agriculture. Continuous monitoring and adaptive management strategies are required to handle the evolving issues provided by nematodes in potato crops.

Keywords:

Potato, Nematodes, Detection, Globodera rostochiensis, and biological control

13.1 Introduction:

Potatoes are a key horticulture crop around the world, including India. The diseases are a significant threat to potato crops globally, affecting both yield and quality. Among the different root and tuber crops farmed in India, the potato has the highest proportion, producing 50.19 MT from an area of 2.17 million hectares in 2020 (FAOSTAT 2017). India is now the second-largest producer behind China (91.88 MT). Potato potential yield is determined by a combination of biotic and abiotic variables. Pathogens such as fungi, bacteria, viruses, insects, and nematodes are important biotic factors that contribute to a 30-40% decrease in overall yield.

Several factors contribute to potato tuber production loss due to nematode parasitism, including cultivar, atmosphere, soil composition, planting period, and nematode population (Noling 2016). Numerous potato plant parasitic nematode species have been identified; some cause considerable yield losses, while others may cause minor damage. Potato cyst nematodes (PCN) (*Globodera* spp.) and root knot nematodes (RKN) (*Meloidogyne* spp.) are two of the most economically significant nematode pests of potatoes worldwide, including India. The Julius Kuhn of Germany made the first record of cyst nematode infestation in potato crops in 1881.

Two PCN species, *Globodera rostochiensis* (Wollenweber) and *G. pallida* (Stone), known as golden nematodes, are detrimental to sustainable potato production. They are subject to strict quarantine and/or regulatory procedures wherever they appear and pose a serious danger to domestic and international potato trade. *Meloidogyne incognita* (Kofoid and White), *M. javanica* (Treub), *M. arenaria* (Neal), *M. hapla* (Chitwood), *M. fallax* (Karssen), *M. thamesi* (Chitwood), and *M. chitwoodi* (Golden) are RKN species linked to potatoes and have global relevance.

The false root-knot nematode *Nacobbus aberrans*, the potato rot nematode *Ditylenchus destructor* and the root lesion nematode *Pratylenchus* spp. can also cause significant yield losses in potato (Medina *et al*. 2017). Further, some nematode species can cause minor problems in potato, including the stubby-root nematodes, *Trichodorus* spp. (Cobb) and *Paratrichodorus* spp. (Siddiqi), the lance nematode *Hoplolaimus galeatus* (Cobb) and the dagger nematode *Xiphinema* spp. (Cobb).

13.2 Potato Cyst Nematodes (*Globodera Species*):

13.2.1 Origin and Distribution:

Potato Cyst Nematodes (PCN), primarily involving two species *Globodera rostochiensis* and *Globodera pallida*, are significant pests in potato cultivation. PCN species *G. pallida* and *G. rostochiensis* are regarded as one of the world's most pressing plant protection issues (CABI/EPPO 2020a; CABI/EPPO 2020b). These nematodes are native to the Andean region of South America, where they co-evolved with wild and cultivated potato species. PCNs originated in the Andean region of South America, particularly in countries like Peru, where potatoes were first domesticated. They have a long evolutionary history with their host plants in this region.

PCNs were introduced to Europe in the late 19th and early 20th centuries, likely through the movement of infested potato tubers Evans *et al*., (1975). They became widespread in potato-growing regions, especially in the UK, the Netherlands, and Germany. PCNs were later detected in North America, with notable infestations in the United States (e.g., Idaho) and Canada. Control measures have been stringent to prevent further spread. It was first introduced into Europe in the 1850s, along with the soil left on potato tubers sent for late blight resistant breeding, and it swiftly expanded over the world as a result of European variety introductions. As a result, Europe is considered the "secondary node" for the PCN diaspora. PCNs have spread to other potato-growing regions, including parts of Asia, Africa, and Oceania, primarily through the global trade of potatoes and soil movement (Jones *et al*., 2013; OEPP/EPPO 2004). Jones discovered the PCN in 1961 at Vijayanagaram Farm in Udhagamandalam, Nilgiri District, Tamil Nadu. Later, their existence was observed from other sections of Nilgiri, Kodaikanal hills, neighboring hills of Karnataka, and Idukki District in the Western Ghats of Kerala; as a result, the Tamil Nadu government enforced a domestic quarantine in 1971.

This pest has recently been documented in several mountainous regions of Himachal Pradesh, Jammu & Kashmir, and Uttarakhand (Aarti *et al*. 2020a; Chandel *et al*. 2020). In 2018, the Indian government limited the movement of potato seed tubers from contaminated areas. Both species of PCN infest other solanaceous crops such as tomato (*Solanum lycopersicum*) and eggplant (*S. melongena*), as well as other members of the Solanaceae such as Datura spp., Capsicum annuum (chili pepper), Hyoscyamus, Lycopersicon, Physalis (husk tomatoes), Physochlaina, Salpiglossis, *Nicotiana acuminata*, Saracha, and Oxalis tuberosa (Sullivan *et al*. 2007).

A. Biology:

The chemical compounds known as hatching factors, which are found in potato root diffusates (PRD) of the host plant roots, encourage cyst hatching. The second-stage juvenile (J2) emerges from the cysts and moves aggressively in the soil, invading the roots by rupturing with its stylet. It enters via the epidermal cell walls before settling with its head toward the stele to feed on cells in the pericycle, cortex, or endodermis via a feeding tube.

This causes root cell growth and the disintegration of their walls, resulting in a huge "syncytium" that offers food for nematode development. The nematode moults and remains in the syncytium until it is fully developed. The nematode's sex is decided during the J3 stage. Females become sedentary, bloated, and linked to the roots. After the last moult, the posterior half of the animal emerges by rupturing the root cells. Males keep their thread-like shape and emerge from the roots to locate and mate with females. *G. rostochiensis* young females are golden yellow, but *G. pallida* immature females are white or cream.

The white PCN remains white or cream-colored until eventually going brown, whereas the yellow PCN undergoes a protracted golden-yellow phase before turning brown or leathery. After the female dies, the body wall thickens to create a hard brown cyst that can withstand extreme environmental conditions. Each cyst contains 200-500 eggs and is easily released in soil before harvest. The eggs inside the cysts can live in soil for up to 30 years without a suitable host. Most PCNs finish their life cycle in 35-49 days.

In general, a generation is completed in a single crop season. Globodera spp. cysts exhibit high egg mortality in warmer climates, however their life cycle is disrupted in subtropical regions when temperatures above 28 ◦C (Caixeta *et al*. 2016). *G. pallida* require 10-18°C to develop on the host, while *G. rostochiensis* needs 15-25°C (EPPO 2013). In the absence of a host, around 30-33% of eggs hatch spontaneously each year, depending on environmental conditions (Oostenbrink 1950; Aarti *et al*. 2021).

Spread:

The PCN is typically transmitted by soil, water, compost, and the usage of diseased tubers in newer regions, as well as through the feet of animals and humans and farm equipment going from infected to disease-free fields.

13.2.2 Symptoms and Yield Loss:

Nematodes are microscopic, worm-like organisms that live in the soil and can infect plant roots, leading to a range of symptoms including stunted growth, yellowing of leaves, and the formation of galls or cysts on roots. The two most common nematode species that affect potato crops are the Potato Cyst Nematodes (PCN), *Globodera rostochiensis* and *Globodera pallida*, and the Root-Knot Nematodes (RKN), *Meloidogyne* species. These nematodes are particularly destructive as they can persist in the soil for many years, making it difficult to eradicate them once a field is infested. Nematode infestations can cause significant economic losses due to reduced yield and quality of potatoes. In severe cases, the entire crop may be unmarketable. The damage caused by nematodes can also increase the susceptibility of potatoes to secondary infections by other pathogens, further exacerbating the problem.

In soils with low PCN population densities, potato crops do not exhibit any above-ground symptoms since most potato plants can survive nematode invasion. However, when the level of invasion increases, the plant is unable to cope and eventually displays a variety of symptoms. When the infestation is severe and confined, little patches of poorly developing plants form in the field, and wilting may occur during hot sunny days. As the season progresses, the lower leaves become yellow/brown and wither, leaving just the young leaves on top. The entire plant develops a "tufted head" appearance, which eventually leads to the plant's untimely death. The browning and wilting of the foliage gradually expand to withering. The root system is underdeveloped, and the yield and size of the tubers vary according to the degree of infestation. The soil PCN population tolerance limit is 1.3-2.1 eggs per gram, but the economic threshold is approximately 20 eggs per gram of soil. Previously, Oerke *et al*. (1994) reported a 30% global yield loss, but Urwin *et al*. (2001) estimated losses of more than 12%, while Krishna Prasad (2008) estimated yield losses ranging from 5 to 80% in high-infestation areas in India.

Management:

Once established, PCN can be exceedingly difficult to remove from contaminated soil. Because no single control method is completely effective in achieving the desired level of nematode suppression, an integrated nematode management module combining a selective mix of various options such as host resistance and chemical, biological, and cultural methods is being proposed to reduce the PCN population to levels that allow for cost-effective potato production.

Quarantine:

Plants, plant products, and goods are all subject to legal restrictions in almost every country to prevent human-introduced pests and diseases from destroying agriculture and the environment. Many pests and illnesses, such as nematodes, are widely dispersed, but their biological range has not yet been fully realized, and they may be absent from a country or geographic area (Taylor and Brown 1998). To manage and prevent the spread of PCN, strict quarantine measures have been adopted globally because to the difficulty of eradicating it once identified in the field.

Strict local and national import regulations have resulted in the local elimination of PCN, while monitoring programs remain in place to keep a check on this pest. Despite these tight efforts, fresh PCN infections occur on a regular basis, even in places where potato production is strongly dependant. *G. pallida* was detected in Idaho, one of the largest potato-growing regions in the United States, demanding huge efforts to limit and eradicate the outbreak (Contina *et al.* 2020). In contrast, the identification of PCN in a number of Sub-Saharan African nations may be even more significant (Niragire *et al*. 2019; Cortada *et al.* 2020).

Domestic quarantine prevents seed tuber migration from infested to uninfested areas. The Ministry of Agriculture and Farmers Welfare in India has issued a notification under Section 4A of the Destructive Insects and Pests Act of 1914, restricting the movement of seed potatoes from PCN-infested areas to other states and union territories. Cysts are sedentary and incapable of moving on their own. Instead of growing an affected crop, they are more likely to spread through soil movement. The most effective strategy to prevent such spread is to institute stringent biosecurity controls.

13.3 Use of Certified Seed:

13.3.1 Crop Rotation:

Crop rotations, according to Urwin *et al*. (2001), keep PCN population densities below the harmful threshold. Maize and lima beans were discovered to be the optimal sequence for influencing PCN density, potato output, and profitability in Peru. In Western Europe, a 7-year interval between potato plantings of vulnerable cultivars is required.

Because of their restricted host range, crop rotation with non-solanaceous crops is widely suggested for PCN management. Menon and Thangaraju (1973) found that growing a potato at the conclusion of a four-year crop rotation that included potatoes, French beans, and peas resulted in a 98.7-99.9% reduction in PCN in the fourth year and a more than 90% increase in yield. Using resistant cultivars alone in a four-year crop rotation scheme enhanced yields by 67-78%.

Growing non-host crops in between host crops reduces PCN population density (Whitehead 1995). Crop rotation using PCN non-host crops such as radish, cabbage, cauliflower, turnip, garlic, and carrot, as well as green manure crops such as lupin, for 3 to 4 years reduces cyst population by 50% (Krishna Prasad 1993). When compared to other non-solanaceous crops, radish had a 19.6-21.0% reduction in cysts and a 12.2-16.2% reduction in eggs per cyst. Garlic came in second, reducing cysts and eggs by 15.9-17.7% and 10.3-11.6%, respectively (Aarti *et al*. 2017).

Crop rotation with barley reduced *G. rostochiensis* by up to 87% (Senasica 2013). Long rotations are frequently employed to regulate PCN, taking advantage of attrition produced by natural hatching and death. In the absence of a host plant, the population declines by 20-30% per year. However, it is difficult to predict since it is influenced by changes in soil composition, soil type, and other environmental conditions such as aeration and moisture.

13.3.2 Inter-Cropping:

Manorama *et al*. (2005) discovered that intercropping potatoes with French beans (3:2 ratio) increased potato equivalent output while decreasing cyst population. Potato and mustard intercropping in a 1:1 plant ratio, combined with carbofuran spraying, reduced PCN infestation while increasing potato output. Potato intercropped with radish at a 2:1 ratio was found to be effective in lowering the PCN population.

13.3.3 Trap Cropping:

The first type of trap crop is a potato crop, which must be destroyed 40 days after planting to produce PCN females. This strategy has been employed in the Netherlands to combat heavy infestations, although it results in the loss of a prospective harvest.

The nematodes are caught and killed inside the plant before maturation, requiring efficient plant destruction. In France, trap farming reduced *G. pallida* populations by 80% each year and 98.5% when two trap crops and ethoprophos were used. Cara, a *G. pallida*-tolerant cultivar, reduced the population by 75% when grown on entire ridges for 6 weeks in severely infested soil.

In India, trap cropping with a sensitive potato cultivar attracted more juveniles than trap cropping with a resistant potato cultivar and reduced nematode population by 53%; however, trap crops should be removed before the PCN life cycle is finished (Aarti *et al*. 2017). The second method of using a trap crop is to grow a S. tuberosum-related crop that stops PCN from finishing its life cycle. There have been several prospective crops researched for this purpose, but *S. sisymbriifolium* has showed the most promise so far (Dandurand *et al*. 2014). Using the wild trap plant *S. sisymbriifolium* led in an 80% drop in the region's PCN population.

Other promising species are S. *tuberosum*, *S. nigrum*, *S. dulcamara*, and *D. stramonium* (Sparkes 2013). Growing potatoes to promote PCN hatching and destroying potato plants following nematode infections in the potato roots can help reduce soil infestations.

A. Host Plant Resistance:

Globodera spp.-resistant cultivars have been effective, with control rates of up to 95%. Furthermore, numerous breeding studies are underway around the world to uncover resistance genes for these nematodes (Sullivan *et al.* 2007).

B. Antagonistic Plants:

Antagonistic plants can initially survive nematode infection, but as they progress through their life cycle, plant factors can prevent them from developing further. *Crotalaria spectabilis*, *C. juncea*, *Tagetes patula*, *T. minuta*, *T. erecta*, and *Estizolobium* spp. are used to address root-knot nematode problems in potato fields in Brazil (Embrapa 2015). They may also be used to control *Globodera* spp.

C. Physical Control:

G. rostochiensis eggs (97%) were unable to hatch in the top 10 cm layer of the soil during the hot summer, and solarizing the soil for 62 days reduced the population of *G. rostochiensis* by 95% (Mani *et al.* 1993). Because only a few centimeters of soil in temperate areas reach lethal temperatures, soil solarization is best suited for small areas with long hot summers.

D. Biocontrol Agents:

Laboratory tests in the United Kingdom have revealed that arbuscular mycorrhizal fungi suppress PCN root invasion. *Pochonia chlamydosporia*, a fungus that parasites nematode larvae, has also been investigated. It has done well in several experiments, but has not been scaled up to commercial levels and may be sensitive to field fungicides. Other fungi that may be predators or rivals of PCN include *Trichoderma harzianum, Plectosphaerella cucumerina*, and *Penicillium oxalicum* (Back *et al*. 2017).

The use of biological control agents such as *P. fluorescens* and *P. lilacinus* (Seenivasan *et al*. 2007), as well as organic amendments such as neem cake (5 t/ha) mixed with *T. viride* (5 kg/ha), resulted in a decrease in PCN population (Umamaheswari *et al.* 2012).

13.4 Conclusion:

Nematode management in potato crops has advanced greatly, incorporating innovative strategies to reduce the impact of these common pests. The most frequent nematode species affecting potatoes are root-knot nematodes (*Meloidogyne* spp.) and cyst nematodes (*Globodera* spp.), which cause significant yield losses worldwide. Traditional solutions, such as crop rotation and chemical nematicides, have been widely used, but they frequently fall short of sustainability and effectiveness. Recent improvements have emphasized integrated pest management (IPM) tactics that incorporate biological control, resistant cultivars, and precision agriculture technologies. The introduction of resistant potato types has proven to be one of the most efficient and environmentally benign methods for lowering nematode populations and eliminating the need for chemical interventions.

Breeding programs continue to focus on cultivars with broad-spectrum resistance, which is critical for nematode infestation management. Biological control treatments, such as nematophagous fungi and bacteria, are becoming increasingly popular as part of long-term worm management. These natural nematode enemies can be utilized into soil health management strategies to improve potato crop resilience. Furthermore, advances in molecular techniques enable the early detection and exact identification of nematode species, allowing for more targeted control strategies.

Precision agriculture, which includes the use of remote sensing and soil health monitoring, allows for the timely deployment of control measures, optimizes input use, and reduces environmental consequences. These technologies enable farmers to properly monitor worm populations and provide treatments as needed, resulting in more efficient and sustainable nematode management.

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