Prevalence and spread of potato cyst nematodes, *Globodera* spp. in northern hilly areas of India

Y. S. Chandel¹, Surendra Singh Bhadu², Rajan Salalia², Sharmishta Thakur¹, Satya Kumar³, Vishal Singh Somvanshi⁴, Abhishek Mukherjee⁵ and R. K. Walia⁶,*

¹CSK Himachal Pradesh Agricultural University, Palampur 176 062, India
²Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Jammu & Kashmir 180 009, India
³G.B. Pant University of Agriculture & Technology, Pantnagar 263 145, India
⁴Division of Nematology, ICAR-Indian Agricultural Research Institute, New Delhi 110 012, India
⁵Agriculture and Ecology Research Unit, Indian Statistical Institute, Giridih 815 301, India
⁶ICAR-All India Coordinated Research Project on Nematodes, Indian Agricultural Research Institute, New Delhi 110 012, India

**Potato cyst nematodes (PCNs), *Globodera rostochiensis* (Woll.) and *G. pallida* (Stone), are globally important pests of potato prevalent in the Nilgiri area of South India. PCNs were first intercepted from North India at Shimla, Himachal Pradesh (HP) in 2010. Subsequent surveys in the hilly areas of North India have revealed the occurrence of PCNs in several districts of HP, Uttarakhand and Jammu & Kashmir, despite domestic quarantine against this nematode. High populations of PCN were mainly encountered in the Potato Seed Multiplication Farms that supply seed potato to farmers. Here, a hypothesis on the dissemination of PCNs within India is proposed.**

**Keywords:** Domestic quarantine, hilly areas, potato cyst nematodes, prevalence and spread.

**Potato cyst nematodes (PCNs), *Globodera rostochiensis* and *G. pallida* are globally considered as important pests of potato. These are known to be prevalent in several countries across continents and are subjected to stringent quarantine and/or regulatory procedures, wherever they occur. PCNs present a severe threat to domestic and international commerce in potato. It is believed that PCN had their origin in the Andes Mountains of South America, which is the original home for potato¹. During the 1850s, PCNs were introduced into Europe along with the breeding materials brought for late blight resistance, from where they spread throughout the world through the introduction of improved varieties developed in Europe². PCNs probably spread from Europe to other countries with exported seed tubers or breeding materials³. John Sullivan, the founder of present-day Udhagamandalam (the Nilgiris, Tamil Nadu (TN), India), initially introduced potatoes to TN in 1822 (ref. 3), where PCNs were first reported⁴.

Subsequent surveys conducted in the Nilgiris revealed the widespread prevalence of PCNs in potato fields around Udhagamandalam⁵. In 1971, the Government of Madras, TN, enforced domestic quarantine in India to check further spread of PCNs within the country. Later, their occurrence was also reported from Kodaikanal hills (TN)⁶, the adjoining hills of Karnataka⁷, and Pazhathotam, Idukki district, Kerala⁸ bordering TN, indicating the possibility of spread by infested seed materials from the nearby Kodaikanal hills.

It is interesting to note the first presence of PCNs in hilly areas of Pakistan in 1980 (ref. 9), since the hilly States/Union Territories (UTs) of North India are adjacent to this geography. PCNs were intercepted in North India in the farm area of ICAR-Central Potato Research Institute (CPRI), Shimla, Himachal Pradesh (HP)¹⁰. Since CPRI Shimla is a nodal institution for the development of potato varieties/hybrids, lot of germplasm and seed material exchange takes place between the institution and other Central/State Government agencies mandated to work on potato in the country. The basic seed produced at the farms of CPRI is multiplied at different Potato Seed Multiplication Farms (PSMFs) of States/UTs, Departments of Agriculture (HP, Uttarakhand, Jammu & Kashmir (J&K)) for further distribution to farmers in these and other states of the country. So it is apprehended that PCNs might have got introduced into some new areas in North India that are conducive for their establishment and multiplication. Therefore, district-wise surveys were initiated under the aegis of ICAR-All India Coordinated Research Project on Nematodes in the three hilly States/UTs, namely, HP, J&K and Uttarakhand to earmark the areas infested with PCNs, with the ultimate aim of regulation and management of this nematode. The results of these surveys conducted during 2011–19 are presented in this article.
Materials and methods

**Survey**

Survey for PCNs was started in HP during 2011, immediately after their interception at CPRI, Shimla. The PSMFs were specifically targeted, since these are mandated to provide seed potato to farmers in their areas of jurisdiction. In J&K and Uttarakhand, the surveys were initiated during 2015 and 2016 respectively.

Surveys were mostly conducted during the *kharif* season, with the exception of some localities during autumn and *rabi* season in HP. Soil and root samples were collected randomly from the rhizosphere of the plants when the crop was nearing maturity, and cysts were easily visible on potato roots. The samples (200 cm³ soil each) were processed in the laboratory of the respective institutions. The soil samples were processed by sieving method and the residue collected over 60 mesh sieve was examined under a stereo zoom microscope. All the cysts from a sample were collected in a vial using a forceps or brush and their numbers counted.

**Identification**

Ten randomly picked cysts were processed for the preparation of vulval cones for preliminary identification of the species according to the characters included in the *EPPO Bulletin*.

The molecular identification of PCNs was performed on three populations from J&K, by mechanical crushing of 10 cysts from each population together and lysing them in 25 μl of molecular-grade water. Next, 25 μl of lysis buffer (0.2M NaCl + 0.2M Tris-HCl (pH 8.0) + 1% (v/v) β-mercaptoethanol + 800 μg/ml proteinase K) was added to the crushed cysts and incubated in a thermocycler at 65°C for 3 h with intermittent vortexing, followed by inactivation of proteinase K by incubation at 100°C for 5 min. Then 2 μl of the lysate (diluted 1 : 10) was used as DNA template in the PCR reaction using PCN species-specific primers (*G. rostochiensis*: forward 5-GCAAGCCCAGCTCAGCAAC-3, reverse 5-GAACATCAACCTCCTATCGG-3, and *G. pallida*: forward 5-TGTCCATTCTCCTCACCAG-3, reverse 5-CGGCTTCCCCAGTTTCG-3)13. The *G. pallida*-specific primers amplified a 798 bp DNA fragment, whereas *G. rostochiensis* amplified a 315 bp product13. The amplified PCR products were resolved on a 1.2% agarose gel and visualized in a gel-documentation system.

**Results**

**Himachal Pradesh**

Among 11 PSMFs surveyed in seven districts of HP, 9 were positive for the presence of PCN (Table 1 and Figure 1). In five of these farms, i.e. Umladwar, Kharapather (Shimla district), Khunna (Kullu district), Rajgunda (Kangra district), and Kamraha (Mandi district), the frequency of occurrence of PCNs in all the samples collected from each farm was 100% with mean density ranging from 23 to 516.6 cysts per 200 cm³ soil. In rest of the PSMFs, i.e. Khadrala (Shimla district), Phuladhar and Kheradhar (Mandi district), and Ahla (Chamba district), the frequency of occurrence ranged from 10% to 91.7% with the mean population ranging from 10.3 to 377.8 cysts per 200 cm³ of soil. In two PSMFs, i.e. Shilaroo (Shimla district) and Darang (Lahaul and Spiti district) from where 40 and 15 samples respectively, were analysed, all the samples were found to be free from cysts of PCN.

From the farmers’ fields, PCN cysts were found in seven locations, all in Shimla district. The frequency of occurrence ranged between 75% and 100% and mean density ranged from 16 to 277.4 cysts/200 cm³ of soil. It was observed that PCNs were prevalent only in locations at elevations more than 1950 m amsl. PCNs were not recorded from autumn or spring season crops both in the soil and in the roots. Autumn and spring season potato crops are grown in low and mid-hills of Una (less than 500 m amsl) and Kangra (mostly less than 1000 m amsl); perhaps PCNs do not establish in these areas due to relatively higher temperature.

**Jammu & Kashmir**

In Jammu division, a large and old PSMF at Nathatop (Udhampur district) was heavily infested (Table 2 and Figure 1).
### Table 1. Survey results for the occurrence of *Globodera* spp. in potato in Himachal Pradesh, India

| District | Locality | Elevation (m amsl) | Latitude | Longitude | Number of samples | Frequency (%) | No. of cysts/200 cm$^3$ soil |
|----------|----------|--------------------|----------|-----------|-------------------|---------------|----------------------------|
| Shimla   | Shilaroo* | 2525               | N31.12290| E77.25450 | 40                | Not recorded  |                           |
|          | Sarapani | 2700               | N31.18588| E77.41196 | 3                 | 100.00        | 28.0 (22–34)              |
|          | Kharapani| 2750               | N31.18077| E77.40416 | 3                 | 100.00        | 16.0 (10–22)              |
|          | Kheni    | 2080               | N31.11666| E77.38139 | 3                 | Not recorded  |                           |
|          | Khadrala | 2687               | N31.12194| E77.35255 | 8                 | 75.00         | 26.8 (18–46)              |
|          | Khadrala*| 2765               | N31.16194| E77.39025 | 12                | 91.67         | 377.8 (8–1830)            |
|          | Tootupani| 2881               | N31.15672| E77.37042 | 5                 | 80.00         | 277.4 (140–370)           |
|          | Umladwar*| 2798               | N31.13186| E77.34943 | 4                 | 100.00        | 77.4 (52–96)              |
|          | Hanstari Teer | 2772   | N31.11544| E77.35431 | 3                 | 100.00        | 260.0 (90–430)            |
|          | Ponidhar | 2715               | N31.11067| E77.35741 | 3                 | 100.00        | 63.0 (256–270)            |
|          | Kharapathar*| 2700       | N31.06492| E77.37843 | 7                 | 100.00        | 347.6 (150–776)           |
|          | Ghorna   | 2237               | N31.07276| E77.15237 | 3                 | Not recorded  |                           |
|          | Deorighat| 2694               | N31.10136| E77.36971 | 7                 | 100.00        | 260.4 (20–824)            |
|          | Sirmour  | Kheradhar*         | 2032     | N30.50055| E77.09235 | 30              | 10.00         | 166.0 (6–284)             |
|          | Mandi    | Phuladhar*         | 2425     | N31.57747| E76.25243 | 15              | 80.00         | 32.0 (4–140)              |
|          | Kamraha  | 1965               | N31.49300| E77.55833 | 3                 | 100.00        | 516.6 (410–610)           |
| Chamba   | Barot    | 1829               | N32.49433| E76.72863 | 7                 | Not recorded  |                           |
| Kullu    | Ahla*    | 2232               | N31.57747| E76.00257 | 64                | 54.69         | 176.2 (2–560)             |
| Una      | Khunna*  | 3200               | N31.43550| E77.41710 | 10                | 100.00        | 65.1 (2–166)              |
|          | Jhalara  | 389                | N32.91933| E76.67433 | 4                 | Not recorded  |                           |
|          | Oel      | 437                | N31.72800| E76.59283 | 10                | Not recorded  |                           |
|          | Ram Nagar| 380                | N31.55750| E76.42316 | 5                 | Not recorded  |                           |
|          | Luhari   | 397                | N31.32946| E76.93240 | 2                 | Not recorded  |                           |
|          | Panjawar | 397                | N31.32946| E76.93240 | 4                 | Not recorded  |                           |
|          | Haroli   | 387                | N31.29274| E76.10543 | 3                 | Not recorded  |                           |
|          | Jhalara  | 363                | N31.28804| E76.13258 | 3                 | Not recorded  |                           |
|          | Rampur   | 382                | N31.57850| E76.51583 | 3                 | Not recorded  |                           |
|          | Santoshgarh | 374      | N31.21966| E76.19650 | 6                 | Not recorded  |                           |
| Kangra   | Malan    | 971                | N32.71370| E76.25306 | 25                | Not recorded  |                           |
|          | Gadiara  | 925                | N32.73200| E76.24131 | 12                | Not recorded  |                           |
|          | Rajgundu*| 2530               | N32.50683| E77.55566 | 14                | 100.00        | 154.6 (130–190)           |
| Lahaul & Spiti | Dalang* | 3045               | N32.5166 | E77.0147  | 15                | Not recorded  |                           |
|          | Jispa    | 3200               | N32.0806 | E77.0603  | 3                 | Not recorded  |                           |
|          | Trilokinath | 2760        | N32.6646 | E76.7085  | 1                 | Not recorded  |                           |
|          | Kishore  | 4650               | N32.6647 | E76.7086  | 5                 | Not recorded  |                           |
|          | Udaipur  | 2742               | N32.7236 | E76.6644  | 5                 | Not recorded  |                           |
|          | Shuiling | 389                | N32.4750 | E77.0801  | 4                 | Not recorded  |                           |
|          | Gemur    | 3200               | N32.6115 | E77.1463  | 5                 | Not recorded  |                           |
|          | Tinno    | 3200               | N32.5805 | E77.1305  | 3                 | Not recorded  |                           |
|          | Cheling  | 4420               | N32.5616 | E77.0514  | 2                 | Not recorded  |                           |
|          | Baring   | 1189               | N32.5242 | E77.0280  | 2                 | Not recorded  |                           |
|          | Karpat   | 1189               | N32.8028 | E76.7726  | 10                | Not recorded  |                           |
|          | Darcha   | 3360               | N32.6779 | E77.1950  | 4                 | Not recorded  |                           |
|          | Mooring  | 1189               | N32.6512 | E76.8171  | 2                 | Not recorded  |                           |

*Potato Seed Multiplication Farms (PSMFs) of the Department of Agriculture, Himachal Pradesh.

Figure 1). Samples were collected from all the three blocks of this farm, and the cyst population ranged from 36 to 1565 (mean 411.2 cysts) per 200 cm$^3$ of soil. All the nine samples from this location were infested with PCNs. Another PSMF located at Kandi Buddhal in Rajouri district of Jammu division also revealed the prevalence of PCNs with 124 cysts per 200 cm$^3$ of soil. The Ishkunda and Narsingha farms located at Gool in Ramban district recorded a mean population of 60.4 and 232.5 *Globodera* cysts per 200 cm$^3$ of soil respectively. Several samples collected from farmers’ fields in the Jammu division (<2000 m amsl) contained either only empty cysts or no cysts of PCN. In the Kashmir valley, only a limited survey could be conducted. Samples collected from PSMF at Sedew in Shopian district revealed 100% frequency of occurrence with cyst population ranging between 30 and 409 (mean 241 cysts) per 200 cm$^3$ of soil. The samples collected from PSMF and farmers’ fields located in Baramula district from the valley were free from PCNs.

**Uttarakhand**

Pithoragarh district in Uttarakhand is located at a relatively higher altitude. Two old PSMFs at Balati and
Table 2. Survey results for the occurrence of *Globodera* spp. in potato in Jammu & Kashmir (J&K), India

| District          | Locality               | Elevation (m amsl) | Latitude   | Longitude   | No. of samples | Frequency (%) | No. of cysts/200 cm³ soil |
|-------------------|------------------------|--------------------|------------|-------------|----------------|---------------|--------------------------|
| Ramban            | Gool, Ishkunda*        | 2023               | N33.28193  | E74.99077   | 5              | 100           | 60.4 (10–172)            |
|                   | Gool, Narsingha*       | 1981               | N33.28193  | E74.98715   | 4              | 100           | 232.5 (70–420)           |
| Ramban            | Sanasar                | 2247               | N33.12481  | E75.24980   | 3              | Not recorded  |                         |
| Udhampur          | Nathatop*              | 2551               | N33.09349  | E75.26447   | 9              | 100           | 411.2 (36–1565)          |
|                   | Marothi, Chenani       | 1786               | N32.940105 | E75.417191  | 1              | 8 empty       |                         |
|                   |                        | 1720               | N32.939650 | E75.416096  | 1              | 7 empty       |                         |
|                   | Bupp, Chenani          | 1760               | N32.939260 | E75.349963  | 1              | 9 empty       |                         |
|                   | Lower Madha, Chenani   | 1820               | N32.953146 | E75.350434  | 1              | 5 empty       |                         |
|                   |                        | 1900               | N33.001306 | E75.273719  | 1              | 6 empty       |                         |
|                   | Panchayat Meer, Chenani| 1810               | N33.036312 | E75.124074  | 1              | 6 empty       |                         |
|                   | Panchuri               | 1650               | N33.030393 | E75.118265  | 1              | 4 empty       |                         |
|                   | Pancheri               | 1728               | N32.89004  | E75.48718   | 3              | Not recorded  |                         |
|                   |                        | 1750               | N33.222420 | E75.690996  | 1              | 6 empty       |                         |
|                   |                        | 1650               | N33.022066 | E75.690765  | 1              | 5 empty       |                         |
|                   |                        | 2320               | N33.88447  | E74.3563    | 2              | 100           | 8 (6–10)                 |
| Udhampur          | Chattri Majouri Ram Nagar | 1780           | N32.816272 | E75.485968  | 1              | Not recorded  |                         |
|                   |                        | 1730               | N33.89004  | E75.48718   | 3              | Not recorded  |                         |
|                   |                        | 1650               | N33.022420 | E75.690996  | 1              | 6 empty       |                         |
|                   |                        | 1650               | N33.022066 | E75.690765  | 1              | 5 empty       |                         |
|                       |                        | 2320               | N33.88447  | E74.3563    | 2              | 100           | 8 (6–10)                 |
| Kishtwar           | Yeerdu                 | 3100               | N33.686750 | E75.667735  | 1              | Not recorded  |                         |
| Rajouri            | Kandi Budhal*          | 2020               | N33.390463 | E74.526684  | 1              | 100           | 124                      |
|                   |                        | 1970               | N33.37320  | E74.6382    | 1              | 100           | 10                       |
|                   | Rajnagar Budhal        | 1650               | N33.3512   | E74.6228    | 1              | 100           | 115                      |
|                   | Ghondha Budhal         | 1780               | N33.3713   | E74.6348    | 1              | 100           | 24                       |
|                   | Ghondha Budhal         | 1600               | N33.3521   | E74.6281    | 1              | 100           | 6                        |
|                   | Lower Gulthi           | 1420               | N33.3041   | E74.1668    | 1              | 100           | 2                        |
|                   |                        | 1500               | N33.29287  | E74.1622    | 1              | 100           | 7                        |
|                   | Lower Rajdheri         | 1570               | N33.547526 | E74.33353   | 1              | 100           | 5                        |
| Shopian            | Sedew*                 | 2240               | N33.665439 | E74.798126  | 5              | 100           | 241 (30–409)             |
| Ganderbal         | Haripora               | 1800               | N34.289792 | E74.835906  | 2              | Not recorded  |                         |
| Baramula          | Tangmarg               | 2080               | N34.068197 | E74.436221  | 3              | Not recorded  |                         |
| Baramula          | Yari khal-Tangmarg road| 2200               | N33.575530 | E74.939282  | 1              | Not recorded  |                         |
| Baramula          | Rafiabad*              | 1600               | N34.253893 | E74.390012  | 7              | Not recorded  |                         |

*PSMFs of the Department of Agriculture, J&K.

Toksain in Munsiyari tehsil harboured high populations of 68 and 94 cysts per 200 cm³ of soil respectively (Table 3 and Figure 1). Data from Pithoragarh district showed that many farmers’ fields also recorded both full and empty cysts of PCN. In such cases with a few exceptions, most of the locations with full cysts were at more than 2000 m amsl, while those located below this elevation contained only empty cysts. In Champawat district, no incidence of PCNs was recorded and all the sampled locations were below 2000 m amsl, except one at Devidhura Pati (2045 m amsl) that contained four full cysts. Four farmers’ field locations in Nainital district (all >2000 m amsl) contained a few full as well as empty cysts.

**Identification**

Fourteen populations were assigned species on the basis of cone morphology characteristics. All the PCN populations from Shimla and Mandi (HP), and two populations each from Pithoragarh (Uttarakhand) and Nathatop (J&K) were identified as *G. rostochiensis*. Three populations, i.e. one each from Shopian (Kashmir), and Chamba
| District/(tehsil) | Village       | Elevation (m amsl) | Latitude   | Longitude  | No. of samples | Frequency of full cyst (%) | No. of cysts/200 cm$^3$ soil | Mean (range) |
|------------------|---------------|--------------------|------------|------------|-----------------|--------------------------|----------------------------|--------------|
| Pithoragarh      | Dor           | N30.007257          | E80.146352 | 3          | 0               | 0                        | 18                         |
|                  | Banik         | N30.034429          | E80.183950 | 3          | 67              | 2 (0–3)                  | 18                         |
|                  | Ratapani      | N30.037434          | E80.193402 | 3          | 100             | 22 (20–25)               | 18                         |
|                  | Nai Basti Bunga| N30.068087          | E80.235079 | 3          | 100             | 11 (10–20)               | 4                          |
|                  | Tiksen Farm*  | N30.068041          | E80.234976 | 3          | 100             | 95 (85–99)               | 0                          |
|                  | Balati Farm*  | N30.063150          | E80.204044 | 3          | 100             | 68 (55–82)               | 0                          |
|                  | Sarmoli       | N30.078902          | E80.237441 | 3          | 67              | 4 (0–7)                  | 18                         |
|                  | Jalat         | –                  | –          | –          | 3               | 0                        | 0                          |
|                  | Darkot        | 1825 N30.097913     | E80.247950 | 3          | 0               | 6                        | 0                          |
|                  | Dhapa         | 1826 N30.114413     | E80.241125 | 3          | 0               | 0                        | 18                         |
|                  | Syangti       | –                  | –          | –          | 3               | 2                        | 0                          |
|                  | Darkot        | 1798 N30.097882     | E80.247022 | 3          | 0               | 8                        | 0                          |
|                  | Jaiti gaon    | 1713 N30.078839     | E80.242926 | 3          | 100             | 8 (3–16)                 | 18                         |
|                  | Dalot         | –                  | –          | –          | 3               | 0                        | Not recorded               |
|                  | Dalot         | –                  | –          | –          | 3               | 0                        | Not recorded               |
|                  | Mallagorbhatta| –                  | –          | –          | 3               | 0                        | Not recorded               |
|                  | Tallagorbhatta| –                  | –          | –          | 3               | 0                        | Not recorded               |
| Champawat        | KVK Lohaghat  | 1718 N30.41685      | E80.072054 | 3          | 0               | Not recorded              | 0                          |
|                  | Patan         | 1895 N30.4215       | E80.0879   | 3          | 0               | Not recorded              | 0                          |
|                  | Suichaube     | 1732 N30.418349     | E80.062274 | 3          | 0               | Not recorded              | 0                          |
|                  | Chaura dhek   | 1696 N30.406988     | E80.062596 | 3          | 0               | Not recorded              | 0                          |
|                  | Koli dhek     | 1716 N30.403828     | E80.048776 | 3          | 0               | Not recorded              | 0                          |
|                  | Tak           | 1729 N30.401227     | E80.043211 | 3          | 0               | Not recorded              | 0                          |
|                  | Serakhal      | 1143 N30.012304     | E80.321062 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Baram         | 826 N30.850992      | E80.354925 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Tiksen Farm*  | 1718 N30.41685      | E80.072054 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Pati          | 1654 N30.406676     | E80.941711 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Dhanuj        | 1744 N30.415099     | E80.891503 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Dhanaj        | 1807 N30.414915     | E80.890398 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Valik         | 1890 N30.413593     | E79.880912 | 3          | 0               | Not recorded              | 0                          |
| Champawat        | Devidhura     | 2045 N30.414906     | E79.868404 | 3          | 67              | 4 (0–9)                  | 10                         |
| Champawat        | Vaka          | 1452 N30.417409     | E79.848537 | 3          | 0               | Not recorded              | 0                          |
| Nainital         | Vedchula      | 1994 N30.427531     | E79.819525 | 3          | 0               | Not recorded              | 0                          |
| Nainital         | Vedchula-II   | 1993 N30.427487     | E79.814732 | 3          | 100             | 5 (3–9)                  | 0                          |
| Nainital         | Vedchula      | 1993 N30.427487     | E79.814732 | 3          | 100             | 5 (3–9)                  | 0                          |
| Nainital         | Sarphatak     | 2151 N30.458359     | E79.764154 | 3          | 33              | 4 (0–12)                 | 0                          |
| Nainital         | Anarpa        | 2202 N30.458135     | E79.719218 | 3          | 0               | Not recorded              | 0                          |
| Nainital         | Shelailek     | 2105 N30.430666     | E79.717072 | 3          | 100             | 10 (7–14)                | 0                          |
| Nainital         | Pahadpani     | 2129 N30.427162     | E79.709748 | 3          | 0               | 0                        | 0                          |
| Nainital         | Chaulekha     | 2097 N30.405804     | E79.691567 | 3          | 67              | 8 (0–16)                 | 0                          |
| Nainital         | Managher      | 2221 N30.396940     | E79.680522 | 3          | 0               | Not recorded              | 0                          |
| Nainital         | Dhunachuli    | 2167 N30.397293     | E79.665423 | 3          | 0               | Not recorded              | 0                          |

*PSMFs of the Department of Agriculture, Uttarakhand.
Table 4. Identification of selected populations of potato cyst nematodes in North India

| Population          | G. pallida (798 bp) | G. rostochiensis (315 bp) | Inference                      | Cone-top morphology | Inference                      |
|---------------------|---------------------|---------------------------|--------------------------------|---------------------|--------------------------------|
| J&K Udhampur Nathatop | +                   | +                         | G. pallida, G. rostochiensis   | G. rostochiensis    |
| J&K Rajouri, Kandi Budhal | –                   | +                         | G. rostochiensis              | –                   |
| J&K Shopian Sedew    | +                   | +                         | G. pallida, G. rostochiensis   | G. rostochiensis    |
| UK Pithoragarh Balati | –                   | –                         | G. rostochiensis              | –                   |
| UK Pithoragarh Tiksen | –                   | –                         | G. rostochiensis              | –                   |
| HP Shimla Khadrala   | –                   | –                         | G. rostochiensis              | –                   |
| HP Shimla Umladwar   | –                   | –                         | G. rostochiensis              | –                   |
| HP Chamba Alha       | –                   | –                         | G. pallida                    | –                   |
| HP Sirmour Kheradhar | –                   | –                         | G. pallida                    | –                   |
| HP Kullu Chowai      | –                   | –                         | G. pallida                    | –                   |
| HP Shimla Poonidhar  | –                   | –                         | G. rostochiensis              | –                   |
| HP Mandi Phuladhar   | –                   | –                         | G. rostochiensis              | –                   |
| HP Shimla Kharapathar| –                   | –                         | G. rostochiensis              | –                   |
| HP Shimla Deorighat  | –                   | –                         | G. rostochiensis              | –                   |
| HP Shimla Tootupani  | –                   | –                         | G. rostochiensis              | –                   |

J&K, Jammu & Kashmir; UK, Uttarakhand; HP, Himachal Pradesh. +, Present; –, Absent.

and Sirmour (HP) revealed mixed populations of G. pallida and G. rostochiensis (Table 4).

Only two populations from J&K and one from Uttarakhand were subjected to molecular characterization. Cysts from Nathatop, Rajouri and Shopian (J&K) were tested by species-specific primers for G. pallida and G. rostochiensis. The Nathatop and Shopian populations showed the presence of both 798 and a 315 bp amplicons, and were positive for both G. pallida and G. rostochiensis. However, the Rajouri population showed the presence of only a 315 bp amplicon, suggesting that only G. rostochiensis cysts were present in samples collected from the region.

Discussion

Considering the present scenario on the distribution of PCNs in the three hilly states/UTs of North India emanating from our surveys, some general inferences can be drawn.

(i) High populations of PCN were recorded at PSMFs; this may be due to continuous cropping of potato in these farms. Circumstantial evidence reveals the nematodes must have been introduced long ago, but due to non-specific above-ground symptoms and lack of awareness, they could not be detected earlier.

(ii) PSMFs may be contributing towards dissemination of PCNs to farmers’ fields, which is clearly discernible in Figure 1, but the low populations in PCN-conducive areas could be due to discontinuous cultivation of potato crop.

(iii) Populations of PCN at lower altitudes (~2000 m amsl) may be G. pallida, wherever full cysts were encountered. The interception of empty cysts in such locations may be due to unfavourable temperatures. The identity of species, however, needs to be confirmed.

(iv) PCN incidence has been recorded only from kharif potato; the autumn and spring season potato crops are grown under low-altitude conditions, not favourable for nematode multiplication.

The distribution pattern of PCNs in the northern hilly States/UTs in India vis-à-vis southern India (the Nilgiris) shows contrasting patterns. While in the Nilgiris, most of the fields are infested harbouring high cyst populations, the same is not valid in the north where such high populations are witnessed mostly in the PSMFs (Figure 1). This leads us to assume that PCNs might have been introduced to the northern hilly states from the south much before the domestic quarantine regulations were enforced against them in 1971. Homologies on the identity of populations from the two geographies through molecular tools can throw light on this. Figure 2 depicts the possible dissemination of PCNs within India.

In view of the economic importance of the nematode and its quarantine importance, the interception of PCNs, particularly in PSMFs, became the main focus of research. AICRP immediately took up the matter with the
Ministry of Agriculture, Government of India (R. K. Walia, pers. commun.). The Ministry took swift action and besides other measures to contain PCNs, imposed restrictions on the movement of seed potato from these areas to other parts of the country vide Gazette notifications dated 12 October 2018 and 2 November 2018.

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