

# CHARACTERIZATION OF POTATO GERMPLASM FOR RESISTANCE TO *GLOBODERA PALLIDA* AND *GLOBODERA ROSTOCHIENSIS*: A STRATEGIC APPROACH TO SUSTAINABLE POTATO PRODUCTION

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**ABSTRACT:** This study evaluates the resistance of 406 potato accessions across different years to potato cyst nematodes (PCNs), *Globodera pallida* and *G. rostochiensis*, a major pest that significantly reduce potato yields. The screening was conducted using a root ball technique in controlled glasshouse conditions over four years (2020-2024) at the ICAR-Central Potato Research Institute (ICAR-CPRI) in Kufri, India. The results revealed a wide range of resistance among the accessions. Notably, accessions such as CP2418, CP1736, CP3641, and JEX/A-15 exhibited high levels of resistance to both PCN species, which showed either immunity or minimal cyst formation. Additionally, accessions such as CP1687 and CP3222 demonstrated moderate resistance. All these highly resistant accessions are potential candidates in breeding for resistance to potato cyst nematode in India. Since major Indian potato varieties used in the current study are susceptible to one or the other species of PCN, the study highlights the importance of continuous screening and the strategic use of resistant germplasm to develop new potato varieties with broad-spectrum resistance, which is crucial for sustainable potato production.

**KEYWORDS:** Potato cyst nematodes, *Globodera pallida*, *Globodera rostochiensis*, resistance, germplasm, susceptibility.

## INTRODUCTION

Potatoes are an essential global food crop, rich in carbohydrates, protein, vitamins, and dietary fiber (Spsychalla and De Jong 2024). In India, it holds significant agricultural importance, being the second-largest producer worldwide. However, potato cultivation is significantly hindered by various plant pathogens, notably potato cyst nematodes (PCN), which represent a substantial production constraint in both developing nations and globally (Sood *et al.* 2023). Potato cyst nematodes are considered

quarantine pests in many countries, including India (Mhatre *et al.* 2019). It comprises two species, *Globodera rostochiensis* and *G. pallida*, and is a significant pest of potato, which causes yield losses ranging from 20% to 70%, if left uncontrolled (Asano *et al.* 2012). These nematodes are soil-inhabiting parasites that attack the roots of solanaceous plants, with five pathotypes identified for *G. rostochiensis* (Ro1 to Ro5) and three for *G. pallida* (Pa1 to Pa3) (Bairwa *et al.* 2023; Mangal *et al.* 2022, 2023, 2025).

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They attack plant roots and form cysts, severely impairing the host plant's ability to uptake essential nutrients and water (Faggian *et al.* 2012). These nematodes are particularly challenging due to their ability to survive in soil for over 20-30 years as dormant cysts (Bachmann-Pfabe *et al.* 2019; Perry 2002).

Potato cyst nematodes have been extensively studied due to their widespread impact on potato production, and genetic resistance has been identified as a crucial strategy to manage these pests effectively (Schultz *et al.* 2012). Traditional control methods, such as long-term crop rotation and pesticide use, are either expensive or environmentally hazardous, which emphasizes the need for breeding resistant varieties (Brodie *et al.* 1991). The genetic diversity present in the different species of potato offers valuable sources of resistance that can be introgressed into commercial cultivars (Gavrilenko *et al.* 2021). For instance, resistance to *G. rostochiensis* has been widely studied and utilized in breeding programs. However, resistance to *G. pallida* is more complex, often involves multiple genes and quantitative trait loci (QTLs) (Gartner 2023). Genetic sources of resistance to this pest exist among various wild and cultivated potatoes (de Jong *et al.* 2001). Both *G. rostochiensis* and *G. pallida* are recognized as quarantine pests, and their management involves strict regulatory measures and concerted research efforts to develop resistant potato cultivars. Breeding for resistance to PCN is a critical component of integrated pest management strategies (Dandurand *et al.* 2019).

The genetic resources or germplasm are crucial for breeding programs aimed at producing nematode-resistant potato varieties, thereby improving crop resilience and productivity (Bradshaw and Ramsay 2005). Host resistance remains a crucial strategy for managing *Globodera* spp. The

*H1* gene provides complete resistance to *G. rostochiensis* pathotypes *Ro1* and *Ro4* and has been successfully introgressed into many commercial cultivars. The first commercial potato cultivar resistant to *G. rostochiensis*, Maris Piper, was registered in 1967. However, with the identification of *G. pallida* as a second PCN species in 1973, subsequent efforts have focused on finding resistance to this species as well (Castelli *et al.* 2003). However, resistance to *G. pallida* is less developed, being polygenic and involves multiple genes that act additively to confer higher resistance levels (Whitworth *et al.* 2018).

Therefore, this study aims to screen diverse potato germplasm and parental lines for resistance to *G. pallida* and *G. rostochiensis*. The goal is to identify new resistant sources to both the species of PCN for the development of new resistant cultivars suitable for the Indian market.

## MATERIAL AND METHODS

In the present investigation, a total of 406 diverse germplasm accessions (Table 1) were tested for resistance to potato cyst nematodes (PCN) using the root ball technique in pots under glasshouse conditions at Kufri. These accessions consisted of germplasm imported from different countries, released Indian varieties, exotic varieties, andigena accessions and advanced breeding clones. The material included in the study is conserved in the National Active Germplasm Repository at CPRI, Shimla and part of the material in field genebank at Jalandhar and Kufri. Potato cyst nematode susceptible varieties i.e. Kufri Jyoti, Kufri Girdhari, Kufri Himalini were used as susceptible checks during all the years. Five tubers from each accession were planted in 15cm diameter earthen pots, with temperature maintained at 20-22°C. The experiment was conducted in three replications over four years (2020-21, 2021-22, 2022-23 & 2023-24).

Table 1. Cultivars and germplasm accessions used for screening

S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name
1	CP658	60	JEXA215	119	CP2010	178	CP3903	237	CP1974	296	CP1431	355	CP3636
2	Kufri Luvkar	61	JEXA202	120	CP1932	179	CP4224	238	CP1971	297	CP1428	356	CP3247
3	CP1263	62	JEXA197	121	CP1824	180	CP4368	239	CP1926	298	CP1427	357	CP3203
4	CP1218	63	JEXA164	122	CP1571	181	CP4398	240	CP1922	299	CP1426	358	CP2089
5	CP1159	64	JEXA1152	123	CP1420	182	JEXA947	241	CP1889	300	CP1418	359	CP2280
6	CP1140	65	Kufri Anand	124	CP1038	183	JEXA920	242	CP1881	301	CP1414	360	CP2350
7	Kufri Swarna	66	JEXA1092	125	Kufri Sangam	184	JEXA865	243	CP1873	302	CP1411	361	CP2348
8	Kufri Surya	67	JEXA1046	126	JEX-A708	185	JEXA801	244	CP1871	303	CP1402	362	CP2346
9	Kufri Sindhuri	68	JEXA10	127	JEXA26	186	JEXA79	245	CP1869	304	CP1399	363	CP2339
10	Kufri Sadabahar	69	CP4316	128	JEXA918	187	JEXA705	246	CP1854	305	CP2049	364	CP2338
11	Kufri Pushkar	70	CP4311	129	CP1175	188	JEXA683	247	CP1846	306	CP2086	365	CP2336
12	Kufri Megha	71	CP4256	130	CP1242	189	JEXA597	248	CP1833	307	CP3939	366	CP2335
13	Kufri Khyati	72	CP4254	131	CP3896	190	JEXA506	249	CP1806	308	CP3412	367	CP2324
14	Kufri Ashoka	73	CP4242	132	CP3783	191	JEXA45	250	CP1800	309	CP3588	368	CP2292
15	Kufri Kanchan	74	CP4226	133	CP3585	192	JEXA296	251	CP1784	310	CP3587	369	CP2284
16	Kufri Jyoti	75	CP4214	134	CP3529	193	JEXA267	252	CP1771	311	CP3579	370	CP2235
17	Kufri Himalini	76	JEXA316	135	CP3261	194	JEXA22	253	CP1764	312	CP3575	371	CP3201
18	Kufri Girdhari	77	JEXA317	136	CP3182	195	JEXA198	254	CP1544	313	CP3506	372	CP2189
19	Kufri Gaurav	78	JEXA329	137	CP2639	196	JEXA19	255	CP1533	314	CP3505	373	CP2171
20	Kufri Frysona	79	JEXA379	138	CP2283	197	JEXA1081	256	CP2059	315	CP3502	374	CP2167
21	Kufri Chipsona3	80	JEXA93	139	CP2065	198	JEXA1016	257	CP1235	316	CP3486	375	CP2163
22	Kufri Chipsona1	81	JEXA912	140	CP2048	199	CP655	258	CP1367	317	CP3475	376	CP2148
23	Kufri Chandramukhi	82	JEXA907	141	CP1988	200	CP4596	259	CP1348	318	CP3442	377	CP2142
24	Kufri Bahar	83	JEXA877	142	CP1884	201	CP4594	260	CP1335	319	CP3387	378	CP2118
25	CP1326	84	JEXA827	143	CP1864	202	CP4433	261	CP1330	320	CP3222	379	CP2110
26	CP1347	85	JEXA804	144	CP1835	203	CP4179	262	CP1325	321	CP3363	380	CP2093
27	CP1480	86	JEXA763	145	CP1802	204	CP4096	263	CP1319	322	CP3352	381	CP2090
28	CP1564	87	JEXA707	146	CP1767	205	CP659	264	CP1304	323	CP3338	382	CP2354
29	CP2368	88	JEXA668	147	CP1667	206	CP1646	265	CP1302	324	CP3334	383	CP2370
30	CP2347	89	JEXA638	148	CP1662	207	CP1711	266	CP1291	325	CP3329	384	CP2381
31	CP2224	90	JEXA612	149	CP1559	208	CP1710	267	CP1246	326	CP3328	385	CP2385
32	CP2183	91	JEXA595	150	CP1486	209	CP1706	268	CP1225	327	CP3318	386	CP3192
33	CP2149	92	JEXA58	151	CP1442	210	CP1688	269	CP1529	328	CP3295	387	CP3180
34	CP2134	93	JEXA539	152	Kufri Karan	211	CP1687	270	CP1215	329	CP3290	388	CP3153
35	CP2071	94	JEXA513	153	Kufri Deva	212	CP1685	271	CP1202	330	CP3256	389	CP3145
36	CP2061	95	JEXA498	154	CP3183	213	CP1672	272	CP1187	331	CP3602	390	CP3142
37	CP2029	96	JEXA459	155	CP3679	214	CP1664	273	CP1177	332	CP3625	391	CP3124
38	CP1918	97	JEXA457	156	CP3901	215	CP1659	274	CP1157	333	CP3626	392	CP3116

S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name	S. No.	Accession Name		
39	CP1868	98	JEXA42	157	CP3894	216	CP1653	275	CP1151	334	CP3634	393	CP3103
40	CP1829	99	JEXA390	158	CP3881	217	CP1642	276	CP1143	335	CP3917	394	CP3102
41	CP1827	100	JEXA380	159	CP3880	218	CP1538	277	CP1137	336	CP3898	395	CP3096
42	CP1747	101	CP2390	160	CP3853	219	CP1633	278	CP1120	337	CP3891	396	CP3091
43	CP1735	102	CP3098	161	CP3816	220	CP1616	279	CP1012	338	CP3871	397	CP3081
44	CP1700	103	CP4149	162	CP3796	221	CP1602	280	CP1368	339	CP3847	398	CP3079
45	CP1693	104	CP3173	163	CP3788	222	CP1597	281	CP1379	340	CP3809	399	CP3068
46	CP1689	105	CP4052	164	CP3763	223	CP1588	282	CP1390	341	CP3799	400	CP3036
47	CP1674	106	CP3893	165	CP3715	224	CP1584	283	CP1395	342	CP3797	401	CP2927
48	CP1673	107	CP3885	166	CP3652	225	CP1581	284	CP1491	343	CP3795	402	CP2418
49	CP1619	108	CP3738	167	JEXA99	226	CP1555	285	CP1479	344	CP3792	403	CP2413
50	Kufri Badshah	109	CP3632	168	CP3600	227	CP1553	286	CP1470	345	CP3768	404	CP2412
51	Kufri Arun	110	CP3491	169	CP3577	228	CP1545	287	CP1468	346	CP3761	405	CP2409
52	CP2397	111	CP3414	170	CP3549	229	CP1730	288	CP1462	347	CP3718	406	CP2399
53	JEXA15	112	CP3296	171	CP3527	230	CP1736	289	CP1454	348	CP3696		
54	JEXA30	113	CP3274	172	CP3525	231	CP1749	290	CP1453	349	CP3690		
55	JEXA299	114	CP3246	173	CP3439	232	CP1753	291	CP1450	350	CP3681		
56	JEXA298	115	CP3044	174	CP3362	233	CP2030	292	CP1447	351	CP3651		
57	JEXA288	116	Kufri Frysona	175	CP3343	234	CP1990	293	CP1440	352	CP3646		
58	JEXA275	117	CP2285	176	CP3211	235	CP1989	294	CP1435	353	CP3641		
59	JEXA232	118	CP2165	177	CP3189	236	CP1982	295	CP1433	354	CP3639		

In different years, the number of accessions varied due to availability of potato tubers.

The planting soil was mixed with FYM and inoculated with approximate 250-300 cysts (mixed population of *G. pallida* and *G. rostochiensis*) per 100 cc soil, which resulted in approximately 8,000-10,000 eggs and juveniles per test tuber. The volume of planting soil was 650 gm per pot. After 55-60 days, once females were visible on the root balls of the susceptible control plants, the number of females on the root balls of each accession were recorded. Figure 5 demonstrates the root ball of a potato plant, which shows varying resistance and susceptibility to *G. pallida* and *G. rostochiensis* across different accessions. The colour of the developing females was used to distinguish between the two *Globodera* species. *G. rostochiensis* females were distinguished

based on golden yellow colour and *G. pallida* females were characterized based on white/pale colour (Krishna Prasad, 2006). Based on the PCN population the accessions were grouped under 0-4 grade. Immune (0 female/root ball), highly resistant (1-5 females/root ball), resistant (6-20 females/root ball), susceptible (21-50 females/root ball), and highly susceptible accession (>50 females/root ball), following established guidelines (Krishna Prasad, 2006). The ideal resistance level is defined as grade 0-1 (Table 2)

## RESULT AND DISCUSSION

The study assessed the resistance of various potato accessions to *G. rostochiensis* (GR) and *G. pallida* (GP) by counting the number of female cysts per plant from the root ball and subsequently converting these counts into a

**Table 2. Grading Scale for Potato Cyst Nematode (PCN) Resistance**

Grade	Females/root ball	Category
0	None	Immune
1	1-5	Highly Resistant
2	6-20	Moderately Resistant
3	21-50	Susceptible
4	>50	Highly susceptible

0 to 4 grading scale, categorizing them from immune to highly susceptible. The screening results have been presented year wise, with a detailed explanation of the findings.

**Screening Outcomes for the year 2020-21**

The study evaluated the resistance of 275 potato accessions to both PCN species during the year 2020-21 (Table 3). For GR, 21 accessions were immune (Grade 0), 19 were highly resistant (HR, Grade 1), 32 were moderately resistant (MR, Grade 2), 70 were susceptible (S, Grade 3), and 133 were highly susceptible (HS, Grade 4) (Fig 2). For GP, 16 accessions were immune (Grade 0), 8 were highly resistant (HR, Grade 1), 42 were moderately resistant (MR, Grade 2), 83 were

susceptible (S, Grade 3), and 126 were highly susceptible (HS, Grade 4) (Fig 1). Among the 275 accessions evaluated, 148 accessions exhibited common resistance behaviour (same grade response) against both PCN species. Of these, 14 were immune, 2 highly resistant (CP1137 and CP1800), 12 moderately resistant, 33 susceptible and 87 highly susceptible to both species.

**Screening Outcomes for the year 2021-22**

In the current year, 269 potato accessions were systematically evaluated for their response to both the species of PCN (Table 3). For GR, 23 accessions were immune, 14 were HR, 25 were MR, 67 were susceptible and 140 were highly susceptible (Fig 2). For GP, 15 accessions were immune, 14 were highly resistant, 24 were moderately resistant, 71 were susceptible, and 145 were highly susceptible (Fig 1). Among the 269 accessions evaluated during 2021-22, 204 accessions exhibited common resistance behaviour against both PCN species. Of these, 14 were immune, 6 highly resistant (CP1012, CP1581, CP1689, CP1706, JEXA15 and JEXA865), 8 moderately resistant, 46

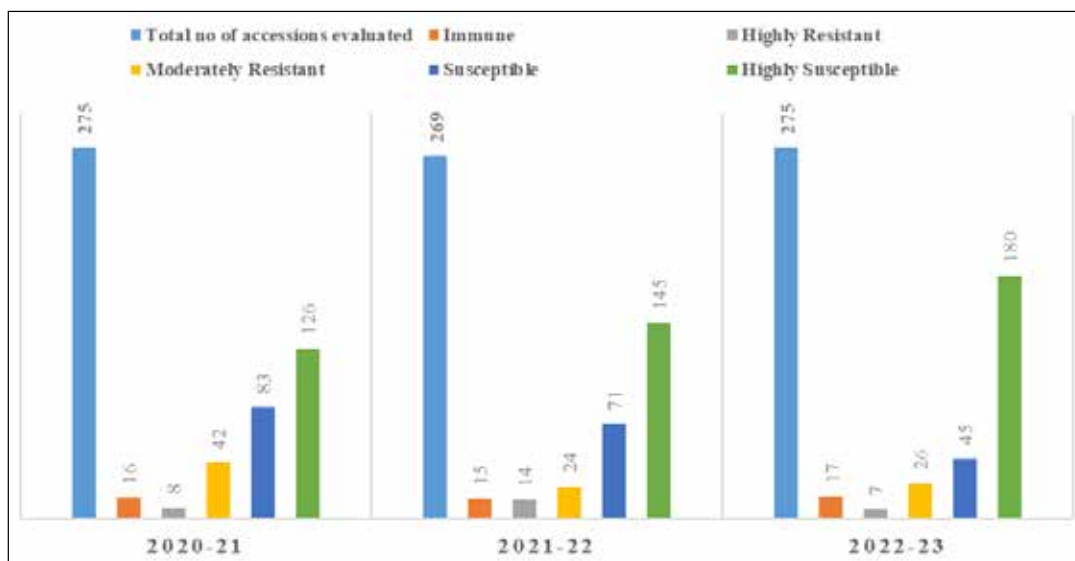


Fig. 1. Summary of potato accession evaluated for *Globodera pallida*

Table 3. Summary and result of potato accession evaluated for *G. pallida* and *G. rostochiensis*

S. No.	Year	Total no of accessions evaluated	<i>Globodera pallida</i>					<i>Globodera rostochiensis</i>				
			Immune	HR	MR	S	HS	Immune	HR	MR	S	HS
1.	2020-21	275	16	8	42	83	126	21	19	32	70	133
2.	2021-22	269	15	14	24	71	145	23	14	25	67	140
3.	2022-23	275	17	7	26	45	180	20	6	17	49	183
4.	Common accessions (over 2020-21 to 2022-23)	125	3	5	12	45	60	3	6	13	39	64
5.	2023-24	10	2	2	3	3	0	2	2	3	3	0

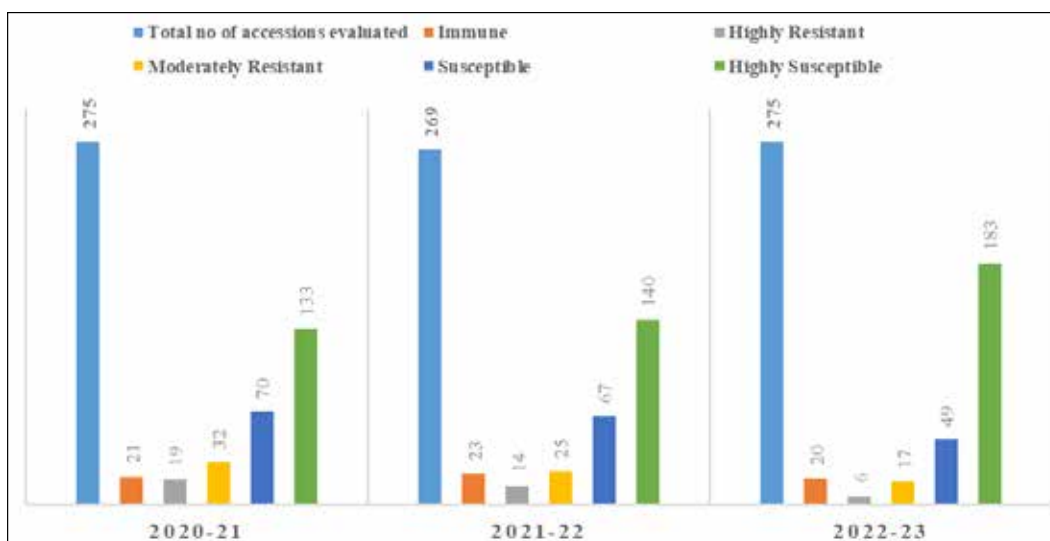


Fig. 2. Summary of potato accession evaluated for *Globodera rostochiensis*

susceptible and 130 highly susceptible to both PCN species.

### Screening Outcomes for the year 2022-23

In this year, 275 potato accessions were evaluated for their response to both species of PCN (Table 3). For GR, 20 accessions were immune, 6 were highly resistant, 17 were moderately resistant, 49 were susceptible, and 183 were highly susceptible (Fig 2). For GP, 17 accessions were immune, 7 were highly resistant, 26 were moderately resistant, 45 were susceptible, and 180 were highly susceptible (Fig 1). Among the 275 accessions evaluated, 227 accessions exhibited common resistance behaviour against both PCN species. Of these, 15 were immune, 1 highly

resistant (CP3939), 9 moderately resistant, 32 susceptible and 170 highly susceptible to both *G. rostochiensis* and *G. pallida*.

Overall, Figure 1 and Figure 2 showed the total number of accessions evaluated in the particular year and their reaction to for *G. pallida* and *G. rostochiensis*, respectively.

### Cumulative Assessment Over Three Years (2020-21 to 2022-23)

The study systematically evaluated the response of 275 potato accessions in 2020-21, 269 in 2021-22, and 275 in 2022-23 to GR and GP at Kufri using root ball techniques, with 125 accessions (Table 4) being consistently assessed across all the three years. For *G. rostochiensis* (GR), three accessions (CP1736,

**Table 4. Reaction of 125 common accessions (2020-21 to 2022-23) for *Globodera pallida* and *G. rostochiensis* (0-4 scale)**

S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )	S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )	S. No.	Accession Name	Grade (G. <i>pallida</i> )	Grade (G. <i>rostochiensis</i> )
1	CP658	3.67	3.67	43	CP1753	4.00	3.67	85	CP3636	3.67	3.33
2	CP659	3.67	3.33	44	CP1764	3.33	3.33	86	CP3641	1.00	1.33
3	CP1012	2.33	2.00	45	CP1784	2.67	3.67	87	CP3651	4.00	3.67
4	CP1143	3.00	4.00	46	CP1806	4.00	4.00	88	CP3681	3.00	3.33
5	CP1157	3.67	3.67	47	CP1869	2.67	3.00	89	CP3718	2.67	2.33
6	CP1187	3.67	3.67	48	CP1871	4.00	3.67	90	CP3761	2.33	2.33
7	CP1246	3.33	2.67	49	CP1889	3.00	3.67	91	CP3768	3.67	4.00
8	CP1291	3.33	3.33	50	CP1922	3.00	3.33	92	CP3797	3.00	2.67
9	CP1302	3.33	4.00	51	CP1971	3.33	3.67	93	CP3799	1.33	1.33
10	CP1304	3.33	3.33	52	CP1974	3.33	2.00	94	CP3809	1.67	1.33
11	CP1319	2.67	1.33	53	CP1982	3.00	3.67	95	CP3891	1.33	2.33
12	CP1325	3.00	3.67	54	CP1989	3.67	4.00	96	CP4149	3.67	4.00
13	CP1330	2.33	2.67	55	CP2086	4.00	4.00	97	CP4179	3.33	3.00
14	CP1335	3.33	3.67	56	CP2089	3.00	3.00	98	CP4254	3.33	3.67
15	CP1348	4.00	4.00	57	CP2090	4.00	4.00	99	CP4316	3.33	4.00
16	CP1367	4.00	4.00	58	CP2110	3.00	2.67	100	JEXA10	4.00	4.00
17	CP1379	3.33	4.00	59	CP2118	4.00	3.67	101	JEXA1152	4.00	3.00
18	CP1399	2.33	3.00	60	CP2142	3.67	3.67	102	JEXA15	0.33	0.33
19	CP1411	3.33	4.00	61	CP2171	2.67	3.33	103	JEXA197	3.00	3.00
20	CP1414	4.00	4.00	62	CP2189	3.67	4.00	104	JEXA202	4.00	4.00
21	CP1427	4.00	4.00	63	CP2335	3.33	2.67	105	JEXA215	3.33	3.33
22	CP1433	2.67	3.67	64	CP2338	2.00	2.67	106	JEXA275	4.00	3.67
23	CP1450	3.33	2.67	65	CP2346	3.33	3.67	107	JEXA298	3.33	3.33
24	CP1454	3.00	2.67	66	CP2348	3.33	3.33	108	JEXA30	4.00	4.00
25	CP1470	3.33	3.33	67	CP2370	4.00	3.00	109	JEXA316	3.67	3.67
26	CP1479	4.00	4.00	68	CP2418	0.00	0.00	110	JEXA317	1.00	0.67
27	CP1529	4.00	4.00	69	CP3036	2.00	2.00	111	JEXA457	3.67	4.00
28	CP1533	2.00	2.33	70	CP3096	2.67	1.67	112	JEXA459	4.00	4.00
29	CP1538	2.67	2.67	71	CP3103	3.33	3.00	113	JEXA668	3.67	3.33
30	CP1597	3.00	4.00	72	CP3116	3.67	3.67	114	JEXA707	3.67	3.33
31	CP1616	4.00	4.00	73	CP3145	3.67	2.67	115	Kufri Anand	4.00	4.00
32	CP1642	4.00	4.00	74	CP3153	4.00	3.67	116	Kufri Arun	4.00	4.00
33	CP1653	3.00	3.33	75	CP3180	3.67	3.67	117	Kufri Ashoka	3.00	3.00
34	CP1664	1.67	2.33	76	CP3201	3.33	2.33	118	Kufri Chandramukhi	3.67	3.67
35	CP1672	4.00	4.00	77	CP3222	2.33	2.00	119	Kufri Chipsona3	3.33	3.33
36	CP1685	3.67	4.00	78	CP3318	3.67	3.00	120	Kufri Girdhari	4.00	4.00
37	CP1687	1.00	1.00	79	CP3334	4.00	3.67	121	Kufri Kanchan	4.00	4.00
38	CP1688	3.67	4.00	80	CP3486	4.00	4.00	122	Kufri Khyati	4.00	4.00
39	CP1706	2.33	2.33	81	CP3505	3.67	3.33	123	Kufri Megha	3.67	3.67
40	CP1730	3.67	3.33	82	CP3575	4.00	3.33	124	Kufri Pushkar	3.67	3.67
41	CP1736	0.00	0.00	83	CP3588	3.67	3.67	125	Kufri Sindhuri	4.00	3.67
42	CP1749	4.00	4.00	84	CP3634	2.00	2.33				

\*Grade values represent the mean of three years (2020-21 to 2022-23) based on the 0-4 resistance scale described in Table 4.

CP2418 and JEXA/15) were immune, six were highly resistant (CP1687, CP1319, CP3641, CP3799, CP3809 and CP3096), 13 were moderately resistant, 39 were susceptible, and 64 accessions were highly susceptible. For *G. pallida* (GP), three accessions were immune (CP1736, CP2418 and JEX-A15), five highly resistant (CP1687, CP3641, JEXA-317, CP3799 and CP3891), twelve moderately resistant, 45 accessions susceptible, and 60 accessions were highly susceptible.

### Validation of promising accessions in the year 2023-24

Promising accessions (CP1012, CP1319, CP2418, CP1687, CP1736, CP3809, CP3641, CP3799, CP3222, and JEX/A-15) identified based on their resistance across three years were reevaluated for their resistance to both the PCN species in the year 2023-24. The accessions demonstrated varying levels of resistance, with some exhibiting high resistance and others showing moderate resistance or susceptibility. Specifically, the majority of the accessions maintained their resistance across the years, with a few showing slight variations. For example, certain accessions had consistently low cyst counts, indicating a high level of resistance,

while others displayed moderate cyst counts, categorizing them as moderately resistant. The mean cyst count per plant over the four years (2020-21 to 2023-24) was calculated, and the accessions were graded based on the predefined scale.

Among the evaluated accessions, two accessions (CP1736 and CP2418) demonstrated an immune response (Grade 0) to both *G. pallida* and *G. rostochiensis* (Table 5, 6 and Fig. 6). These accessions had consistently zero cyst counts across all evaluation years (2020-21 to 2023-24), which indicate their complete resistance to both nematode species. Additionally, two accessions, CP3641 and JEX/A-15, exhibited high resistance (Grade 1) to both species, with cyst counts ranging from 1 to 5. This consistent performance across multiple years and against both nematode species suggests that these accessions possess strong genetic resistance, making them valuable resources for breeding programs aimed at developing potato varieties with enhanced resistance to PCN species.

The heatmap illustrates the resistance of ten promising potato accessions to *both* PCN species from 2020-21 to 2023-24, using

**Table 5. Phenotypic data of ten promising accessions for *Globodera pallida***

Accession Name	Female cyst/plant ( <i>Globodera pallida</i> )					Grade	Reaction
	2020-21	2021-22	2022-23	2023-24	Mean		
CP1012	41.67	0.33	7.33	59.33	27.17	3	S
CP1319	18.67	9.33	33.00	53.00	28.50	3	S
CP2418	0.00	0.00	0.00	0.00	0.00	0	Immune
CP1687	0.00	0.00	20.33	0.00	5.08	2	MR
CP1736	0.00	0.00	0.00	0.00	0.00	0	Immune
CP3809	0.00	59.00	0.67	64.33	31.00	3	S
CP3641	4.67	0.33	0.00	0.00	1.25	1	HR
CP3799	0.00	0.00	66.67	0.00	16.67	2	MR
CP3222	42.33	0.00	47.67	0.00	22.50	2	MR
JEX/A-15	0.00	1.67	0.00	0.00	0.42	1	HR

**Table 6. Phenotypic data of ten promising accessions for *Globodera rostochiensis***

Accession Name	Female cyst/plant ( <i>Globodera rostochiensis</i> )				Mean	Grade	Reaction
	2020-21	2021-22	2022-23	2023-24			
CP1012	23.33	1.33	14.33	58.67	24.42	3	S
CP1319	1.33	0.00	28.67	60.33	22.58	3	S
CP2418	0.00	0.00	0.00	0.00	0.00	0	Immune
CP1687	0.00	0.00	22.67	0.00	5.67	2	MR
CP1736	0.00	0.00	0.00	0.00	0.00	0	Immune
CP3809	0.00	53.00	0.00	58.67	27.92	3	S
CP3641	6.33	4.00	0.00	0.00	2.58	1	HR
CP3799	0.00	0.00	63.33	0.00	15.83	2	MR
CP3222	6.67	0.00	41.00	0.00	11.92	2	MR
JEX/A-15	0.00	3.00	0.00	0.00	0.75	1	HR

a gradient from light green (high resistance) to orange (low resistance). Accessions CP2418, JEX/A-15 and CP1736 consistently exhibit high resistance with zero cyst counts across all years for golden nematode (Fig 3). In contrast, accessions like CP1012 and CP1319 show low resistance in specific years, indicated by higher cyst counts, particularly in 2023 (58.67 and 60.33). Other accessions such as CP3809 and CP3799 display variable resistance, suggesting possible environmental or genetic influences.

For *G. pallida* accessions CP2418 and CP1736 consistently exhibited high resistance with zero cyst counts across the years (Fig 4). Accessions like CP1012 and CP1319 show low resistance in certain years, indicated by higher cyst counts, especially in 2023. Accessions CP3809 and CP3799 demonstrate variable resistance, with high cyst counts in some years, suggesting potential environmental or genetic influences. This heatmap highlights accessions such as CP1736 and CP2418 as strong candidates for breeding



**Fig. 3. Heatmap of Female Cysts per Plant Across Years (2020-21 to 2023-24) for Potato Accessions Evaluated against *Globodera rostochiensis***



**Fig. 4. Heatmap of Female Cysts per Plant Across Years (2020-21 to 2023-24) for Potato Accessions Evaluated against *Globodera pallida***

programs aiming to enhance resistance to *G. pallida*.

Overall, three accessions, CP2418, JEX/A-15 and CP1736 exhibited highly resistant reaction to both PCN species during four years (2020-21 to 2023-24) and are strong candidates for use in resistance breeding.

## DISCUSSION

Breeding potatoes for resistance to PCN, specifically *G. rostochiensis* and *G. pallida*, require long term sustainable strategy through the identification and introgression of resistant genes (Mangal *et al.* 2025). Incorporating resistance genes from resistant germplasm sources into commercial potato varieties can significantly reduce the impact of nematode infestations, leading to improved yields and reduced reliance on chemical nematicides. By continuously improving and expanding the genetic diversity of resistance germplasm, breeders can create potato varieties that are better equipped to withstand the evolving threats posed by these persistent pests. Therefore, in the present study a diverse set of potato accessions were evaluated to both the species of PCN. The findings from our study align with previous studies on resistance to both the PCN species. Bachmann-Pfabe *et al.* (2019) screened 749 wild potato accessions and identified 78

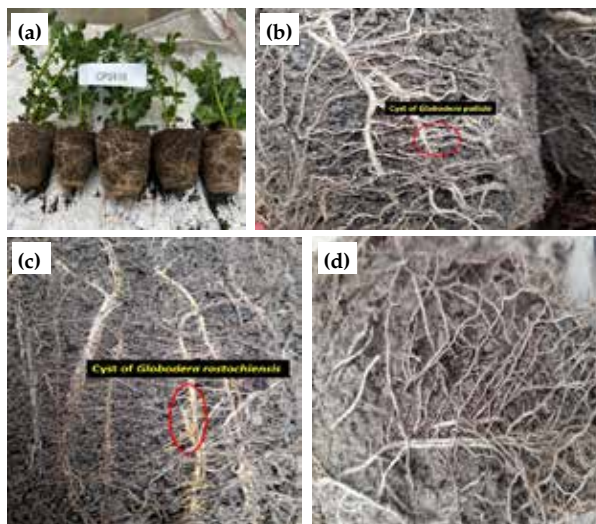


Fig. 5. (a) Root ball of potato plant (b) *Globodera pallida* susceptible accession (c) *Globodera rostochiensis* susceptible accession (d) Resistant accession to both PCN species

accessions resistant to *G. pallida* (Pa2/3), with fewer than five cysts per plant. Our results further corroborate the importance of dual-resistant accessions, as highlighted by Brodie *et al.* (1991) in North American breeding programme and Castelli *et al.* (2003) at Commonwealth Potato Collection (CPC), who emphasized the value of accessions that resist both *G. pallida* and *G. rostochiensis*. The dual-resistant accessions identified in our study are particularly promising, offering potential for developing potato cultivars with broad-spectrum resistance, which is



Fig. 6. Comparative root response of potato accessions CP2418 (a), CP1736 (b) and Kufri Jyoti (c) under both PCN species infestation which shows absence of cysts in CP2418 and CP1736 and high cyst density in Kufri Jyoti.

essential for effective pest management in regions affected by both nematode species. The study conducted by Dalamu *et al.* (2017) supports current investigation on the grouping of potato genotypes based on their resistance profiles. In their work, they identified genotypes such as CP 1843, CP 1879, and JEX/A 267 that demonstrated combined resistance to both species of potato cyst nematode (PCN). Similarly, this study has identified accessions that exhibit strong potential as candidates for breeding programs aimed at pyramiding resistance genes to improve resistance against PCN. These findings are crucial for developing more resilient potato varieties. The resistance patterns observed in our study also resonate with the findings of Faggian *et al.*, (2012), who screened 302 potato cultivars for resistance to *G. rostochiensis* (*Ro1*) and identified a range of resistant, susceptible, and very susceptible cultivars.

Environmental factors may influence resistance expression, as suggested by the varying resistance levels observed in this study across different years. This observation aligns with the work of Silvestre *et al.* (2021), who highlighted the impact of genetic diversity and environmental conditions on PCN resistance. Accessions such as CP2418 and CP1736, which exhibited consistent resistance across multiple years, support the findings of Gartner (2023) and Gavrilenko *et al.* (2021), who also identified genotypes with stable resistance to PCNs. The resistant germplasm identified in this study will be utilized in the development of PCN resistant varieties suitable for regions affected by nematode infestations. The distribution of resistance and susceptibility in present investigation is consistent with the findings of Limantseva *et al.* (2014) and Mangal *et al.* (2023), who reported that while many accessions exhibited resistance to *G. rostochiensis* and *G. pallida*, a

significant proportion remained susceptible. This highlights the necessity of continuous screening and the strategic use of resistant accessions in breeding programs.

Finally, the present study identified new sources of resistance (CP2418, CP1736, CP3641, and JEX/A-15) to both *G. pallida* and *G. rostochiensis*. The resistant accessions identified, particularly with combined resistance to both the species, are valuable for future breeding programs aimed at enhancing potato cultivars' resistance to PCNs, thereby improving potato production and sustainability.

## CONCLUSION

This study systematically evaluated the response of various potato accessions to *G. rostochiensis* and *G. pallida* over multiple years, and identified accessions with varying levels of resistance. Accessions such as CP2418, CP1736, CP3641, and JEX/A-15, which exhibited either immunity or high resistance across the study period, are particularly valuable for breeding programs aimed at the development of potato cultivars with broad-spectrum resistance to PCNs. Accessions such as CP1687, CP3641, CP3799 and JEXA/317 exhibited high resistance (HR, Grade 1) to both *G. rostochiensis* and *G. pallida*. Most of the released varieties (Kufri Anand, Kufri Arun, Kufri Ashoka, Kufri Chandramukhi, Kufri Girdhari, Kufri Kanchan, Kufri Khyati, Kufri Megha, Kufri Pushkar and Kufri Sindhuri) exhibited highly susceptible reaction to both PCN species in the present investigation. Therefore, the identified new sources of resistance can be used for breeding new potato varieties with enhanced resistance to PCN. Overall, the study also highlights the importance of continuous screening and utilization of resistant germplasm in breeding programs. These efforts are essential for the improvement of resilience of potato

against PCNs and sustainable agricultural practices.

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## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest

## ETHICAL STATEMENT

This article does not contain any studies with human participants or animals performed by any of the authors

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