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Effect of Root-knot Nematode (*Meloidogyne javanica*) Infection on Mungbean Genotypes: Identification and Characterization of Host Plant Resistance

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ABSTRACT

Background: Mungbean (*Vigna radiata*) has great socio-economic importance and is one of the main food legumes widely distributed worldwide. Yield losses caused by Root-knot nematodes (*Meloidogyne* spp.) have been widely recorded in mungbean growing areas. Screening for stable resistant genotypes has the potential to reduce the damage caused by the root-knot nematodes.

Methods: The present investigation screening of 100 mungbean genotypes against *M. javanica* infection were carried out in field-laboratory during 2023. Host plant resistance sources of mungbean genotypes were identified and characterized based on number of galls, galling index (GI) and a number of egg mass index against *M. javanica* infection.

Result: The result exhibited that, three accessions namely UPM 02-17, IPM 1620-6 and IPM 1718-1 were resistant to *M. javanica* infection having GI ± 2 and five accessions *viz*., PARAT M 8, PUSA 9531, RMG 353, PAU-911 and PM-2 showed moderately resistant reaction with GI ± 10 and rest of the screened genotypes were either susceptible or highly susceptible against nematode infection. Nematode development and multiplication on mungbean resistance accessions had significantly weakness in pathogenic ability and nematode infection appeared to be antibiosis that was associated with reduced nematode penetration, retardation of nematode development and impeding the giant cell formation as compared to RKN susceptible mungbean genotypes.

Key words: Evaluation, Host plant resistance, *Meloidogyne javanica*, *Vigna radiata*.

INTRODUCTION

Mungbean [*Vigna radiata* (L.) Wilczek] is an important nutritious pulse crop that plays a pivotal role in addressing malnutrition among vegetarian populations in Africa, South America, Australia and Southeast Asian countries including India (Parihar *et al*., 2017). In India, during 2022 total mungbean area of 5.5 million hectares produced 3.17 million tonnes with a productivity of 570 kg/ha (AICRP on *Kharif* Pulses, 2023). Despite its expanding cultivation and production, the crop's productivity lags behind that of other pulse crops due to various biotic and abiotic stresses. The crop yield of mungbean depends on climatic condition (Khatik *et al*., 2022), however in biotic stress the root-knot nematodes being a major contributor (Siddiqui *et al*., 2001; Ali and Singh, 2007). Root-knot nematodes (RKNs), known as *Meloidogyne* spp., significantly impact mungbean production, causing yield damage ranging from 18 to 90 percent under suitable conditions (Gupta and Verma, 1990). Over 80 species of *Meloidogyne* have been reported worldwide, with *M. incognita* and *M. javanica* species having significant effects in pulse-based cropping systems (Datta *et al*., 1987; Khan *et al*., 2016; Suresh *et al*., 2017). RKNs parasitize plant root systems, directly impacting the absorption of water and essential nutrients necessary for regular plant growth and reproduction. Nematode infestation of plant roots can contribute to disease complexes in conjunction with other pathogens, such as vascular diseases like *Fusarium* wilt and root rots (Roberts *et al*., 1995). However, cost and safety constraints associated with chemical nematicides, alternative management strategies for RKNs, such as crop rotations and host-plant resistance, are preferable (Roberts *et al*., 1995). However, the development of nematode-resistant cultivars faces limitations due to the scarcity of efficient resistant genotypes. Therefore, a significant challenge lies in identifying suitable stable resistant genotypes for mungbean breeding programs. Hence, we conducted a comprehensive assessment of 100 mungbean genotypes, subjecting them to both field (nematode sick plots) and

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controlled environments to evaluate their resistance against *Meloidogyne javanica* infection.

MATERIALS AND METHODS

Root knot nematode culture

Pure culture of root-knot nematode were maintained in the greenhouse in the Division of Crop Protection, ICAR-Indian Institute of Pulses Research (IIPR), Kanpur and species was identified as *M. javanica* based on the perineal pattern structure as per Taylor *et al*. (1955) protocol. The population of the test nematode was developed from a single egg mass well in advance of the experiment's commencement. After two months of inoculation on brinjal plants, the pure culture of the nematode was maintained for the experimental setup.

Seed material

In this study we utilized a diverse panel of 100 mungbean genotypes, comprised of a wide range of genetic backgrounds, such as elite genotypes, breeding lines, local landraces, germplasm and pre-breeding materials (Table 1). These genotypes were obtained from the Crop Improvement Division Medium-Term Cold Storage Pulses Gene Bank unit at ICAR-IIPR, Kanpur.

Experimental procedure

An initial screening experiment was conducted under controlled conditions in the Division of Crop Protection at ICAR-Indian Institute of Pulses Research, Kanpur, India during 2023-2024. Utilizing a panel of one hundred different mungbean genotypes. Fertile sandy loam soil was autoclaved at 15 kg/cm^2 pressure at 121°C for 30 minutes and mixed with nematode culture-contained soil, maintaining a nematode inoculums level at 2 Infective Juveniles (J2) per cc of soil. The mixture was then filled into PVC pipes (10 cm diameter and 30 cm length) with a lead placed at the bottom of the pipes. These pipes, with off portion of their length inserted into the soil, to maintain the natural soil temperature for nematode infection, followed by sowing of mungbean seeds in the pipes with five replications. Forty days after sowing, the plants were uprooted and roots were examined for nematode infection and data were recorded. Further confirmation of the resistance status of mungbean genotypes was repeated and screened in nematode sick plots (5×4 m). The initial population of *Meloidogyne javanica* juveniles (J2s) was maintained at 2 J2s per cc of soil and mungbean genotypes seeds were sown with susceptible check having five replications. Plants were uprooted 45 days after sowing and the number of root galls per root, the number of egg masses per root and plant growth parameters were recorded.

Development of *M. javanica* in the roots of mungbean resistant and susceptible genotypes

Mungbean seeds of the *M. javanica* resistant genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1) and the susceptible genotypes (SML 191, PUSA-0891 and MH-805) were sown in 10 PVC pipes, following the description above. Each pipe contained one seedling and the nematode inoculum level was maintained at 10 Infective Juveniles (J2) per cc of soil. Seedlings were harvested at 3 to 30 days after inoculation, the roots were then removed from the pipes and soil was gently washed off the root systems with tap water. Nematodes within the roots were stained with NaOCl-acid fuchsin following the method described by Byrd *et al*. (1983). Stained roots were observed under a stereo zoom microscope and different stages of the nematode were recorded as per the method described by Moens *et al*. (2009).

Histopathological experiment

The nematode resistant genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1) and the susceptible genotypes (SML 191, PUSA-0891 and MH-805) were cultivated in 10 PVC pipes, following the description above. Each pipe (replicate) was inoculated with 1,000 J2s of *M. javanica*. Ten root tips with galls (50 mm in length) from each pipe were randomly harvested from the resistant and susceptible plants at 30 days after inoculation (DAI). Root sections were prepared following the method described by Silva *et al*. (2013). The root tissues were observed under a light microscope and photographs were taken to elucidate differences in host-plant interactions between the resistant and susceptible genotypes.

Statistical analysis

The infected roots were observed for recording nematode egg masses/root; number of galls /roots, Gall index (GI) and degree of resistance for different mungbean genotypes. The host suitability of genotypes (degree of resistance) was determined on the basis of GI, 0 to 5 scale (Table 2) based on Taylor and Sasser, (1978) standard protocol. The statistical data analysis on egg masses, gall index, were analysed in completely randomised design using Web-based Agricultural Statistics Package (WASP, version on 2.0) developed by ICAR- Central Coastal Agricultural Research Institute, Goa, India.

RESULTS AND DISCUSSION

Host plant resistance screening

The evaluation and identification of host plant resistance in mungbean genotypes against *M. javanica* infection were studied and the results are presented in Table 1, 2, 3, 4 and 5. In the comparative screening of 100 mungbean genotypes under controlled conditions and *M. javanica* sick plot, significant variations among the genotypes were observed in terms of nematode penetration, development, formation giant cell, root gall formation, egg mass on the host. The results showed that three genotypes namely, UPM 02-17, IPM 1620-6 and IPM 1718-1 were resistant to *M. javanica* infection with a Galling Index (GI) of ±2. Additionally, five genotypes namely, PARAT M 8, PUSA 9531, RMG 353, PAU-911 and PM-2 were classified as moderately resistant with a GI of ±10, while the rest of the screened

Table 1: Reaction of mungbean accessions against *M. javanica*.

Germplasm	No. of egg mass/plant	No. of galls/plant	Gall index	Degree of resistance	Plant ht (cm)	No. of pods/plant	Biomass (g)	No. of pods/seeds
SML 191	80.5	66.66	4	S	52.33	9.00	23.67	4.00
PUSA-0891	75.6	50.50	4	S	55.50	8.50	25.50	3.50
MH-805	75.50	65.5	4	S	60.20	8.10	24.50	4.00
ML 1256	56.40	45.6	4	S	65.50	9.00	26.50	4.00
PDM 54	65.40	50.4	4	S	60.50	8.50	25.80	4.00
OBGG-52	65.40	48.6	4	S	55.50	9.00	26.50	4.00
LM-95	75.50	65.40	4	S	50.50	8.20	20.50	3.50
PDM -281	55.60	45.80	4	S	45.50	8.00	18.50	3.00
PDM-178	58.60	30.50	3	MS	40.50	7.50	18.80	3.00
ML-515	45.60	30.50	3	MS	55.80	8.00	20.00	4.00
NDU-1	120.50	118.50	4	S	38.67	5.00	21.00	2.67
PUSA 9072	75.60	60.50	4	S	45.50	7.00	15.50	3.00
ML 2056	58.50	30.12	3	MS	45.50	7.50	15.60	3.00
UPM 02-17	8.50	2.00	1	R	70.50	10.50	28.50	5.00
SUKETI -1	45.50	28.50	3	MS	55.00	14.00	36.67	8.67
RMU 991	50.50	27.80	3	M	45.50	8.00	20.50	4.00
POM 191	45.50	29.50	3	MS	55.50	7.50	15.80	3.50
MH 521	48.50	30.00	3	MS	50.50	8.00	18.50	4.00
BLACK MUNG	50.20	25.40	3	MS	45.50	7.50	18.40	4.00
PUSA BOLD-2	45.20	26.50	3	MS	55.50	8.00	20.00	4.00
SONA-GREEN	58.50	27.40	3	MS	58.50	7.50	21.50	4.00
ML 1299	48.50	28.50	3	MS	55.00	7.00	20.50	3.50
IPM 1701-2	56.50	30.00	3	MS	54.50	8.00	21.50	4.00
IPM 6-5X IPM 409-4	55.60	29.00	3	MS	60.50	8.50	24.50	4.00
PAIRY MUNG	45.60	30.50	3	MS	45.50	7.50	24.50	4.50
PARAT M 8	15.50	10.00	2	MR	55.50	7.00	21.50	3.50
PUSA 9531	40.50	10.50	2	MR	45.80	7.50	20.50	3.20
OMG-1045	45.50	9.80	3	MS	50.50	6.50	15.50	3.00
SM-48	40.50	28.50	3	MS	45.50	7.50	14.50	3.00
SML 1815	45.60	26.50	3	MS	50.00	7.00	15.50	3.00
PHULEM-2	40.50	25.40	3	MS	45.50	7.80	18.50	3.50
SML 134	45.60	23.50	3	MS	50.50	7.20	18.50	4.00
ML 818	42.50	25.60	3	MS	51.20	7.50	20.50	3.50
LGG-460	40.50	28.50	3	MS	45.80	8.00	18.50	4.00
TM 96-2	41.50	30.50	3	MS	48.50	7.50	17.50	3.00
MGG-295	50.20	28.50	3	MS	55.50	7.40	18.50	3.00
PRAUKSH NEPAL	55.50	28.50	3	MS	45.50	6.50	15.50	3.00
SPS-5(early)	45.60	26.80	3	MS	48.50	6.50	14.50	3.50
SML 832	48.50	27.50	3	MS	55.80	7.00	16.50	3.50
TARM-2	50.20	30.00	3	MS	58.50	7.50	17.50	3.80
IPM 1604-1	48.50	28.50	3	MS	60.50	8.00	20.50	3.80
PDM139XTMB37	75.50	60.00	4	S	60.33	13.33	50.00	4.00
IPM 410-3	65.50	55.80	4	S	65.50	8.20	25.50	3.00
IPM 312-18	55.80	45.80	4	S	58.50	8.50	24.50	4.00
IPM 1716-2	60.50	55.50	4	S	60.50	8.50	26.50	4.00
PDM 228	54.50	45.60	4	S	58.50	8.20	24.50	4.00
ML-5	65.60	55.60	4	S	55.50	8.50	22.50	4.00
ML-729	55.80	45.60	4	S	60.50	9.00	24.50	4.50
MASH-218	56.50	46.50	4	S	58.50	8.50	22.50	4.00

Table 1: Continue....

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CBKOPERGOAN	58.60	45.60	4	S	60.50	8.50	20.40	3.50
F9 (MXU) 701704	65.40	55.60	4	S	62.50	8.50	24.50	4.00
IPM 1620-6	14.50	2.00	1	R	51.00	7.67	41.00	5.50
IPM 1718-1	12.10	2.00	1	R	61.67	19.00	65.33	6.50
IPM 1732-1	25.50	10.00	2	MR	75.00	31.00	136.33	6.00
PDM139XTMB37	56.50	28.50	3	MS	65.50	10.50	30.50	4.50
MH 3-18X EC369223	45.60	27.50	3	MS	65.40	9.50	28.50	4.50
IPM 1718-2	55.40	28.60	3	MS	58.50	9.80	26.50	4.50
IPM 14-31	56.50	24.50	3	MS	60.50	9.50	25.40	4.50
IPM1716-2	54.50	25.60	3	MS	58.50	9.80	27.80	4.50
IPM 1708-1	52.50	28.50	3	MS	60.50	9.80	25.40	4.50
IPM 99-125	55.20	29.50	3	MS	61.40	10.50	28.60	5.50
ML-1464	54.50	30.50	3	MS	61.20	9.50	25.50	5.50
PDM40-123	52.50	24.50	3	MS	58.50	8.50	24.50	5.60
RMG 353	15.50	10.00	2	MR	65.67	22.67	57.67	11.00
PAU-911	14.20	10.00	2	MR	61.67	21.00	57.00	9.67
PM-2	13.50	10.00	2	MR	61.00	20.33	54.67	10.33
PDM-262	60.50	55.60	4	S	58.50	9.50	28.80	6.50
TJM-3	55.50	45.40	4	S	50.50	8.80	25.40	6.50
TM 2000-2	45.50	35.60	4	S	55.50	9.50	24.50	6.70
PS-16	55.40	35.40	4	S	48.50	9.50	26.50	6.50
IPM 1704-14	60.00	55.60	4	S	58.50	8.50	25.60	5.40
IPM 205-7	55.80	45.50	4	S	55.50	8.40	28.50	5.50
IPM 1711-1	48.50	35.50	4	S	54.50	8.50	27.50	5.40
IPM 1715-2	55.60	45.70	4	S	55.50	9.50	26.50	5.40
IPM 1722-1	58.40	44.50	4	S	52.50	8.50	25.60	4.50
IPM 1722-5	60.50	44.50	4	S	60.50	8.40	26.50	5.50
IPM 1715-1	55.40	42.50	4	S	55.50	8.50	24.50	5.40
MH 3-18	60.50	42.50	4	S	52.50	8.40	26.50	5.50
IPM 2-3X BBG 04-003	45.50	35.60	4	S	60.50	9.50	28.50	5.50
IPM 1701-1	50.50	40.50	4	S	58.50	8.80	30.50	5.00
IPM 14-28	60.50	44.50	4	S	45.80	7.50	24.50	4.50
IPM 409-4X IPM2-3	55.60	45.50	4	S	55.50	8.50	25.50	5.40
IPM 14-12-12	35.60	38.50	4	S	56.50	9.50	28.50	5.60
IPM1704-13	45.50	35.50	4	S	60.20	9.40	24.50	6.50
IPM14-17-4	55.50	45.50	4	S	55.40	8.50	24.50	4.50
IPM 14-34-27	48.50	35.50	4	S	50.20	7.50	24.60	4.20
IPM 1708-3	55.60	40.00	4	S	52.50	6.50	25.80	4.00
IPM 1707-1	60.50	55.80	4	S	60.50	7.50	30.10	5.50
IPM 1716-1	55.60	44.60	4	S	58.50	8.50	28.50	5.60
IPM 1706-2	45.50	35.50	4	S	79.00	33.33	54.67	11.67
IPM 512-1	55.60	40.50	4	S	65.50	28.50	29.50	8.50
IPM 1707-1	45.60	35.60	4	S	68.50	8.50	30.50	4.50
IPM 410-3	55.60	35.60	4	S	58.50	9.50	31.50	5.50
IPM 1704-18	60.60	45.60	4	S	55.50	8.50	30.50	6.50
IPM 312-18	55.60	45.60	4	S	56.50	9.50	28.50	7.50
IPM 312-18	100.00	92.00	4	S	61.00	28.67	57.00	11.67
IPM 1718-3	60.50	55.60	4	S	58.50	9.50	35.50	6.00
IPM 1604-1	55.60	45.60	4	S	60.50	9.80	34.50	6.50
IPM 312-20	45.60	35.60	4	S	58.50	9.50	30.50	6.50
IPM 1603-3	58.60	38.50	4	S	65.50	10.50	38.50	6.50

Numerical values are mean of 6 replications.

genotypes were classified either susceptible or highly susceptible to nematode infection. However, nematode development and multiplication on mungbean resistance genotypes was significantlyless due weak pathogenic ability, nematode infection appeared to exhibit antibiosis, associated with reduced nematode penetration, retardation of nematode development and impeding giant cell formation compared to root-knot nematode susceptible mungbean genotypes (Fig 1, 2, 3 and Table 1, 2, 3, 4, 5, 6).

Table 2: Scale for the presence of root-knot nematode galls or egg masses on roots Taylor and Sasser (1978).

No. of galls/plant	Gall index	Resistant rating
0	0	Immune (I)
1 to 2	1	Resistant (R)
3 to 10	2	Moderately resistant (MR)
11 to 30	3	Moderately susceptible (MS)
31 to 100	4	Susceptible (S)
100 +	5	Highly susceptible (H.S.)

Table 3: Reaction of different mungbean germplasm to *Meloidogyne javanica*.

Reaction	Name of mungbean germplasm
Immune (I)	0
Resistance (R)	UPM 02-17, IPM 1620-6 and IPM 1718-1 (3)
Moderately resistance (MR)	PARAT M 8, PUSA 9531, RMG 353, PAU-911 and PM-2 (5)
Moderately susceptible (MS)	PDM-178, ML-515, ML 2056, SUKETI -1, RMU 991, POM 191, MH 521, BLACK MUNG, PUSA BOLD-2, SONA-GREEN, ML 1299, IPM 1701-2, IPM 6-5X, IPM 409-4, PAIRY MUNG, SM-48, SML 1815, PHULEM-2, SML 134, ML 818, LGG-460, TM 96-2, MGG-295, PRAUKSH NEPAL, SPS-5 (early), SML 832, TARM-2, PM 1604-1, PDM 139XTMB37, MH 3-18X EC369223, IPM 1718-2, IPM 14-31, IPM1716-2, IPM 1708-1, IPM 99-125, ML-1464, PDM40-123 (36)
Susceptible (S)	SML 191, PUSA-0891, MH-805, ML 1256, PDM 54 , OBGG-52, LM-95, PDM -281, NDU-1, PUSA 9072, PDM139XTMB-37, IPM 410-3, IPM 312-18, IPM 1716-2, PDM 228, ML-5, ML-729, MASH-218, KOPERGOAN, F9 (MXU) 701-704, PDM-262, TJM-3, TM 2000-2, PS-16, IPM 1704-14, IPM 205-7, PM 1711-1, IPM 1715-2, IPM 1722-1, IPM 1722-5, IPM 1715-1, MH 3-18, IPM 2-3X BBG 04-003, IPM 1701-1, IPM 14-28, IPM 409-4X IPM2-3, IPM 14-12-12, IPM1704-13, IPM14-17-4, IPM 14-34-27, IPM 1708-3, IPM 1707-1, IPM 1716-1, IPM 1706-2, IPM 512-1, IPM 1707-1, IPM 410-3, IPM 1704-18, IPM 312-18, IPM 312-18, IPM 1718-3, IPM 1604-1, IPM 312-20 IPM 1603-3 (56)

Table 4: Comparable differential host plant reaction in selected resistant and susceptible mungbean accessions against *Meloidogyne javanica* infection at 30 days after inoculation (DAI).

Mungbean accessions	No. of galls/plant	No. of egg mass/plant	Gall index	Degree of resistance
UPM 02-17	1.67±0.33	7.67±0.33	1	R
IPM 1620-6	2.00±0.0	8.33±0.33	1	R
IPM 1718-1	1.33±0.33	7.00±0.57	1	R
SML 191	66.33±0.88	78.33±1.66	4	S
PUSA-0891	68.33±0.88	81.00±2.08	4	S
MH-805	71.33±1.76	85.00±1.73	4	S

Numerical values are Mean±SE of 6 replications; Degree of resistance; R- Resistance, S- Susceptible.

Table 5: Number of each stage of *Meloidogyne javanica* in roots of mungbean resistance and susceptible accessions against *M. javanica* infection at 30 days after inoculation (DAI).

Name of nematode	Resistance accessions			Susceptible accessions		
	UPM 02-17	IPM 1620-6	IPM 1718-1	SML 191	PUSA-0891	MH-805
J2	15.67±0.33	11.67±0.33	10.33±0.33	54.33±2.33	56.00±3.06	61.00±2.08
J3	12.00±0.57	12.67±0.88	13.00±0.57	47.67±1.45	46.33±1.85	50.67±2.33
J4	13.00±0.57	13.33±0.33	21.33±0.88	49.67±0.88	51.33±1.76	49.33±2.96
Females	15.33±0.33	14.67±0.66	15.33±0.33	52.00±1.52	50.33±3.92	51.67±1.85
Males	14.67±0.33	17.00±0.57	17.67±0.33	63.33±2.75	65.33±3.71	65.00±1.73

Numerical values are Mean±SE of 6 replications.

Development of *M. javanica* in the roots of mungbean resistant and susceptible genotypes

Juvenile stages of *M. javanica* were observed in the roots of both resistant genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1) and susceptible genotypes (SML 191, PUSA-0891 and MH-805) from 3 to 30 days after inoculation. On day 3, J2s were detected in the roots of the susceptible genotypes but were not found in the resistant genotypes. By day 5, J2s were present in the roots of all mungbean genotypes. However, the numbers of J2s in the roots of the susceptible genotypes were higher than those in the resistant genotypes. The mean numbers of nematodes in each stage of each accession at 30 days after inoculation (DAI) with J2s are presented in Table 5. Overall, the numbers of juveniles in the roots of the susceptible genotypes were higher than those in the resistant genotypes. At day 30, the numbers of juveniles in the roots followed the same trend as those at day 15. J2s, J3s, J4s, adult females and adult males were detected in the roots of all genotypes. The numbers of adult females in the roots of the resistant genotypes were significantly lower than those in the susceptible genotypes. The numbers of all juvenile stages in each resistant accession were significantly lower than those in the susceptible genotypes of the mungbean.

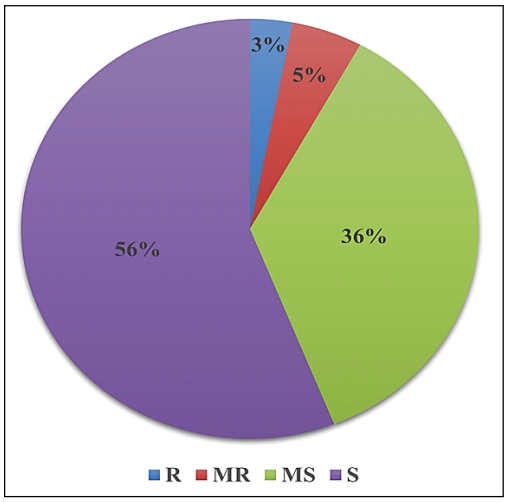
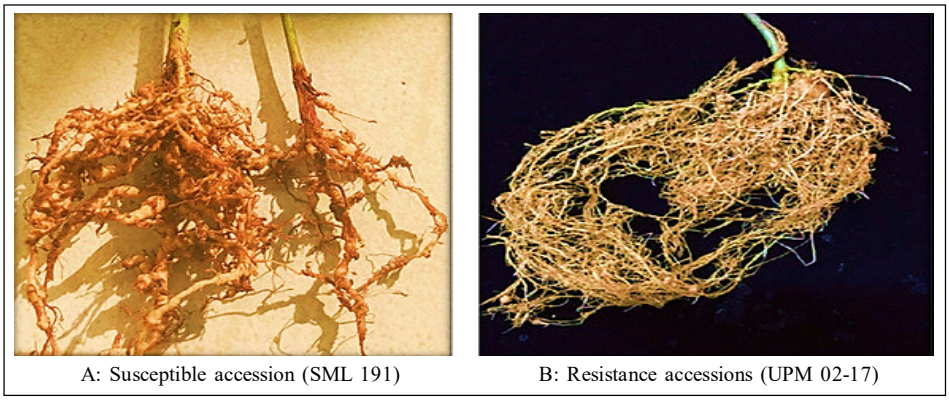


Fig 1: Percentage of resistance reaction of mungbean against *Meloidogyne javanica* infection.

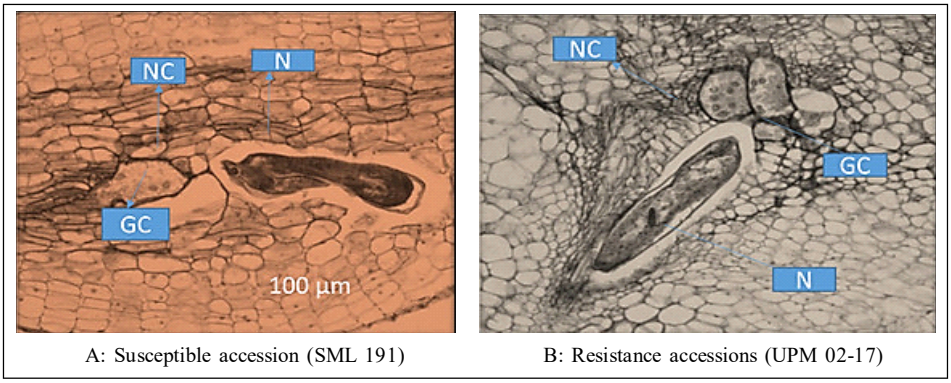
Effect of *M. javanica* on giant cell formation in resistant and susceptible mungbean genotypes roots

The observations of giant cell formation in both *M. javanica* resistant (UPM 02-17, IPM 1620-6 and IPM 1718-1) and susceptible genotypes (SML 191, PUSA-0891 and MH-805) were recorded at 20 days after inoculation. The size of the



A: Susceptible accession (SML 191) B: Resistance accessions (UPM 02-17)

Fig 2: Roots of mungbean accessions infected with second-stage juveniles (J2s) of *Meloidogyne javanica* at 20 days after inoculation (DAI).



A: Susceptible accession (SML 191) B: Resistance accessions (UPM 02-17)

Fig 3: Light microscopic representation of root tissues of mungbean accession infected with *Meloidogyne javanica* at 20 days after inoculation (DAI).

Table 6: Effect of *Meloidogyne javanica* infection on variation of root galls in roots of mungbean resistance and susceptible accessions at 20 days of inoculation (DAI).

Root galls characters	Resistance accessions			Susceptible accessions		
	UPM 02-17	IPM 1620-6	IPM 1718-1	SML 191	PUSA-0891	MH-805
Width of GC (im)	28.33±2.02	27.33± 2.02	28.00±1.15	57.67±1.45	57.67±2.33	52.00±2.30
Length of GC (im)	45.33 ±3.17	44.67±2.02	40.33±2.84	71.33±1.76	69.00±3.21	74.33±2.33
No. of GC/N	5.00±0.57	6.00±0.57	5.00±0.57	10.00±0.57	11.00±0.57	11.33±0.88
No. of NC/GC	12.00±0.57	12.33±1.20	14.00±0.57	20.00±1.15	25.00±0.57	26.00±1.15

Numerical values are Mean±SE of 6 replications.

giant cells, determined by their width and length, was significantly smaller in the resistant genotypes than that in the susceptible genotypes (Fig 3). Further, the number of giant cells per nematode in the roots of resistant genotypes was less than that in the susceptible genotypes at 20 DAI. However, the number of nuclei per giant cell did not show a significant difference between the resistant and susceptible genotypes (Fig 3).

The present study, involving the comparative screening of 100 mungbean genotypes under controlled conditions and nematode sick plots, revealed significant variations among the genotypes in terms of gall number, egg masses and nematode development on the host. In this study, the root-knot gall index (GI) and egg mass index (EI) were used for measuring the resistant mungbean genotypes against *M. javanica* infection. Karuri *et al*. (2017) have reported that, strong and positive correlations between the GI and the number of eggs. The GI and EI serve as valuable guides to evaluate resistance by measuring nematode establishment and reproduction in the host, respectively (Devindrappa *et al*., 2023; Hadisoeganda and Sasser, 1982; Sasser *et al*., 1984; Marchese *et al*., 2010; Gomes *et al*., 2015; Mukhtar *et al*., 2017). Resistant mungbean genotypes exhibited low GI and EI values, indicating successful selection of RKN-resistant Vigna varieties (Mukhtar *et al*., 2017). The development of *M. javanica* on both resistant (UPM 02-17, IPM 1620-6 and IPM 1718-1) and susceptible (SML 191, PUSA-0891 and MH-805) mungbean genotypes at 30 days resulted in significant decreases in the numbers of egg masses and galls in the resistant genotypes and no significant changes in these parameters in susceptible genotypes. Conversely, the numbers of galls increased significantly in susceptible genotypes, suggesting the difficulty for *M. javanica* to overcome resistance in the resistant genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1). However, further continuous development of nematodes on these three genotypes were carried out to confirm their resistance durability. Characterization of the *M. javanica* resistance in the resistant and susceptible genotypes revealed differences in nematode penetration. Juveniles (J2s) were not found in the roots of resistant genotypes at 3 days after inoculation (DAI) but were detected in the roots of susceptible genotypes. The inability of nematodes to enter the resistant roots may be attributed to the presence of toxic or antagonistic chemicals or barriers to penetration in the root tissue (Bendezu and Starr, 2003; Anthony *et al*., 2005; Ye *et al*., 2017). The fewer number of nematodes, along with smaller gall and giant cell sizes and a more number of adult males, as well as a delay in nematode development in the roots of resistance genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1), indicated that these three genotypes were not suitable hosts for *M. javanica*. This could be because they could not provide sufficient nutrients to complete the nematode life cycle (Dhandaydham *et al*., 2008; Ye *et al*., 2017). In *M. javanica* resistant mungbean genotypes, resistant genes block or suppress giant cell formation by interfering with one or more of the important steps required for successful parasitism of nematodes (Mukhtar *et al*., 2017).

The results indicated that mungbean accession *viz*., UPM 02-17, IPM 1620-6 and IPM 1718-1 were *M. javanica*-resistant genotypes were related to the obstruction of J2s penetration, delay of nematode development and suppression of giant cell formation. These findings can contribute to the identification of genotypes resistance to *M. javanica* for genetic improvement in *Vigna* species and enhance understanding of the resistance mechanisms of plants to this pest. The nematode-resistant mungbean genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1) were found to be highly cross-compatible with cultivated mungbean (*Vigna radiata* var. *sublobata*) and partially cross-compatible with cultivated black gram (*Vigna mungo* var. *mungo*) (Tomooka *et al*., 2002). Therefore, these nematode-resistant mungbean genotypes can serve as valuable gene sources for the development of nematode-resistant genotypes in mungbean and black gram breeding program.

CONCLUSION

In this study, we assessed one hundred mungbean genotypes for their host plant resistance to *M. javanica*. Among them, mungbean genotypes (UPM 02-17, IPM 1620-6 and IPM 1718-1) demonstrated resistance to *M. javanica* infection and exhibiting a reduced capability to penetrate, development in the root cells and induce giant cell formation compared to susceptible species. The identified promising genetic resources in this study hold significant potential for the breeding of mungbean genotypes with resistance to root-knot nematodes.

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Data availability

Data will be made available on request.

Conflict of interest

The authors are declaring that, they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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