Chapter-6

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The present research work is entitled “Studies on Meloidogyne incognita – Rhizoctonia solani disease complex on Pseuderanthemum atropurpureum and its management”. To the best of my knowledge and literature available revealed that so far no work has been carried out on the nematode and fungal diseases of P. atropurpureum in India and elsewhere. The summary of different objectives studied during the present study is described below.

Survey was conducted to assess the community analysis of plant parasitic nematodes associated with P. atropurpureum growing in and around the Aligarh district of Western Uttar Pradesh. During the survey of fifteen different localities viz., A.M.U. Campus, Akrahab, Atrauli, Bijuli, Chandaus, Chharra, Gangiri, Gonda, Harduaganj, Hasangarh, Jalali, Kasimpur, Khair, Raya and Tapal of Aligarh district 345 soil samples were collected from the rhizosphere of P. atropurpureum. Ten genera of plant parasitic nematodes viz., Meloidogyne, Helicotylenchus, Hemicriconemoides, Hoplolaimus, Xiphinema, Pratylenchus, Trichodorus, Tylenchorhynchus, Aphelenchoides and Rotylenchus were found associated with P. atropurpureum. The population density and frequency of occurrence of plant parasitic nematodes greatly varied at all examined locations.

Out of the 345 soil samples, the species of Meloidogyne were found to be present in maximum number of soil samples followed by Helicotylenchus sp., Hemicriconemoides sp., Xiphinema sp., Hoplolaimus sp., Pratylenchus sp., Trichodorus sp., Tylenchorhynchus sp., Aphelenchoides sp. and Rotylenchus sp. It was further observed that among the plant parasitic nematodes, Meloidogyne species was present in all the localities of Aligarh district, except at Khair.

The highest absolute frequency and relative frequency was observed in Meloidogyne species followed by Helicotylenchus sp., Hemicriconemoides sp., Xiphinema sp., Hoplolaimus sp., Pratylenchus sp., Trichodorus sp., Tylenchorhynchus sp., Aphelenchoides sp. and Rotylenchus sp. The results further confirmed that among the ten plant parasitic nematodes, the species of Meloidogyne showed greatest absolute density and relative density followed by Hoplolaimus sp., Helicotylenchus sp., Pratylenchus sp., Aphelenchoides sp., Hemicriconemoides sp.,
Xiphinema sp., Tylenchorhynchus sp., Trichodorus sp. and Rotylenchus sp. Similarly, the highest prominence value was also recorded in Meloidogyne species and it was followed by Hoplolaimus sp., Helicotylenchus sp., Pratylenchus sp., Hemicriconemoides sp., Aphelenchoides sp., Xiphinema sp., Tylenchorhynchus sp., Trichodorus sp. and Rotylenchus sp.

The identification of root-knot nematode revealed that two species of the genus Meloidogyne viz., M. incognita and M. arenaria were infecting the roots of P. atropurpureum. The highest percentage of infection of M. incognita was observed on P. atropurpureum growing in different localities of Aligarh district as compared to the plants infected with M. arenaria. Out of 15 localities, the infection of M. incognita on P. atropurpureum was found in all the localities except Khair. Whereas, the M. arenaria infection was observed in only seven localities viz., Akrabad, Atrauli, Bijuli, Chandaus, Gangiri, Harduaganj and Kasimpur. It was further observed that there was no concomitant infection of M. incognita and M. arenaria in the roots of P. atropurpureum. However, a sufficient number of P. atropurpureum plants showed the concomitant infection of M. incognita and R. solani. It was interesting to note that the plants which were found to be infected with M. arenaria did not show the infection of R. solani. Furthermore, the highest number of average root galls and egg masses were present in the plants infected with M. incognita. Whereas, the lowest number of root galls and egg masses were recorded in the plants infected with M. arenaria. Hence, it can be concluded from the present study that P. atropurpureum was more susceptible host to M. incognita as compared to M. arenaria.

After the identification of species of root-knot nematode the occurrence of race(s) of M. incognita and M. arenaria in Aligarh district was also studied. Three races of M. incognita (race-1, 3 and 4) and two races of M. arenaria (race-1and 2) were found to be associated with P. atropurpureum in Aligarh. Among the races of M. incognita, the race-3 of M. incognita was present in 14 examined localities of Aligarh district viz., A.M.U. Campus, Akrabad, Atrauli, Bijuli, Chandaus, Chharra, Gangiri, Gonda, Hasangarh, Harduaganj, Jalali, Kasimpur, Raya and Tapal. The race-1 was present in 7 localities viz., Atrauli, Bijuli, Chandaus, Chharra, Gonda, Hasangarh and Tapal. Whereas, race- 4 was observed in only 4 localities viz., Hasangarh, Jalali, Kasimpur and Raya. Among the races of M. arenaria, the race-2 was present in 6 localities viz., Akrabad, Atrauli, Bijuli, Gangiri, Harduaganj and
Kasimpur and race-1 of *M. arenaria* was present only in two localities viz., Chandaus and Chharra.

Out of 70 isolates of *Meloidogyne* spp. collected from the roots of *P. atropurpureum* growing in different localities of Aligarh district, 14 isolates were designated as race-1, 36 isolates race-3 and 5 isolates race-4 of *M. incognita*. The remaining 15 isolates showed the presence of *M. arenaria* Race-1 in 3 isolates and *M. arenaria* Race-2 in 12 isolates. Among the races of *M. incognita*, the highest frequency of occurrence was recorded in race-3 followed by race-1 and race-4. However, on the other hand, among the races of *M. arenaria* the frequency of occurrence of race-2 was higher as compared to race-1.

Since, no reports are available in the literature regarding the pathogenicity of *M. incognita* and *R. solani* on *P. atropurpureum*. Therefore, it was found desirable to study the pathogenicity of the *M. incognita* and *R. solani* on *P. atropurpureum*. The main objective of pathogenicity tests in the present study was to determine the effect of different inoculum levels of *M. incognita* / *R. solani* on *P. atropurpureum* and to provide data on the effective population levels of pathogens which consequently caused significant plant damage.

To determine the inoculum threshold level of root-knot nematode (*M. incognita* Race-3), *P. atropurpureum* plants were separately inoculated with different inoculum levels of *M. incognita* Race-3 (250, 500, 1000, 2000, 4000, 8000 and 16000 J2 per kg soil). The results showed that the reduction in plant growth (plant length, fresh weight, dry weight, number of leaves and leaf area) and physiological parameters (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content in leaves) was directly proportional to the inoculum levels of *M. incognita* Race-3. However, no significant reduction in plant growth and physiological parameters was observed at inoculum levels of 250, 500 and 1000 J2 per kg soil. The significant reduction in plant growth and physiological parameters was recorded at and above the inoculum levels of 2000 J2 per kg soil. It was further observed that there was no significant reduction in plant growth and physiological parameters between the inoculum levels of 8000 J2 and 16000 J2 per kg soil.

The population of *M. incognita* Race-3 was maximum at the highest inoculum level and minimum at the lowest inoculum level. Moreover, the reproduction factor of
the root-knot nematode decreased significantly with an increase in nematode inoculum level from 250-16000 J2 per kg soil. The reproduction factor was highest at the minimum inoculum level and lowest at the maximum inoculum level. It was also observed that the number of galls and egg masses increased with the increase in inoculum levels.

The characteristic symptoms caused by root-knot nematode appeared on the above ground as well as underground parts of the *P. atropurpureum* plant, particularly which received the higher inoculum levels of *M. incognita* Race-3 i.e. at and above 2000 J2 per kg soil. The *P. atropurpureum* plants infected with *M. incognita* Race-3 showed varying degree of stunted growth, accompanied with premature yellowing, drying and shedding of leaves, giving the infected plants an unhealthy appearance. The plants inoculated with higher inoculum levels (8000 and 16000 J2) also showed temporary day time wilting during hot hours even in presence of enough soil moisture. It was noticed that the severity of the symptoms in *P. atropurpureum* were directly proportional to the density of *M. incognita*. The above ground symptoms appeared within 10-11 weeks after inoculation of 2000 and 4000 J2, and 7-8 weeks at higher inoculum levels of 8000 and 16000 J2/kg soil. However, on the other hand no above ground symptoms were observed at lower inoculum levels of *M. incognita* Race-3 (250 to 1000 J2/kg soil).

The characteristic symptoms of root-knot disease also appeared on the below ground parts of *P. atropurpureum* inoculated with *M. incognita* Race-3. The typical galls of varying size developed on the *M. incognita* Race-3 infected roots. In case of multiple infections on the nearby tissues smaller galls may coalesce to form large galls. The eggs were laid down by the adult females in a gelatinous egg mass which was visible on the galled root surfaces. Besides galling on roots, appearance of galls at the base of the stem near the soil level was also observed at higher inoculum levels (8000 and 16000 J2/kg soil) of *M. incognita* Race-3. The symptoms of dirty roots were also observed upon gently uprooting the plants. Soil particles adhered to the sticky gelatinous matrix secreted by mature females caused the “dirty root” symptoms.

From the present results it was concluded that the tolerance limit of *P. atropurpureum* plant is up to 1000 J2 of root-knot nematode per kg soil. As significant reduction in plant growth and physiological parameters were observed at and above
2000 $J_2$ per kg soil. The damaging threshold level of *M. incognita* Race-3 on *P. atropurpureum* was determined as 2000 $J_2$ per kg soil.

The pathogenicity test of *R. solani* revealed that with the increase in inoculum level of *R. solani* (0.25, 0.5, 1.0, 2.0, 3.0 and 4.0 g of mycelial mat of *R. solani* per kg soil) there was no significant difference in plant growth and physiological parameters in the plants inoculated up to 2.0 g mycelial mat of *R. solani* kg soil as compared to control. Moreover, the significant differences in plant growth and physiological parameters were observed at higher inoculum levels of 3.0 and 4.0 g of *R. solani* kg soil. Further, it was observed that *R. solani* caused the root-rot in all the plants inoculated with different inoculum levels of *R. solani*. However, the intensity of rotting was not uniform and it increased with the increase in inoculum level of the *R. solani*. The statistical analysis of the data showed that there was no significant difference in percentage of root-rot, reduction of plant growth and physiological parameters in *P. atropurpureum* plants inoculated with 3.0 and 4.0 g mycelial mat of *R. solani* kg soil. At lower inoculum levels of *R. solani* (0.25, 0.5, 1.0, 2.0 g/ kg soil) no aerial symptoms were observed. The *P. atropurpureum* plants inoculated with 3.0 and 4.0 g mycelial mat of *R. solani* kg soil showed stunting of plant growth and premature yellowing of leaves. The yellowing started from the lower leaves and proceeded upwards, followed by drying and falling of leaves. The above ground symptoms appeared after 17 weeks in both the inoculum levels of *R. solani*.

It was noted in the present study that no significant damage was observed in the plant growth and physiological parameters of *P. atropurpureum* inoculated upto 2.0 g fungus. Hence, this inoculum level (2.0 g *R. solani* kg soil) was referred to as tolerance limit of *P. atropurpureum*. While, damaging threshold level of *R. solani* on *P. atropurpureum* was recorded as 3.0 g fungus per kg soil, because, this inoculum level caused the significant reduction in plant growth and physiological parameters.

The *P. atropurpureum* cuttings were inoculated with *M. incognita* Race-3 (2000 $J_2$/ kg soil) and *R. solani* (2.0 g mycelial mat / kg soil) individually, concomitantly as well as sequentially with an interval of 21 days between the nematode and fungal inoculations to determine whether the interaction is synergistic, antagonistic or additive in nature. The results revealed that the inoculation of *M. incognita* Race-3 and *R. solani* on *P. atropurpureum* individually, concomitantly and
sequentially, caused a significant reduction in plant growth and physiological parameters as compared to un-inoculated plants (control).

The individual inoculation of *M. incognita* Race-3 caused significantly greater reduction in plant growth and physiological parameters as compared to individual inoculation of *R. solani*. Moreover, the simultaneous and sequential inoculations of *M. incognita* Race-3 and *R. solani* were more drastic in terms of damage potential than the individual inoculation of either of the pathogens. The significant highest reduction in plant growth and physiological parameters was observed in sequential inoculation of *M. incognita* Race-3 twenty-one days prior to *R. solani*, followed by simultaneous inoculation of *M. incognita* Race-3 and *R. solani*, and *R. solani* twenty-one days prior to *M. incognita* Race-3. The results confirmed that plant growth and physiological parameters were synergistically reduced in *P. atropurpureum* inoculated either concomitantly or sequentially with *M. incognita* Race-3 and *R. solani*.

The root-knot nematode, *M. incognita* Race-3 multiplication, development of galls and egg masses per root system in *P. atropurpureum* were significantly reduced in presence of root-rot fungus, *R. solani*, as compared to when the *M. incognita* Race-3 was present alone. The highest number of galls, egg masses and reproduction factor was recorded in plants inoculated with *M. incognita* Race-3 alone, followed by *M. incognita* Race-3 twenty-one days prior to *R. solani*, *M. incognita* Race-3 simultaneously with *R. solani* and, *R. solani* twenty-one days prior to *M. incognita* Race-3.

It was observed that the root galling caused by nematode decreased in presence of *R. solani*, whereas, the percentage of rotting in roots caused by *R. solani* increased in presence of *M. incognita* Race-3 irrespective of whether both were inoculated simultaneously or sequentially. Moreover, the intensity of rotting varied in plants, depending upon the nature of inoculation of the test pathogens. The minimum percentage of root-rot was recorded in plants inoculated with *R. solani* alone as compared to when both *M. incognita* Race-3 and *R. solani* were inoculated either concomitantly or sequentially. The significant highest percentage of root-rot was observed in plants inoculated with *M. incognita* Race-3 twenty-one days prior to *R. solani*, followed by plants inoculated concomitantly with *M. incognita* Race-3 and *R. solani* and *R. solani* inoculated twenty-one days prior to *M. incognita* Race-3.
In addition to root-rot, the collar-rot and crown-rot symptoms were also observed in the plants inoculated with *M. incognita* Race-3 and *R. solani* either concomitantly or sequentially, except in one of the sequential inoculations i.e. *R. solani* twenty-one days prior to *M. incognita* Race-3, where crown-rot symptom was not recorded. Moreover, the plants showed yellowing, drying and shedding of leaves followed by rotting in branches but the size of rotted spots around the circumference of branches was less than 1 cm. The time required for expression of collar-rot and crown-rot symptoms in the plants also varied, depending upon the nature of inoculation of the test pathogens. The plants inoculated with *M. incognita* Race-3 twenty-one days prior to *R. solani* showed earlier expression of collar-rot symptoms followed by plants inoculated concomitantly with *M. incognita* Race-3 and *R. solani* and sequentially, with *R. solani* twenty-one days prior to *M. incognita* Race-3.

It was also observed that the severity of disease symptoms increased when both the pathogens were inoculated either concomitantly or sequentially as compared to when both were inoculated singly. Among the concomitant and sequential inoculations, the greatest severity of both, above ground and underground disease symptoms was observed in the plants inoculated with *M. incognita* Race-3 twenty-one days prior to *R. solani* followed by plants inoculated concomitantly with *M. incognita* Race-3 and *R. solani* and sequentially with *R. solani* twenty-one days prior to *M. incognita* Race-3. The symptoms produced by the interaction of *M. incognita* Race-3 and *R. solani* in different types of inoculations of the test pathogens on *P. atropurpureum* are described as follows.

The yellowing of leaves in infected plants first started from the base of lower branches, gradually moving upwards and it was followed by browning, drying and premature falling of leaves. In leaves, the yellowing followed by browning and drying started from the margin and extending inwardly towards midrib. The premature yellowing, drying and withering of leaves gradually proceeded upward and then followed by appearance of brown to black coloured rotted spot on the stem near the soil line. Later, the collar-rot spot enlarged and extended upwards and downwards on the stem up to a considerable distance and covering all around the circumference of the stem. Thereafter, brown to black coloured rotted spots also appeared in the branches of infected plants. The spots first appeared in lower branches and then to
upper branches. The rotted spots also gradually increased in size and finally covered all around the circumference of the infected branch.

The underground symptoms in the form of root-knot were observed in *M. incognita* Race-3 and *R. solani* infected *P. atropurpureum* plants. Besides galling on infected roots, dark brown to black coloured areas due to rotting caused by *R. solani* were also observed, which led to varying degree of destruction and deterioration of root tissues. The simultaneously and sequentially inoculated plants showed the brown to black coloured root lesions on primary and secondary roots. These lesions later developed into cankers which were spherical to hemispherical in shape, gradually increased in size and finally girdled the root. The canker symptoms were more prominent and numerous on primary and secondary roots as compared to other lateral roots. In addition, numerous, minute fungal sclerotia also appeared as raised white dots when young, becoming brown to dark brown with age on the surfaces of collar-rot, root cankers, rotted roots and galls.

*Peuderanthemum atropurpureum* plants were inoculated with varying inoculum levels of *M. incognita* Race-3 and *R. solani* to find out the minimum inoculum level of *M. incognita* and *R. solani* required to cause the disease complex and also its impact on plant growth and physiological parameters. The combined inoculation of *M. incognita* Race-3 at and above 2000 J$_2$/ kg soil and *R. solani* at and above 3 g mycelial mat/ kg soil on *P. atropurpureum* caused significant reduction in various plant growth as well as physiological parameters viz., plant length, fresh weight, dry weight, chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content. However, on the other hand, the lowest inoculum level of *M. incognita* Race-3 (1000 J$_2$) and *R. solani* (2.0 g) did not cause significant damage to growth and physiological parameters of *P. atropurpureum*. The concomitant inoculation of varying inoculum levels of *M. incognita* Race-3 (Mi) and *R. solani* (Rs) synergistically reduced the growth and physiological parameters of the test plant as compared to their individual inoculations. The highest reduction in growth and physiological parameters of *P. atropurpureum* was recorded in the plants inoculated simultaneously with *R. solani* (3.0 g) and *M. incognita* Race-3 (2000 J$_2$), followed by Rs (2.0 g) + Mi (2000 J$_2$), Rs (4.0 g) + Mi (1000 J$_2$), Rs (3.0 g) + Mi (1000 J$_2$) and Rs (2.0 g) + Mi (1000 J$_2$). Further, it was observed that in concomitant inoculations
reduction in various plant growth and physiological parameters was increased with an increase in inoculum level of either of the pathogen.

The population of root-knot nematode, number of galls and egg masses increased with the increase in inoculum level of *M. incognita* Race-3. Whereas, the reproduction factor decreased with the increase in inoculum levels. Irrespective of inoculum levels of root-knot nematode, the reduction in number of galls, egg masses and reproduction factor of nematode was significantly increased with an increase in the inoculum of *R. solani*. However, on the other hand, intensity of root-rot increased in presence of *M. incognita* Race-3 and it was further increased with an increase in inoculum level of *R. solani*. The greatest percentage of root-rot caused by *R. solani* and reduction in reproduction factor of nematode, number of galls and egg masses was recorded in the plants inoculated simultaneously with *R. solani* (3.0g) and *M. incognita* (2000 J2), followed by Rs (2.0g) + Mi (2000 J2), Rs (4.0g) + Mi (1000 J2), Rs (3.0g) + Mi (1000 J2) and Rs (2.0g) + Mi (1000 J2) as compared to plants inoculated with *M. incognita* Race-3 alone.

The combined inoculation of *M. incognita* Race-3 and *R. solani* not only increased the reduction in growth and physiological parameters but also induced the appearance of collar-rot and/ or crown-rot symptoms. The crown-rot symptoms were not recorded in the plants inoculated concomitantly with lowest inoculum of *M. incognita* Race-3 (1000 J2) and either of the inoculum level of *R. solani* (2, 3 or 4 g fungus). It was further observed that in concomitant inoculations, the number of days required for the expression of collar-rot and crown-rot symptoms in *P. atropurpureum* were reduced with an increase in the inoculum levels of either *M. incognita* Race-3 (Mi) or *R. solani* (Rs). The earliest expression of collar-rot and crown-rot symptoms were noticed in the plants inoculated with highest inoculum level of Mi (4000 J2) and Rs (4.0g) and it was followed by in the plants inoculated with Rs (3g) + Mi (4000 J2), Rs (2.0g) + Mi (4000 J2), Rs (4.0g) + Mi (2000 J2), Rs (3.0g) + Mi (2000 J2), Rs (2.0g) + Mi (2000 J2), Rs (4.0g) + Mi (1000 J2), Rs (3.0g) + Mi (1000 J2) and Rs (2.0g) + Mi (1000 J2).

Furthermore, it was interesting to note that concomitant inoculation with higher inoculum levels of *M. incognita* Race-3 and *R. solani* not only reduced the number of days required for the expression of collar-rot and crown-rot symptoms but also resulted in the mortality of *P. atropurpureum* plants. The duration of survival of
plants also decreased with the increase in inoculum level of fungus. The earliest mortality was recorded in the plants inoculated concomitantly with highest inoculum level of *M. incognita* Race-3 (4000 J2) and *R. solani* (4.0 g fungus) followed by in the plants inoculated with Rs (3.0 g) + Mi (4000 J2), Rs (2.0 g) + Mi (4000 J2) and Rs (4.0 g) + Mi (2000 J2).

Both the underground symptoms (root galling, root-rot, root cankers, girdling of roots and deterioration of galls) and aerial symptoms (collar and crown rot) were produced by the disease complex caused by *M. incognita* Race-3 and *R. solani* at variable higher inoculum levels in *P. atropurpureum* plants. The symptoms were generally similar to those as observed in the simultaneous inoculation of *M. incognita* Race-3 and *R. solani* and sequential inoculation of *M. incognita* 21 days prior to *R. solani* except the mortality of plants. Before mortality of plants, in addition to collar-rot symptoms, cracking and girdling at the base of stem were also observed, which led to toppling down of the plants. The plants inoculated with lowest inoculum of *M. incognita* Race-3 (1000 J2) and either of the inoculum levels of *R. solani* (2, 3 or 4 g fungus) showed all the symptoms except crown rot and mortality of the plants. Moreover, the severity of these symptoms gradually increased with the increase in level of inoculum of both the pathogens.

To the best of my knowledge, the literature available revealed that the synergistic association in terms of damage to plant and development of disease caused by *M. incognita* Race-3 and *R. solani* not only constituted the first disease complex of *P. atropurpureum*, but also reported as new host for root-rot fungus (*R. solani*) and root-knot nematode (*M. incognita* Race-3) from India and elsewhere.

The studies on the life cycle of *M. incognita* Race-3 in presence and absence of *R. solani* showed that when *M. incognita* Race-3 was inoculated alone the second stage juvenile (J2) of nematode invaded the roots of *P. atropurpureum* as early as 12 hours after inoculation. However, in the same duration, the penetration of juveniles was not recorded when both *M. incognita* and *R. solani* were concomitantly inoculated. The results further revealed that the presence of *R. solani* not only delayed the penetration of second stage juveniles but also decreased the percentage of penetration and occurrence of different stages in the roots, and also subsequently delayed the development of different stages of nematode in *P. atropurpureum*. The fecundity of females was found to be reduced with an average of only 156 eggs/ egg
mass in *M. incognita* and *R. solani* inoculated plants as compared to 287 eggs per egg mass in *M. incognita* alone. The highest number of juveniles (2248 J₂ / kg soil) was observed in plants inoculated with *M. incognita* Race-3 alone, whereas, 1561 J₂ / kg soil in presence of *R. solani*. The life cycle of *M. incognita* Race-3 on *P. atropurpureum* was completed in 30 days, however, the duration of life cycle was adversely affected in the presence of *R. solani* and it took 44 days to complete the life cycle. Thus, the presence of *R. solani* delayed the life cycle of root-knot nematode, *M. incognita* by 14 days.

The studies were also conducted on the management of *M. incognita* – *R. solani* disease complex in *P. atropurpureum* by using nematicide, some fungi, chopped leaves and sawdust of some plants. The individual inoculation of biocontrol agents *viz.*, *Trichoderma atroviride* and *T. asperellum* significantly improved the plant growth parameters as compared to un-inoculated plants (control). The maximum increase in plant growth parameters *viz.*, length, fresh weight, dry weight, number of leaves and leaf area was recorded in the plants inoculated with *T. atroviride* in comparison to *T. asperellum*. However, the plants inoculated with *A. niger*, *C. epiphyllum*, *M. hiemalis*, *P. lilacinus*, *V. glaucum* and bare root dip treatment with nematicide-carbofuran did not significantly affect the plant growth parameters as against control.

The results showed that out of the eight soil fungi, inoculated individually only three fungi *viz.*, *T. atroviride*, *T. asperellum* and *P. lilacinus* and bare root dip treatment with nematicide-carbofuran significantly improved the plant growth and physiological parameters of *P. atropurpureum* infected with *M. incognita* Race-3 and *R. solani* as compared to untreated and *M. incognita* Race-3 and *R. solani* inoculated plants (control-II). The significant highest improvement in plant growth parameters (length, fresh weight, dry weight, number of leaves and leaf area) and physiological parameters (chlorophyll a, chlorophyll b, total chlorophyll and carotenoid content) was recorded in the plants treated with *T. atroviride*, followed by *P. lilacinus*, carbofuran and *T. asperellum*. However, on the other hand the application of *A. niger*, *C. epiphyllum*, *C. verticillata*, *M. hiemalis* and *V. glaucum* neither significantly improved the plant growth and physiological parameters nor reduced the intensity of disease caused by *M. incognita* Race-3 and *R. solani* in terms of root-galling, root-rot, collar-rot and crown-rot symptoms. The intensity of root-rot caused by *R. solani* was
significantly reduced in the plants treated with *T. atroviride*, *P. lilacinus*, *T. asperellum* and carbofuran as compared to untreated and *M. incognita* Race-3 and *R. solani* inoculated plants (control-II). The highest reduction in root-rot was recorded in plants treated with *T. atroviride* followed by *P. lilacinus*, *T. asperellum* and carbofuran. The plants treated with these fungal bioagents and nematicide not only reduced the intensity of root-rot but also delayed the appearance of collar-rot and crown-rot symptoms. The maximum delay in the appearance of collar-rot and crown-rot symptoms was observed in the plants treated with *T. atroviride* followed by *P. lilacinus*, carbofuran and *T. asperellum*.

Similarly, the application of biocontrol agents viz., *P. lilacinus*, *T. asperellum*, *T. atroviride* and bare root-dip treatment with carbofuran not only reduced the root-rot and delayed the appearance of crown and collar rot symptoms of *P. atropurpureum*, but, also inhibited the multiplication of nematode and number of galls and egg masses per root system which in turn increased the plant growth and physiological parameters as compared to untreated and inoculated plants. The greatest reduction in nematode reproduction factor and number of galls and egg masses / root system were observed in *P. lilacinus* inoculated plants followed by *T. atroviride*, carbofuran and *T. asperellum*.

The individual application of chopped leaves of *C. cordifolia*, *P. hysterophorus*, *P. niruri* and *W. somnifera* significantly increased the plant growth parameters of *P. atropurpureum* as compared to control. The highest increase in the plant growth parameters viz., plant length, fresh weight, dry weight, number of leaves and leaf area was observed in the plants grown in soil amended with chopped leaves of *P. niruri* followed by *P. hysterophorus*, *W. somnifera* and *C. cordifolia* as compared to plants grown in un-amended soil. However, on the other, hand plants amended with chopped leaves of *A. mexicana*, *C. sativa*, *C. angustifolia*, *C. forskohlii*, *D. erecta* and *T. cordifolia* did not show any significant effect on plant growth parameters in comparison to control.

It was observed that out of the leaves of ten plants, used in the present study to manage the disease complex caused by *M. incognita* Race-3 and *R. solani*, only the amendment of leaves of four plants viz., *A. mexicana*, *P. niruri*, *P. hysterophorus* and *T. cordifolia* showed improvements in plant growth and physiological parameters of *P. atropurpureum* infected with *M. incognita* Race-3 and *R. solani* as compared to
unamended and *M. incognita* Race-3 and *R. solani* inoculated plants (control-II). Moreover, the highest improvement in plant growth and physiological parameters was recorded in the plants grown in soil amended with leaves of *P. niruri*, followed by *T. cordifolia, A. mexicana* and *P. hysterophorus*. It was also observed that the amendment of leaves of these plants viz., *A. mexicana, P. niruri, P. hysterophorus* and *T. cordifolia* showed a significant reduction in the disease development in terms of root galling, egg masses as well as reproduction factor in comparison to control-II. The maximum decrease in number of galls, egg masses, reproduction factor, root-rot and delayed appearance of collar-rot and crown-rot symptoms was observed in the plants amended with leaves of *P. niruri* followed by *T. cordifolia, P. hysterophorus* and *A. mexicana*, which in turn increased the plant growth and physiological parameters of *P. atropurpureum*.

The studies were also conducted to manage the disease complex involving *M. incognita* Race-3 and *R. solani* in *P. atropurpureum* by using sawdust of some plants. The soil amended with sawdust of three plants viz., sheesham (*Dalbergia sissoo*), teak (*Tectona grandis*) and neem (*Azadirachta indica*) also significantly improved the plant growth parameters of *P. atropurpureum* as compared to control. Moreover, the highest improvement in plant growth parameters was recorded in the *P. atropurpureum* plants amended with sawdust of neem followed by teak and sheesham sawdust. While, the plants amended with sawdust of sal, babool, cedrus and chir pine did not show significant variation in plant growth parameters of *P. atropurpureum* as compared to control.

The results showed that out of seven types of sawdust, only the sawdust of three plants viz., neem, teak and sheesham showed the improvement in plant growth and physiological parameters of *P. atropurpureum* infected with *M. incognita* Race-3 and *R. solani* as compared to unamended and *M. incognita* Race-3 and *R. solani* inoculated plants (control-II). Moreover, the highest improvement in growth and physiological parameters was obtained in the plants amended with neem sawdust followed by teak and sheesham sawdust. The data further, revealed that, the soil amended with sawdust of neem, teak and sheesham showed a significant reduction in the development of disease caused by *M. incognita* Race-3 and *R. solani* in terms of reproduction factor of nematode, root galling and rotting in underground and aerial parts of plants as compared to control-II. The highest decrease in number of galls, egg
masses, and reproduction factor was observed in plants amended with sawdust of neem followed by teak and sheesham sawdust. Similarly, the intensity of root-rot caused by *R. solani* was reduced, while, the duration of appearance of collar-rot and crown-rot symptoms increased significantly in the plants amended with sawdust of neem, teak and sheesham as compared to control-II. The maximum significant reduction in root-rot and delayed appearance of collar-rot and crown-rot symptoms were recorded in the plants grown in soil amended with neem sawdust followed by teak and sheesham sawdust.

At the end, the experiment on integrated management of disease complex caused by *M. incognita* Race-3 and *R. solani* was also carried out by using nematicide – carbofuran (as bare root-dip treatment), fungal biocontrol agents, chopped leaves and sawdust of some plants. The findings revealed that the integration of bare root dip treatment with carbofuran, inoculation of fungal biocontrol agent (*T. atroviride/P. lilacinus*) and soil amended with either of the sawdust of neem, teak and sheesham or chopped leaves of *A. mexicana, P. hysterophorus, P. niruri* and *T. cordifolia* in different combinations, increased the plant growth and physiological parameters by reducing the intensity of disease development in terms of root galling, reproduction factor of nematode and root-rot in *P. atropurpureum* in comparison to control-II. Furthermore, the components used in various combinations also delayed/ completely suppressed the expression of collar-rot and crown-rot symptoms in *P. atropurpureum*. The complete suppression of collar-rot and crown-rot symptoms was recorded in the plants treated with carbofuran, *P. lilacinus* and either of the leaves of *P. niruri, T. cordifolia* and *P. hysterophorus* or neem sawdust; and carbofuran, *T. atroviride* and either of the leaves of *A. mexicana, P. hysterophorus, P. niruri* and *T. cordifolia* or neem sawdust.

Among the above treatments, the significantly highest improvement in plant growth and physiological parameters was recorded in plants treated with carbofuran + *T. atroviride + P. niruri* leaves, followed by carbofuran + *T. atroviride + neem sawdust, carbofuran + *T. atroviride + P. hysterophorus* leaves, carbofuran + *P. lilacinus + P. niruri* leaves, carbofuran + *T. atroviride + T. cordifolia* leaves, carbofuran + *P. lilacinus + P. hysterophorus* leaves, carbofuran + *P. lilacinus + T. cordifolia* leaves, carbofuran + *T. atroviride + A. mexicana* leaves and carbofuran + *P. lilacinus + neem sawdust* as compared to control-II.

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The results clearly revealed that the maximum reduction in root-rot was recorded in plants treated with carbofuran + *T. atroviride* + *P. niruri* leaves, followed by carbofuran + *T. atroviride* + neem sawdust, carbofuran + *T. atroviride* + *T. cordifolia* leaves, carbofuran + *P. lilacinus* + *P. hysterophorus* leaves, carbofuran + *P. lilacinus* + *P. niruri* leaves, carbofuran + *T. atroviride* + *A. mexicana* leaves, carbofuran + *P. lilacinus* + *T. cordifolia* leaves, and carbofuran + *P. lilacinus* + neem sawdust as compared to control-II. Moreover, the highest reduction in reproduction factor of root-knot nematode, number of galls and egg masses per root system were noticed in the plants treated with carbofuran + *P. lilacinus* + *P. niruri* leaves, followed by carbofuran + *P. lilacinus* + *P. hysterophorus* leaves, carbofuran + *T. atroviride* + *P. niruri* leaves, carbofuran + *P. lilacinus* + *T. cordifolia* leaves, carbofuran + *T. atroviride* + *P. lilacinus* + *T. cordifolia* leaves, carbofuran + *T. atroviride* + *P. hysterophorus* leaves, carbofuran + *T. atroviride* + *A. mexicana* leaves and carbofuran + *P. lilacinus* + neem sawdust.

The integration of carbofuran + *T. atroviride* + teak sawdust and carbofuran + *P. lilacinus* + *A. mexicana* leaves showed the complete suppression of crown-rot symptom, whereas, appearance of collar-rot was delayed. However, on the other hand, the remaining three treatments viz., carbofuran + *P. lilacinus* + teak sawdust, carbofuran + *P. lilacinus* + sheesham sawdust and carbofuran + *T. atroviride* + sheesham sawdust could not suppress the appearance of collar-rot and crown-rot symptoms. Among these treatments, the greatest improvement in plant growth and physiological parameters and reduction in percentage of root-rot was recorded in the plants treated with carbofuran + *P. lilacinus* + *A. mexicana* leaves, followed by carbofuran + *T. atroviride* + teak sawdust, carbofuran + *P. lilacinus* + teak sawdust, carbofuran + *P. lilacinus* + sheesham sawdust and carbofuran + *T. atroviride* + sheesham sawdust. Whereas, the highest reduction in nematode reproduction factor, number of galls and egg masses per root system was recorded in plants treated with carbofuran + *P. lilacinus* + *A. mexicana* leaves, followed by carbofuran + *P. lilacinus* + teak sawdust, carbofuran + *P. lilacinus* + sheesham sawdust, carbofuran + *T. atroviride* + teak sawdust and carbofuran + *T. atroviride* + sheesham sawdust.

The treatments, particularly showing the higher improvement in plant growth and physiological parameters and complete suppression of collar-rot and crown-rot
symptoms may be suggested to the floriculturists/ growers only after making field trials for the management of disease complex involving *M. incognita* Race-3 and *R. solani* in *P. atropurpureum*. 