% reduction in plant growth as compared to control. The reproduction factor of reniform nematode and percent disease index of root-rot fungus was recorded as 0.8 and 7.5, respectively. Similarly, the treatments of Cr and Ni resulted in 2.1 and 4.2 % reduction in plant growth of chickpea variety Phule G 8602. The reduction in plant growth was found as 4.2 and 6.3 % in the plants inoculated with *R. reniformis* and soil treated with either Cr or Ni, respectively. The reproduction factor of *R. reniformis* was recorded as 0.3 and 0.6 in the corresponding treatments. Similarly, the reduction in plant growth was observed as 5.2 and 7.3 % in plants inoculated with *F. solani* and treated with either Cr or Ni, respectively. The disease index of *F. solani* was recorded as 4.0 and 6.2% in the corresponding treatments. Therefore, it was concluded from these results that chickpea variety Phule G 8602 did not lose its resistance even in concomitant presence of test pathogen and heavy metal.
Discussion
Man is aware of the problems of maintaining himself and his descendants on the planet of fixed size. Not only the problem of food supply is becoming critical, but the waste and the end products of man's existence must be disposed off or utilized in such a way that the quality of his environment is not impaired for this or future generations. However, the lavish life styles and comforts have been achieved at the cost of many environmental problems, the pollution being the foremost. Pollution may be defined as an undesirable accumulation of residues of various organic and inorganic materials in soils and water as a result of man's activities. The problem of pollution would appear to have three phases-uncontrolled release of materials into ecosystems, release of pollutants from disposal systems because of improper or insufficient treatment or lack of knowledge concerning possible hazards and use of materials for specific purposes on land and vegetation which may have unrecognized pollutant hazards due to other properties of materials.

Heavy metals like lead, cadmium, chromium, nickel, mercury etc. have significantly been detected in soils due to industrial effluents, organic wastes, refuse burning, transport, power generation, smoke release from domestic and industrial chimneys etc. and are also found to depress the plant growth and yield at their different levels of application. Similarly, microorganisms including plant parasitic nematodes and plant-pathogenic fungi may also be greatly influenced by heavy metal contamination in the soil. Information with respect to the impact of heavy metals on reniform nematode, Rotylenchulus reniformis and root-rot fungus Fusarium solani on chickpea is not available. The focal theme of the present study is to assess the effect of heavy metals viz. Cr and Ni on pathogenic potential and management of R. reniformis and F. solani infecting chickpea. The results of different experiments are discussed in detail in the present chapter.
5.1: IDENTIFICATION OF RACE OF RENIFORM NEMATODE, *ROTYLENCHULUS RENIFORMIS* ASSOCIATED WITH CHICKPEA:

Since biological races are known to occur in *Rotylenchulus reniformis*, it was considered desirable to study the populations of reniform nematode in the present study and identify its race before initiating the research work so that the results obtained may be interpreted more scientifically and with authenticity. The results (Table 1 and Figs 1 to 1.1) clearly showed that all the isolates of *R. reniformis* were able to attack and multiply on castor, cowpea, cotton and mustard, but these populations were unable to infect bajra, therefore, the populations of *R. reniformis* collected from different locations belonged to the same race, which is designated as Race-3. Hence *R. reniformis* Race-3 was used for the experimental purposes. So far there is no information regarding the races of reniform nematode associated with chickpea. Moreover, there are some reports which showed the occurrence of different races of reniform nematode on different plants (Dasgupta and Seshadri, 1971; Nakasona, 1983; Khan, 1986; Prasada Rao and Ganguly, 1996).

5.2: EFFECT OF CHROMIUM AND NICKEL ON THE HATCHING AND MORTALITY OF RENIFORM NEMATODE, *ROTYLENCHULUS RENIFORMIS* IN VITRO:

It is evident from the results that both the heavy metals (Cr and Ni) were inhibitory to nematode hatching, Cr being more toxic than Ni. The percentage mortality of *R. reniformis* was correlated with the concentrations of heavy metals and exposure period. There was a gradual increase in the nematode mortality with an increase in the exposure period and the concentration of either Cr or Ni (Tables 2 to 2.1 and Figs 2 to 2.1).

In the present study, increase in the concentration of both Cr and Ni resulted in the increased inhibition in the hatching of *R. reniformis*. Khan and Salam (1990) in conformity with the present findings recorded that Ni was
inhibitory to the hatching of *Meloidogyne javanica* at all concentrations except 9.71 mg / l. Similar findings with different heavy metals on plant parasitic nematodes have also been reported by Robinson and Neal (1959), Khan *et al.* (1994) and Parveen and Alam (1999a). Robinson and Neal (1959) reported that adding microgram amounts of zinc sulphate and cadmium chloride to dithizone - extracted potato root diffusate inhibited hatching of *Heterodera rostochiensis* and they suggested that the metal ions were responsible for the inhibition of hatching. Khan *et al.* (1994) reported that the hatching of *M. incognita* was greatly suppressed by all the concentrations of cobalt used. Parveen and Alam (1999a) reported that with an increase in the concentration of Pb and Cd, there was a gradual increase in the inhibition of hatching of *M. incognita*, however, the former was reported to be more toxic. Moreover, my findings are contradictory with Clarke and Shepherd (1965, 1966) who indicated that several ions including Ni^2+^ and Cr^3+^ stimulated the hatching of *Heterodera* spp.

In the present study, the mortality of the nematode increased with an increase in the concentrations of heavy metals and the exposure periods. Adverse effect of the heavy metals on mortality of plant parasitic nematodes has been reported by others also (Khan and Salam, 1990; Khan *et al.* 1994; Parveen and Alam, 1999a). Khan *et al.* (1994) reported that all the concentrations of cobalt were effective in inducing mortality of second stage larvae of *M. incognita*. Khan and Salam (1990) found that Ni and Co were toxic to the second stage juveniles of *M. javanica* and all the juveniles were killed in 9710 mg/l of Ni and Co at and above 1111.7 mg/l. However, on the other hand, Jaworska *et al.* (1997) reported that several metals including Cr and Ni (except Pb II) even at naturally unrealistic concentrations did not cause mortality of *Heterorhabditis bacteriophora*.

According to Clarke and Shepherd (1966), it seems more probable that heavy metal ions are taken up by some constituent of egg or larvae, which alter the structure and function of the binding materials viz. nucleic acids and
proteins that provide many suitable ligands. The binding of ions by either nucleic acid or protein might alter their secondary and tertiary structure enough to change their behavior within the biological system, where they occur, which might be responsible for the mortality and inhibition of hatching of nematode. The variable effect of heavy metals on hatching and mortality of nematode could be due to the differences in the relative toxicity of heavy metals.

5.3: EFFECT OF CHROMIUM AND NICKEL ON THE GROWTH, SPORULATION AND HEAVY METAL UPTAKE OF Fusarium solani IN VITRO:

The effect of heavy metals viz. Cr and Ni on the growth and sporulation of Fusarium solani and, uptake of these metals by F. solani was assessed in vitro. The results revealed that the growth and sporulation of F. solani significantly decreased with an increase in the concentration of Cr or Ni (except at 25 ppm Cr and, 25 and 50 ppm Ni). Moreover, the growth and sporulation of the fungus was significantly enhanced when it was grown in medium added with 25 ppm Ni. As far as the uptake of the heavy metal in the fungus was concerned, it increased with the increasing concentration of the heavy metals. However, the uptake of Ni by F. solani was more than that of Cr. Chlamydospore formation initiated at and above 50 ppm of Cr and 100 ppm of Ni, which increased further with an increase in the concentration of the heavy metals (Table 3 and Fig. 3).

The above results are in consonance with the findings of Singh et al. (1992), who reported that with an increase in the concentration of Cr and Ni, there was a corresponding decrease in the growth of fungus Paecilomyces lilacinus irrespective of the fact whether the fungus was raised either in liquid or solid medium. Similarly, Parveen and Alam (1993, 1997) reported that Cd and Pb were inhibitory to the growth of P. lilacinus and Pb was more toxic than Cd. The effect of heavy metals on the growth of different fungi have also been reported by various workers
from time to time (Babich and Stotzky, 1979; Lokesha and Somashekar, 1990; Kredics et al., 2001b; Levinskaite, 2001). Moreover, according to Lokesha and Somashekar (1990) Aspergillus versicolor and Colletotrichum dematium showed good growth on Ni amended medium with 100mg/l as compared to control, which was found to be against my findings. This difference might be attributed to the use of different genera of fungi used in the experiments.

The sporulation of *F. solani* decreased with an increase in the concentration of Cr or Ni (except at 25ppm Ni), which holds true with the findings of Levinskaite (2001) who reported that conidiogenisis of *Penicillium* was affected by Ni. Rajendran et al. (2002) also tested the toxicity of NiCl₂ to *Aspergillus niger* and found that 1.7 mM nickel caused 50% conidial inhibition. Similar effects of Pb and Cd on the sporulation of *P. lilacinus* has also been reported by Parveen and Alam (1993, 1997). The inhibition in the growth and sporulation of *F. solani* in the presence of Cr and Ni may be due to the toxicity of these heavy metals. Another probable reason may be the interference of these metals in different metabolic activities such as enzyme synthesis and other biochemical reactions etc. (Kredics et al., 2001a). The heavy metals had more toxic effects on the development of macroconidia as compared to that of microconidia which could be probably due to the reason that macroconidia had more absorption and accumulation of heavy metals because of their bigger size and greater surface area. It was interesting to note that there was no chlamydospor formation by *F. solani* in the medium either free from heavy metals or medium incorporated with 25ppm Cr and, 25 and 50ppm Ni. Moreover, the higher concentrations of either Cr or Ni lead to the formation of chlamydospores by *F. solani*, which might be due to the survival of the fungus under stress conditions created by these heavy metals. It is commonly known that *F. solani*
produces chlamydospores under unfavorable conditions. According to Booth (1971), this fungus abundantly produces only chlamydospores in nutrient deficient medium, however, it produces conidia when the nutrient status of the medium is raised by the addition of glucose (Alexander, 1965).

In the present study the heavy metals viz. Cr and Ni were taken up by the *F. solani* and it was increased with an increase in the concentration of heavy metals. Similar results on the uptake of copper by *Aspergillus* species has also been reported by Chandra and Muthumary (1993).

Narayana and Manoharachary (1994) reported that the fungi belonging to genera *Aspergillus, Penicillium* and *Trichoderma* were tolerant and highly adapted to the effluents containing heavy metals. However, some Mucorales and Ascomycetes were reported to be sensitive, towards heavy metals. It was concluded that the predominantly occurring fungi might have degraded the effluent residues and later multiplying with the help of some useful metabolites. Nordgren et al. (1985) also found that the fungal community was strongly affected by the heavy metal pollution.

The differences in the effect of Cr and Ni on growth, sporulation and their uptake by *F. solani* may be due to their variable toxicity.

**5.4: STUDIES ON POTENTIAL PATHOGENIC LEVEL OF RENIFORM NEMATODE, *Rotylenchulus reniformis* AND ROOT-ROT FUNGUS *Fusarium solani* ON CHICKPEA:**

To determine the potential pathogenic level of reniform nematode and root-rot fungus, the seedlings of chickpea were separately inoculated with different inoculum level of *Rotylenchus* nd 8000 immature females per plant) and *F. solani* (0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 g
per plant). There was a gradual increase in the reduction of plant growth, nodulation, yield, chlorophyll content, protein content and water absorption capacity of roots of chickpea with increase in inoculum level of *R. reniformis* except at the inoculum level of 250 immature females per plant which slightly increased plant growth as compared to uninoculated plants. However, the significant reduction in the above mentioned parameters of chickpea plants was recorded at and above 1000 immature females of reniform nematode.

The rate of nematode multiplication of *R. reniformis* decreased with an increase in the inoculum level. Since the root surface area for both, the lower and higher inoculum levels remained the same, crowding of reniform nematode at higher inoculum densities created competition among the nematodes, which resulted in their natural death and reduced multiplication. The high rate of nematode multiplication at low levels of inocula, on the other hand, could possibly be due to the positive factors like abundance of food, lack of competition and the ability of host to support these population levels. According to Oostenbrink (1966), the increase in the nematode populations and subsequent reductions in the yield of crop are directly influenced by the initial density of nematodes in the soil. His view holds true with the present findings wherein plant growth and yield of chickpea was proportionately affected with an increase in the initial inoculum levels of nematode. The progressive decrease in the plant growth parameters and nematode multiplication with increasing inoculum of *R. reniformis* on chickpea has also been reported by various workers (Mahapatra and Padhi, 1986; Ahmad *et al.*, 1987; Daraker and Jagdale, 1987; Zaidi *et al.*, 1988; Tiyagi and Alam, 1987; 1990).

In present study, the percentage of disease index of *F. solani* increased with increase in the inoculum level. Similarly, a direct correlation between increasing initial inoculum level with decreasing plant growth, yield, nodulation, chlorophyll content, protein content and water absorption capacity of roots was observed for the root-rot fungus, *F. solani*. However, the
significant reduction in respective parameters of chickpea was observed at and above 3.0 g of *F. solani* / plant. These results are in agreement with those of Mani (1982) and Khan and Husain (1991) who reported that with an increase in the inoculum level of *F. solani*, there was a corresponding increase in the plant growth reduction and the percentage of root-rot of chickpea and papaya, respectively.

The reduction in plant growth parameters may be due to physiological and structural alterations caused by the pathogens. The infection caused by reniform nematode and root-rot fungus might disrupt the root system and interferes with the physiological process involved in water and nutrient relations and the phytohormones originating in the roots (primary factors) . thereby creating a cascade effect on chlorophyll synthesis, photosynthesis and respiration in shoot (secondary factors) . The combination of these primary and secondary effects may lead to the reduction in plant growth, yield, protein content and chlorophyll content as compared to uninfected plants (Melakeberhan, 2004). My results are also in agreement with those of Tiyagi and Alam (1990) and Murukumar and Chavan, (1985) who reported that chlorophyll content in the leaves of chickpea decreased in plants infected with *R. reniformis* and Fusarium wilt fungus, respectively. Similarly, my results are in accordance with Khan *et al.* (1996) who reported that protein content of chickpea seeds decreased in plants infected with *Meloidogyne incognita*.

The reduction in the number of nodules in chickpea plants infected with either *R. reniformis* or *F. solani* might be due to the adverse effect of toxic substances from nematode and fungus infected roots on the rhizobium itself and / or due to nutritional interference particularly carbohydrates (Nutman, 1958). It is well known that rhizobial infection takes place through the root hairs into the cortex where the sites of nodulation exist. As the nematode and fungus infection depletes the root hairs, the rhizobial infection is inhibited. Reduction in nodulation may also be attributed to some changes in the host.
metabolism due to nematode / fungus infection which makes it unsuitable or less preferred by the rhizobium. The reduction in number of nodules in the plants infected with *R. reniformis* was also reported by Taha and Raski (1969), Darekar and Jagdale (1987) and Tiyagi and Alam (1987). Similarly, these results are in agreement with the findings of Mani (1982) who reported that number of nodules decreased in chickpea plants infected with *F. solani*.

With an increase in the inoculum level of either *R. reniformis* or *F. solani*, there was a corresponding decrease in the water absorption capacity of chickpea roots, which is in agreement with the findings of Tiyagi and Alam (1990) who reported that inhibition in water absorption of chickpea plants was directly proportional to the inoculum level of *R. reniformis*. Khan (1986) also reported that the water absorption capability of cowpea roots was adversely affected by the infection of *R. reniformis, M. incognita* and *Rhizoctonia solani*. Subramanian and Saraswathidevi (1959) pointed that poor water absorption in diseased plants may be due to injury to roots as a result of infection with bacteria and viruses or due to the deformation, chocking and disturbance in the arrangement of tracheary elements. These possibilities cannot be ruled out in fungus or nematode infected plants as *F. solani* is an endoparasite known to damage, deform and disrupt the cortical and the conducting tissues of roots (Ren et al., 2008), while *R. reniformis* a semiendoparasite causes aberrations in the internal tissues (Agudelo et al., 2005). Infection of either *R. reniformis* or *F. solani* inhibited the root growth and thus reduced total surface area of roots resulting in the poor absorption of water by the infected roots. Alternatively, the reduction in shoot weight (or leaf surface area) due to nematode or fungal infection might have also resulted in reduced transpiration pull which in turn retarded the water absorption capacity.

From the present investigations, it could be inferred that the potential pathogenic level of *R. reniformis* on chickpea is 1000 immature females / plant, which is in agreement with the finding of Tiyagi and Alam (1987) and Zaidi et
al. (1988) on chickpea. However, the results are contradictory with the finding of Mahaptra and Padhi (1986) who reported that an initial inoculum level of 500 nematodes / plant as pathogenic level on chickpea. According to Daraker and Jagdale (1987) and Sharma and McDonald (1990) the damage threshold level of *R. reniformis* on chickpea range from 1.0 to 2.0 nematodes per gram of soil. This variation in the inoculum threshold level of *R. reniformis* might due to different experimental conditions, races / strains of reniform nematode and chickpea variety used in their study.

Similarly, the potential pathogenic level of *F. solani* on chickpea was recorded as 3.0 g of *F. solani* per plant which is against the findings of mani (1982) and Khan and Husain (1991) who reported 4.0 g and 2.5 g of *F. solani* as pathogenic level in chickpea and papaya, respectively. This variation may also be attributed to the different experimental conditions, host status and different strains of *F. solani* used in the study.

The information gathered from the present study may provide a baseline for further research to develop appropriate strategies for the management of reniform nematode and root-rot fungus infecting chickpea.

5.5: EFFECT OF CHROMIUM AND NICKEL ON PATHOGENIC POTENTIAL OF RENIFORM NEMATODE, *ROTYLENCHULUS RENIFORMIS* AND ROOT-ROT FUNGUS, *FUSARIUM SOLANI* INFECTIONG CHICKPEA:

An experiment was conducted to assess the effect of heavy metals (chromium and nickel) on the pathogenic potential of *Rotylenchulus reniformis* and *Fusarium solani* infecting chickpea. The results presented in Tables 5 to 5.7 clearly showed that with an increase in the concentration of heavy metal (Cr or Ni) from 25 to 200 ppm, there was a significant gradual increase in the reduction of plant growth, yield, nodulation, chlorophyll content, protein content and water absorption capacity of chickpea only at 100 and 200 ppm of Cr or Ni. Several studies have also revealed the adverse effects of chromium on
DISCUSSION

plant growth (Ottabbong, 1989; Sharma and Sharma, 1993; Shanker et al., 2005); yield (Sharma and Sharma, 1993; Panda and Choudhury, 2005), nodulation (Wani et al., 2007), chlorophyll content (Rai et al., 1992; Panda and Choudhury, 2005), protein content (Rai et al., 1992; Panda and Choudhury, 2005), and water absorption capacity of roots (Shanker et al., 2005) of different plants. The reduction in plant growth parameters of chickpea in presence of Cr might be attributed to the deleterious effects of chromium on various physiological processes such as photosynthesis, water relations and mineral nutrition etc. (Cervantes et al., 2001; Shanker et al. 2005). The reduction in the chlorophyll content in the Cr treated plants might be due to inhibition of chlorophyll synthesis and also an increase in chlorophyll degradation by heavy metal (Cervantes et al., 2001; Shanker et al., 2005).

The increase in the concentration of Ni in soil proved to be potentially toxic to chickpea plants, causing chlorosis and necrosis of leaves and reduced plant growth. Similar symptoms of Ni toxicity have also been reported on lettuce (Temple and Bisessar, 1981), celery (Bisessar et al., 1983) and tomato (Khan et al., 2006). Several studies have also revealed that nickel reduced the plant growth (Hagemeyer, 1999); yield (Hagemeyer, 1999); nodulation (Wheeler et al., 2001); chlorophyll content (Myśliwa-Kurdziel et al., 1999) and water absorption capacity of roots (Poschenrieder and Barcelo, 1999) of different plants. It has been reported that the excess of nickel inhibits the chlorophyll biosynthesis and induces degradation (Krupa and Baszynski, 1995; Abdel-Basset et al., 1995) with a subsequent decrease in chlorophyll concentration (Molas, 2002) that is manifested as chlorosis and/or necrosis of foliage. There are considerable evidences that the excess of Ni acts as a potent inhibitor of growth, development and various metabolic processes in plants (Van Assche and Clijsters, 1990; Hagemeyer, 1999) which induces visible symptoms of phytotoxicity, depressing growth and dry matter of plants (Agarwala et al., 1977; Austenfield, 1979; Hagemeyer et al., 1999).
With an increase in the concentration of heavy metals (Cr and Ni), there was a corresponding decrease in the number of nodules per root system. This might be because the heavy metal pollutants reduce the population of symbiotic nitrogen fixing organisms (McGrath, 1994).

It is well known fact that heavy metals can act at different sites to inhibit a large number of enzymes having functional sulphydryl groups resulting in the disruption in the pathways of protein synthesis (Valle and Ulmer, 1972). According to Hampp et al. (1976) the relatively strong affinities of ligands of protein indicate that enzymes and other functional proteins are one of the prime targets of metal toxicity. These reasons might be responsible for the decrease of protein content with an increase in the concentration of Cr and Ni in the present study.

It is well known that the heavy metals may enter the xylem cells where they may form complexes with the elements of xylem cell sap and get deposited on the cell walls causing a hindrance in the supply of water to the different parts of plants (Panda and Patra, 2000). This might be the reason for reduction of water absorption capacity with an increase in the concentration of heavy metals (Cr and Ni) in the present study.

The inoculation of chickpea plants separately with *R. reniformis* and *F. solani* significantly reduced the plant growth, yield, nodulation, chlorophyll content, protein content and water absorption capacity of roots. However, the reniform nematode was less damaging than root-rot fungus.

In the plants inoculated with *R. reniformis* and grown in soil treated with 25, 50, 100 and 200 ppm concentrations of Cr and Ni, a synergistic reduction in plant growth, yield, nodulation, chlorophyll content, protein content and water absorption capacity of roots of chickpea was recorded except at 25ppm Cr. Moreover, the effect of interaction between *R. reniformis* with either of the heavy metals (Cr / Ni) on growth and other parameters was directly proportional to the concentrations of heavy metals. Khan *et al.* (1996) and
Khan et al. (2006) reported that the combined effect of Ni and root-knot nematodes viz. *M. javanica* and *M. incognita* on chickpea and tomato was synergistic at 50 ppm Ni, which is in agreement with my results also. At the same time they reported the combined effect of Ni and root-knot nematode on chickpea and tomato was not synergistic at 100 and 200 ppm Ni which is against my findings.

In the present study, the reproduction factor of the reniform nematode was significantly reduced with an increase in the concentration (25-200 ppm) of Ni/Cr. This might be due to the toxic effects of Cr/Ni to *R. reniformis*. However, Khan et al. (1996) and Khan et al. (2006) reported the increased number of galls, eggmasses, fecundity and soil population of *M. incognita* and *M. javanica* infecting chickpea and tomato, respectively at the 50 ppm Ni while it decreased with further increase in the concentration of heavy metal (100 and 200 ppm Ni). My observations are also in contrast with another study where even the higher concentration of Ni (7500 Ni/Kg soil) significantly increased the number of galls on celery roots (Bisessar et al., 1983). But, the reason given to it was that the study was conducted in the soil contaminated with other metals (80 mg Cu and 100 mg Co/Kg soil). These differences in the results may also be due to the different nematodes and/or plants used in the experiments.

The plant growth, yield, nodulation, chlorophyll content, protein content and water absorption capacity of roots was synergistically reduced in the plants inoculated with *F. solani* and grown in soil treated with 25, 50, 100 and 200 ppm concentrations of Ni. However, on the other hand plants inoculated with *F. solani* and grown in soil treated with 25, 50, 100 and 200 ppm concentrations of Cr did not show synergistic effect on these parameters. Moreover, the effect of interaction between *F. solani* with either of the heavy metals on plant growth and other parameters was directly proportional to the concentration of heavy metal. Khan and Salam (1990) reported that the
interactive effect of *F. udum* and heavy metals on plant growth reduction was directly proportional to the concentration of heavy metals, which is in accordance with my results. In the present study, the disease index of *F. solani* showed a declining trend with increasing the concentration of heavy metals (Cr / Ni), which might be due to the toxic effects of Ni and Cr to *F. solani*. According to Khan and Salam (1990) nickel inhibited wilting caused by *F. udum* on pigeonpea, which is in conformity with my findings. The inhibitory effect of Ni has also been reported against rust diseases on wheat (Chatrath *et al*., 1974), groundnut (Seshadri, 1976) and sugarcane (Bachchhav *et al*., 1978).

The present study demonstrates a concentration dependent relationship of heavy metals (Cr/Ni) in the soil with reniform nematode and root-rot fungus. The nematode or fungal infection can increase plant sensitivity to heavy metals in the soil which is also supported by my findings in which the accumulation of heavy metals increased in the plants grown in soil treated with heavy metals (Cr or Ni) and inoculated with either *R. reniformis* or *F. solani*. It can be concluded from the above study that the heavy metals in the soil can enhance the reduction in plant growth and yield of chickpea in presence of *R. reniformis* / *F. solani*.

**5.6: ACCUMULATION OF CHROMIUM AND NICKEL IN CHICKPEA PLANTS INFECTED WITH *ROTYLENCHULUS RENIFORMIS* AND *FUSARIUM SOLANI*:**

The amount of heavy metals viz. Cr and Ni in chickpea was estimated on dry weight basis by Atomic Absorption Spectrophotometry (AAS). It was interesting to note that Cr was accumulated by plants in a lesser amount than Ni. However, the concentration of the heavy metal accumulation was more in inoculated plants than the uninoculated plants. The heavy metals were accumulated in greater amounts by plants inoculated with fungus than the plants inoculated with the nematode. It was further noted that the amount of
heavy metals was more in roots than in the shoots (Tables 6 to 6.3). It was also observed that heavy metal accumulation in plants increased with an increase in the concentration of Cr or Ni.

The heavy metals accumulated in different parts of both inoculated and uninoculated plants but accumulation was greater in the former. In the nematode or fungus infected plants the heavy metals accumulation was greater in roots than in the shoots. These findings are in accordance with those of Bisessar et al. (1983) and Khan et al. (2006) who found similar accumulation of Ni in celery plants infected with *M. hapla* and tomato plants infected with *M. incognita*, respectively. Similar observations on the accumulation of Cd and Pb have also been reported by Parveen (1995) in tomato plants infected with *M. incognita*.

The induced accumulation of heavy metals in roots of nematode or fungus infected plants as compared to uninoculated plants was not clear, however, the nematode or fungal infection might be potentially disrupt the translocation of heavy metals from roots to aerial organs thus causes their greater accumulation in the roots (Wilcox-Lee and Loria, 1987). Similarly, Koeppe (1977) also reported that the translocation of heavy metals from roots to aerial parts is highly dependent on the physiological status of the plant.

**5.7: EFFECT OF CHROMIUM AND NICKEL ON THE LIFE CYCLE OF RENIFORM NEMATODE, *ROTYLENCHULUS RENIFORMIS* ON CHICKPEA:**

It is clear from the Tables 7 to 7.2 that the penetration, development and multiplication of reniform nematode, *R. reniformis* on chickpea was affected by the presence of heavy metals viz. Cr and Ni. *Rotylenchulus reniformis* required 28 days to complete the life cycle in chickpea, however, it was delayed by 11 and 5 days in the presence of Cr and Ni, respectively as compared to control. Several studies on the life cycle of reniform nematode were conducted by various workers on different pulse crops, which revealed that the duration of
life cycle of reniform nematode varied from 15-31 days. Moreover, no information is available regarding the duration of life cycle of reniform nematode in chickpea. Life cycle of reniform nematode was worked out initially by Linford and Oliveira (1940), according to him it takes about 25 days from egg to egg on cowpea. However, on the other hand, Peacock (1956) and Sharma and Haque (1993) reported that the life cycle of reniform nematode on cowpea was completed either in 15 days or 30-31 days. Similarly, the life cycle duration is reported to be either 25 days or 19 days on soybean (Peacock, 1956; Rebois, 1973) and 31 days on cluster bean (Bishnoi and Yadav, 1989). The number of eggs per eggmass also varied from host to host and on an average it ranges from 39 -120 eggs per eggmass (Swarup et al., 1989). The variation in time required to complete its life cycle and number of eggs laid by single female might be due to various ecological factors, especially host status, temperature, moisture, pH etc. (Swarup and Dasgupta, 1986; Bhatti and Walia, 1992).

As far as the delay in the life cycle of reniform nematode is concerned, the reason may be due to the delay in the penetration and development of different stages of nematode in the presence of Cr and Ni. The delay in the penetration of root-knot nematode in the presence of different heavy metals on different crops has also been worked out by Khan et al. (1994) and Parveen (2004). Moulting is an important phase in the life cycle of nematode in which nematode undergoes structural changes (Bird and Bird, 1991). Cuticle changes with each moult and each new cuticle has a distinct composition of proteins (Blaxter and Robertson, 1998). The binding of heavy metal ions with proteins which might alter their secondary and tertiary structure enough to change their behavior within the biological system, where they occur (Sampson et al., 1965). These reasons may also be responsible for the delay of life cycle and reduced population of reniform nematode in presence of Cr and Ni. Another
reason for this might be due to toxicological effects of Cr and Ni on reniform nematode.

The production of more males in Cr or Ni treated plants could be due to nutrition stress resulting due to various toxicological effects of heavy metals on plants. It is well established that the host nutrition is an important factor in altering sex ratios, usually with a shift towards males as nutrition becomes more unfavourable or when less food in the host tissue is available for nematode. These facts have been revealed by Triantaphyllou (1960) and Trudgill (1967).

5.8: EFFECT OF CHROMIUM AND NICKEL ON THE EFFICACY OF OIL-CAKES, BIOCONTROL AGENTS AND BAVISTIN IN THE MANAGEMENT OF ROTALYCHULUS RENIFORMIS AND FUSARIUM SOLANI INFECTING CHICKPEA:

The effect of heavy metal (Cr and Ni) on the efficacy of oil-cakes (neem, mustard, mahua, castor, linseed and sesame), fungal biocontrol agents (*Paecilomyces lilacinus* and *Trichoderma harzianum*) and fungicide (*Bavistin*) in the management of *R. reniformis* and *F. solani* infecting chickpea was studied. The results presented in Tables 8 to 8.3 revealed that the inoculation of *R. reniformis* or *F. solani* significantly reduced the plant growth and yield of chickpea. Similarly, the treatments of both the heavy metals (Cr and Ni) also caused significant reduction in plant growth and yield of chickpea. Moreover, the plant growth and yield of chickpea plants was synergistically reduced in the plants inoculated with *R. reniformis* and grown in soil treated with either Cr or Ni. However, the synergistic reduction in plant growth and yield of chickpea was observed only when *F. solani* was inoculated in the Ni-treated soil and no such reduction was found when the fungus was inoculated in Cr-treated soil.

In the present study the amendments of oil-cakes viz. neem cake, mustard cake, castor cake, sesame cake and mahua cake significantly improved
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the plant growth and yield of chickpea as compared to unamended-uninoculated plants, which may be due to their beneficial effects. The improvement in the growth of chickpea plants achieved by application of oil-cakes was attributed directly to the increase in nutrient status of soil, serving as manure. According to McConnell et al. (1993), the organic matter contributes to cation exchange capacity, water holding capacity and aggregate stability that leads to increase in crop yield (Muller and Gooch, 1982; Bryan and Lance, 1991). 

It is well known fact that organic materials are good suppressants of plant-parasitic nematodes and plant pathogenic fungi, and the diseases they cause. Oil-cakes of different plants have consistently shown their efficacy against a variety of plant-parasitic nematodes (Singh and Sitaramaiah, 1971; Khan et al., 1974a; Khan and Husain, 1988b; Pandey et al., 2003b) and plant-pathogenic fungi (Khan et al., 1974c; Zakaria et al., 1980; Chattopadhyay and Rai, 2004) on many crops. In the present study, oil-cakes of neem, mustard, castor and mahua were found effective in the management of *R. reniformis* by reducing the reproduction factor of nematode which consequently increased plant growth and yield of chickpea. These results on the efficiency of oil-cakes for the control of reniform nematode are also in agreement with those reported by Khan et al. (1974); Mishra and Prasad (1974), Yasssin and Ismail (1994), Mishra and Goswami (1996) and Ashraf et al. (2005) on different crops. Similarly, the amendments of oil-cakes viz. neem, mustard, castor, mahua and linseed were effective in reducing disease index of *F. solani*, which consequently increased the plant growth and yield of chickpea. The effectiveness of these oil-cakes in the management of diseases caused by *Fusarium* spp. have also been reported by several workers on different crops (Zakaria et al., 1980; Mukhopadhyay and Gupta, 1991; Raj and Kapoor, 1996; Pamodaya and Reddy, 1999; Chattopadhyay and Rai, 2004), which is in agreement with the present findings. The results on the inefficiency of sesame
cake in managing *F. solani* are against the findings of Khan *et al.* (1974c), Matti and Sen (1984), Singh *et al.* (1980) who reported this cake to be effective in controlling *F. solani* on different crops.

It is believed that oil-cakes release some nematotoxic and fungitoxic substances during their degradation in the soil (Singh and Pandey, 1965; Khan *et al.*, 1973; Khan *et al.*, 1974c). Alam and Khan (1974) reported that with the liberal supply of water, oil-seed cakes decomposed and released many compounds including ammonia, phenols, and aldehydes. These compounds have a nematicidal nature which has been proved by many workers (Khan *et al.*, 1974a; Whitehead, 1976; Alam *et al.*, 1978; 1979). These compounds have also been reported to possess fungicidal nature (Krishnamurthy *et al.*, 1959; Zakaria *et al.*, 1980). Decomposition of oil-cakes also produces water soluble fractions which are highly toxic to nematodes (Alam *et al.*, 1982). Sayre (1980) and Mian and Rodriguez-Kabana (1982) suggested that the action of organic amendments against plant parasitic nematodes may be due to the decomposing specific proteins or specific material that affects cuticle structures of nematodes. Sitararmaiah and Singh (1978) also reported release of fatty acids, while Khan (1969) and Hasan (1977) have indicated the release of amino acids and carbohydrates during the decomposition of organic matter. All these chemicals have been reported to be highly deleterious to many plant parasitic nematodes (Khan, 1969; Alam *et al.*, 1979; Badra *et al.*, 1979) and pathogenic fungi (Zakaria *et al.*, 1980). The efficacy of organic amendments in controlling nematodes and fungi may also be due to the release of organic acids, ammonia and nitrates during decomposition of the organic material, which are toxic to nematodes and fungi (Zakaria *et al.*, 1980; Yassin and Ismail 1994). Better growth in oil-cake amended plants appears to be due to the reduction in nematode population and disease index of fungus as well as due to the effect of oil-cakes as manure. Besides, the roots of plants grown in soil amended with oil-cakes undergo physiological changes which make them unfavorable for
nematode penetration and feeding, thus inducing a certain degree of resistance against the nematode attack (Alam et al., 1980) and this may be also be true in case of fungus. The ineffectiveness of linseed cake and sesame cake in the management of *R. reniform* and, that of sesame cake in the management of *F. solani* may be due to small quantity of these oil-cakes used or possibly because of their active principles being diluted due to the frequent watering.

The present study revealed that the application of fungal biocontrol agent *P. lilacinus* significantly improved the plant growth and yield of chickpea by reducing the population of *R. reniformis*. My result are also in conformity with the findings of Khan and Husain (1988,89) Khan and Saxena (1996), Vicente et al. (1991), Vicente and Acosta (1992), Walters and Barker (1994) and Ashraf et al. (2005) who reported the effectiveness of *P. lilacinus* in the management of reniform nematode on different crops. *Paecilomyces lilacinus* has been reported to reduce population densities of different plant parasitic nematodes and is considered as the most promising and practicable biocontrol agent (Jatala, 1986; Morgan-Jones et al., 1984; Siddiqui et al., 2000; Arif and Parveen, 2003). The inhibitory effect of *P. lilacinus* on the multiplication of reniform nematodes might be due to the parasitism of females, eggs and egg masses by *P. lilacinus* and/or toxic metabolites produced by the fungus. The *P. lilacinus* has been reported to produce peptidal antibiotics viz. P 168, lilacinin, leucinonastatin and paecilotoxin (Arai et al., 1973; Isogai et al., 1980; Mikami et al., 1989). These chemicals might be responsible for the killing of reniform nematode. Acetic acid has also been identified from culture filtrate of this fungus, which affects the movement of nematodes (Djian et al., 1991). The mortality and inhibition in the hatching of reniform nematode in culture filtrates of *P. lilacinus* has also been reported by Khan and Husain (1989) and Ashraf and Khan (2005). Moreover, Lara et al. (1996) found that *P. lilacinus* did not affect the population levels of *R. reniformis*, which is against my findings. The differences in the results could be due to the
differences in experimental conditions, different strain of *P. lilacinus* and/or race of reniform nematode.

*Pseudoloma* *lilacinus* exhibits proteolytic and chitinolytic activity (Qkafor, 1967; Gintis *et al.*, 1983; Jatala, 1986; Khan and Saxena, 1997). This feature is of some significance because the eggshell of nematodes is mostly made up of protein and chitin (Bird and McClure, 1976). Moreover, it has been reported that the fungal hyphae penetrate the eggshell through small pores formed by the chitinase activity in the vitelline layer. The fungus then grows inside the eggs, crushes the chitin and lipid shell layers, and destroys the contents of the eggs including the developing larva whose cuticle are disrupted (Morgan-Jones *et al.*, 1984). It has been observed that the mycelial proliferation on the body of females of reniform nematode might result in probable biosynthesis of destructive metabolites endogenously. This endopathic activity of the fungus leads to the ultimate mortality of reniform nematode. In the present study *P. lilacinus* was unable to reduce the damage caused by *F. solani* infecting chickpea, which is against the findings of Siddiqui *et al.* (1999; 2000) and Shahzad and Ghafrar (1989) who reported that *P. lilacinus* controls *Macrophomina phaseolina*, *Rhizoctonia solani*, *F. oxysporum* and *F. solani* infection on sunflower, chickpea, mungbean, mashbean and tomato. The differences in the results could be due to the varied experimental conditions, different strains of *P. lilacinus* and *F. solani* used.

In the present study *T. harzianum* significantly improved the plant growth and yield of chickpea as compared to unamended-uninoculated plants which is also in confirmity with the findings of Paulitz *et al.* (1986), Windham (1989), Harman and Bjorkman (1998) and Harman *et al.* (2004) who reported enhanced growth of many plants induced by *T. harzianum*. The increase in plant growth and yield of chickpea plants might be due to the root colonization of *T. harzianum* which improved mineral uptake, mineral release from the soil
and organic matter and enhanced the production of plant growth hormones
(Windham et al., 1986; Beyrle, 1995).

Similarly, the soil application of *T. harzianum* also significantly improved the plant growth and yield of chickpea infected with reniform nematode by reducing the reproduction factor of *R. reniformis*. The reduction in reproduction factor of reniform nematode may be attributed to the parasitism of eggs and egg masses of reniform nematode by *T. harzianum* as observed in the present study. *Trichoderma harzianum* has also been reported as nematophagous fungus on eggs, juveniles and females of cyst nematode (Susan et al., 1990), *Globodera rostochiensis* (Saiffullah and Thomas, 1996) and *Meloidogyne javanica* (Sharon et al., 2007). Besides parasitism of eggs and eggmasses of reniform nematode as observed in the present study it is also hypothesized that the production of nematicidal compounds by *T. harzianum* (Suarez et al., 2004) directly affected the nematode multiplication or made the roots less attractive and thus reduced nematode penetration which might have resulted in the reduction of nematode population. *Trichoderma harzianum* has also been found effective in the management of plant parasitic nematodes on many crops (Windham, et al., 1989; Rao et al., 1996; Siddique et al., 1999; Sharon et al., 2001; Haseeb et al., 2005; Pandey et al., 2007). Haggag and Amin (2001) reported that *T. harzianum* significantly reduced the infection of reniform nematode on sunflower which is also in accordance with present findings. Biocontrol activity of *T. asperellum* -203 and *T. atroviride* IMI 206040 (both fungi, previously defined as strains of *T. harzianum*) have been reported antagonistic to *M. javanica* in soil (Sharon et al., 2001). The effect of *Trichoderma* metabolites on root knot nematodes was demonstrated by implementing root – dip treatments with the fungal culture filtrate (Khan and Saxena, 1997a). Sharon et al. (2007) suggested that improved proteolytic activity of *Trichoderma* may also be important for the control of nematodes.
In the present study the application of *T. harzianum* significantly improved the plant growth and yield of chickpea inoculated with *F. solani* by reducing the disease index. My results are also in conformity with the findings of Okhovat and Karampour (1996), who reported the effectiveness of *T. harzianum* in controlling root-rot of chickpea caused by *F. solani*. Similarly, *T. harzianum* effectively managed *F. solani* on sunflower (Haggag and Amin, 2001) and ginger (Ram et al., 1997). The inhibitory effect of *T. harzianum* against *F. solani* was probably due to mycoparasitism, competition for space and nutritional sources and antagonistic chemicals produced and released into the environment. Mukerji and Garg (1988) reported that *Trichoderma* spp. produced the antibiotic compounds (Trichodermin, Acetaldehyde), extra cellular enzymes (Chitinase, Cellulase, (1-3) -β Glucanase), unsaturated monobasic acid (Dermadine) and peptides (Alamethicine, Sugukacillin). Enzymes such as chitinases, glucanases and proteases seem to be very important in the mycoparasitic process (Harman et al., 2004). According to Howell (2003) the production of chitinases may have direct significance in the parasitism of *Fusarium* spp. as these enzymes function by breaking down the polysaccharides, chitin and β-glucan that are responsible for the rigidity of the fungal cell walls thereby destroying cell wall integrity.

Moreover, *T. harzianum* may also induce systemic resistance mechanisms (Yedidia et al., 1999) in chickpea plants that might have provided the protection against *R. reniformis* and *F. solani*.

In the present study Bavistin was also found to be effective in controlling the damage caused by *R. reniformis* and *F. solani* in chickpea by reducing the reproduction factor and disease index, respectively. This can be due to the persistent and systemic antinematode and antifungal effects of Bavistin. The effectiveness of Bavistin in controlling plant-parasitic nematodes on different crops has also been documented by Haseeb et al. (2005) and Khan.
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and Husain (1988a). Bavistin was found to be most effective in reducing the disease index of fungus which might be due to its antimitotic effect by forming a complex with sub-unit of microtubuli and preventing the normal assembly of microtubulin units into spindle fiber. Therefore, mitotic spindle is distorted and daughter nuclei fails to separate, resulting in cell death of fungi (Hewitt, 1998). Moreover, it has also been reported that Bavistin inhibited the synthesis of DNA and other related processes of fungi due to its antimetabolic nature (Vyas, 1993). The effectiveness of Bavistin in the management of Fusarium spp. infecting different plants has also been reported by Etebarian, (1992), Haseeb and Shukla (2002) and Haseeb et al. (2005).

The effect of heavy metals (Cr and Ni) on the efficacy of oil-cakes in management of R. reniformis and F. solani infecting chickpea revealed that only neem cake, mustard cake, castor cake and mahua cake proved to be effective in managing R. reniformis and F. solani both in presence and absence of heavy metals. The reason attributed to this may be that these oil-cakes might adsorb heavy metals, thus limiting their uptake by plants. According to Ajmal et al. (2005), the oil-cakes of mustard adsorb Cr and Ni. Parveen and Alam (1999b) found that neem cake was effective in the management of M. incognita on tomato in presence and absence of Pb and Cd. Since on one side these oil-cakes reduced nematode / fungal damage to chickpea and on other side they adsorbed heavy metals (Cr and Ni), thus reducing their uptake capacity in plants, and hence also reduced the combined effect of pathogens and heavy metals. The ability of T. harzianum in reducing the damage caused by R. reniformis or F. solani in the presence and absence of heavy metals (Cr and Ni) could be because of its ability to accumulate heavy metals (Ledin et al., 1996) and its resistant nature towards heavy metals as reported by (Kredics et al., 2001a;b).

It can be concluded from the present study that the application of neem cake, mustard cake, mahua cake, castor cake and T. harzianum seem to be best
options for managing *R. reniformis* and *F. solani* on chickpea in presence and absence of heavy metals (Cr and Ni).

**4.9: SCREENING OF CHICKPEA VARIETIES FOR RESISTANCE AGAINST *ROTYLENCHULUS RENIFORMIS, FUSARIUM SOLANI, CHROMIUM* AND NICKEL:**

In nature performance of pathogens/parasites vary with changes in the host as well as environmental conditions, including pollutants. Crop cultivars, in addition to possessing gradation in resistance to parasitic or pathogenic agencies may also differ in their reaction to their pollutants. So it was considered worthwhile to work out that whether the observed disease response of a particular variety was a matter of resistance to the pathogen or to the pollutant. It was observed that different chickpea varieties responded differently to *R. reniformis, F. solani* and heavy metals viz. Cr and Ni. There was an adverse effect of each test pathogen and heavy metal on the growth of chickpea varieties, irrespective the level of its resistance against heavy metal or pathogen. These results are in conformity with those of earlier workers (Parveen and Alam, 1998; Ashraf and Khan, 2003).

Out of 25 chickpea varieties screened, 8 were highly susceptible (Annegiri-1, KUSCR-2, Pant-186, Pragati, Pusa-1103, Pusa-120, Radhey and Vardan), 8 susceptible (Avarodhi, Gaut, Gulab, K-850, Phule G 96020, Pusa-1060, Vijay and XVSCR-2), 5 tolerant (CSJD, JG-74, Phule G 92028, Sadabahar and WCG-2 (Surya)), 3 moderately resistant (Gauraw, KGD-1168 and KWR-108) and one resistant (Phule G 8602) against the reniform nematode, *R. reniformis*. Chickpea varieties namely Annegiri-1 and Radhey were found highly susceptible to *R. reniformis*. However, variety Annegiri-1 has been reported as susceptible to *M. incognita* (Krishna Rao and Krishnappa, 1995) and tolerant to *M. javanica* (Sharma *et al.*, 1995). Similarly, chickpea
variety Radhey has been reported as susceptible to *M. incognita* (Mani and Sethi, 1985; Pandey and Singh, 1990; Krishna Rao and Krishnappa, 1995). In the present study the chickpea variety Avrodhi was rated as susceptible to *R. reniformis*. Similarly, this variety has also been reported as susceptible and moderately susceptible to *M. incognita* by Krishna Rao and Krishnappa (1995) and Jaisani (1991), respectively. The chickpea variety Vijay was found as susceptible to *R. reniformis*, but, it was reported as resistant (Pandey *et al.*, 2003a) and tolerant (Ashraf *et al.*, 2003) to *M. incognita*. Pandey and Singh (1990) and Shelke *et al.* (1995) also reported the chickpea varieties viz. Anupam and Gaurav as susceptible against *M. incognita*.

Out of 25 chickpea varieties screened in the present study, 7 were highly susceptible (Annegiri-1, KUSCR-2, Pusa-1103, Radhey, Vardan, Vijay and XVSCR-2), 12 susceptible (Avarodhi, CSJD, Gauraw, Gaut, Gulab, K-850, Pant-186, Phule G 92028, Phule G 96020, Pragati, Pusa-120 and Pusa-1060), 3 tolerant (JG-74, KGD-1168 and Sadabahar), 1 moderately resistant (WCG-2 (Surya)) and 2 resistant (KWR-108 and Phule- G 8602) against the root-rot fungus, *F. solani*. In the present findings two varieties viz. Pragati and Gaurav were susceptible to *F. solani* which are in confirmity with those of Yadav and Narain (1993) who also reported these varieties as susceptible against *Alternaria alternata*. Similarly, the chickpea variety Vijay was found highly susceptible and KWR-108 as resistant to *F. solani*, these varieties also showed similar reaction to *R. bataticola* (Gangwar, 2002) and *F. oxysporum* (Shukla and Haseeb, 2001; Mishra *et al.*, 2001). In the present results, chickpea varieties Avrodhi and Radhey were rated as susceptible and highly susceptible to *F. solani*, respectively but the variety Avrodhi was reported as resistant to *F. oxysporum* (Mishra *et al.*, 2001) and variety Radhay as susceptible to *Alternaria alternata* (Yadav and Narain, 1993) and *R. bataticola* (Gangwar, 2002). Similarly, the varieties viz. Phule G 92028 and Phule G 96020 were
rated as susceptible to *F. solani* in the present experiment, but Gangwar (2002) observed these varieties as susceptible and moderately resistant to *R. bataticola*, respectively.

Similarly, out of 25 chickpea varieties, 15 were susceptible (Annegiri-1, CSJD, JG-74, Gauraw, KGD-1168, KUSCR-2, KWR-108, Phule G 92028, Phule G 96020, Pragati, Pusa-120, Sadabahar, Vardan, Vijay, and XVSCR-2), 7 tolerant (Avarodhi, Gaut, Gulab, K-850, Pusa-1103, Pusa-1060 and WCG-2 (Surya)), two moderately resistant (Pant-186 and Radhey) and 1 resistant (Phule G 8602) against chromium, while, 2 were highly susceptible (Pragati and XVSCR-2), 19 susceptible (Annegiri-1, Avarodhi, CSJD, JG-74, Gaut, Gulab, K-850, KGD-1168, KUSCR-2, Phule G 92028, Phule G 96020, Pusa-1103, Pusa-120, Pusa-1060, Radhey, Sadabahar, Vardan, Vijay and WCG-2 (Surya)), 3 tolerant (Gauraw, KWR-108 and Pant-186) and one resistant (Phule G 8602) against the nickel.

It was interesting to note that the chickpea variety, Phule-G 8602 showed resistance against both the pathogens and heavy metals. Therefore, this variety was once again tested for its resistance to check whether the resistance persisted if the plants were grown in the soil treated with either Cr or Ni even in the presence of either *R. reniformis* or *F. solani*. The results indicated that the variety Phule-G 8602 showed resistance towards *R. reniformis*, *F. solani* and both the heavy metals (Cr and Ni) even when the same chickpea variety was grown in soil infested with the test pathogen (*R. reniformis/F. solani*) and contaminated with heavy metal (Cr/Ni). Therefore, this variety may be recommended to farmers to grow in the fields infested with reniform nematode and root-rot fungus and contaminated with Cr and Ni after making field trials.

These results indicate that there are good possibilities for finding resistant chickpea varieties against test pathogens and heavy metals and the replacement
of susceptible varieties with resistant ones appears to be the most economic and suitable method for control of plant diseases.

Resistance may be used as a key component in the integrated management programme for the management of *R. reniformis* and *F. solani* infecting chickpea and also to reduce the adverse effect of heavy metals (Cr and Ni). Moreover, the variety identified as resistant, can be used to introgress the genes for resistance against *R. reniformis*, *F. solani* and heavy metals (Cr and Ni) on chickpea, because resistant varieties give low cost, have no adverse effect on natural enemies or non-target organisms, do not show toxicity or residue problems, no special skill necessary for farmers. Similarly, the use of resistant cultivars could provide a way to maintain or increase crop production without increased land demands or adverse environmental consequences.