Increased industrialization and human activities have impacted on the environment through the disposal of waste containing heavy metals such as Cd, Pb, Cr, Ni, etc. Mine drainage, metal industries, refining, electroplating, dye and leather industries, domestic effluents, landfill leachate, agricultural runoff, and acid rain contribute such a kind of waste. All these metals are known to be highly toxic to plants and animals. Growth and activity of microorganisms including plant pathogens may be greatly influenced by the nature and concentration of heavy metals in soil, which in turn may influence the disease development in plants.

The focal theme of the present study is to assess the effect of two important heavy metal pollutants viz. chromium and nickel on pathogenic potential and management of reniform nematode, *Rotylenchulus reniformis* and the root-rot fungus, *Fusarium solani* infecting chickpea, *Cicer arietinum* var. Kranti. The results of the different experiments embodying the thesis are briefly presented as under:

1: IDENTIFICATION OF RACE OF RENIFORM NEMATODE, *ROTYLENCHULUS RENIFORMIS* ASSOCIATED WITH CHICKPEA:

The results revealed that all the isolates of *R. reniformis* collected from chickpea fields 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 Race-3.

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

The results clearly indicated that both the heavy metals adversely affected the hatching of *R. reniformis*, Cr being more toxic than Ni. Not only the hatching of the nematode was inhibited but the heavy metals also caused significant mortality of the nematode. Both, hatching and mortality were found
to be directly proportional to the concentration of heavy metals. Inhibition in the hatching was minimum at the lowest concentration (25 ppm) and maximum at the highest concentration (400 ppm) for Cr and Ni. Hundred percent inhibition in the hatching was observed at 400 ppm of Cr. Similarly, the nematode mortality was also increased with an increase in the concentration of the heavy metals as well as the exposure period. The lowest mortality was recorded at 25 ppm of Cr at 12 h exposure period and 100% mortality was obtained in 400 ppm concentration of Cr at 96 h. The nematode mortality was lowest in 25 ppm Ni at 12 h and it increased to 71.0% in 400 ppm Ni at 96 h exposure period.

3: EFFECT OF CHROMIUM AND NICKEL ON THE GROWTH, SPORULATION AND HEAVY METAL UPTAKE OF FUSARIUM SOLANI 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 was significantly enhanced when the fungus was grown in the medium added with 25 ppm Ni. The chlamydospore formation initiated at and above 50 ppm Cr and 100 ppm Ni, which increased further with an increase in the concentration of the heavy metals. Similarly, the uptake of heavy metals by *F. solani* was increased with an increase in their concentration. Overall, it was observed that Cr was more toxic to the fungus than Ni.

4: STUDIES ON POTENTIAL PATHOGENIC LEVEL OF RENIFORM NEMATODE, ROTYLENCHULUS RENIFORMIS AND ROOT-ROT FUNGUS FUSARIUM SOLANI ON CHICKPEA:

The potential pathogenic level of reniform nematode and root-rot fungus, was determined by inoculating the seedlings of chickpea separately with different inoculum levels of *R. reniformis* (250, 500, 1000, 4000 and 8000 immature females per plant) and *F. solani* (0.5, 1.0, 2.0, 3.0, 4.0 and 5.0 g...
mycelium + spores 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 levels. 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. Hence, the potential pathogenic level of *R. reniformis* and *F. solani* on chickpea was recorded as 1000 immature females of *R. reniformis* / plant and 3.0 g of *F. solani* / plant, respectively.

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

The results clearly showed that the plant growth, yield, nodulation, chlorophyll content of leaves, protein content of seeds and water absorption capacity of roots of chickpea decreased in the plants grown in soil treated with heavy metals either alone or in combination with the test pathogens. Chromium was found to be less toxic to chickpea plants and more toxic to nematode and fungus, whereas, nickel was less toxic to nematode and fungus, and more toxic to chickpea plant. With an increase in the concentration of heavy metals (Cr or Ni) from 25 to 200 ppm, there was a corresponding decrease in plant growth,
yield, nodulation, chlorophyll content, protein content and water absorption capacity, which was further ameliorated in the presence of either nematode or fungus. This reduction in plant growth and other parameters of chickpea was synergistically ameliorated when plants were inoculated with either nematode or fungus and grown in soil treated with different concentrations of either Cr or Ni, except the treatment of 25 ppm Cr with nematode and all concentrations of Cr with fungus, which were unable to show synergistic effect.

6: ACCUMULATION OF CHROMIUM AND NICKEL IN CHICKPEA PLANTS INFECTED WITH ROTYLENCHULUS RENIFORMIS AND FUSARIAUM SOLANI:

It was interesting to note that Cr was accumulated by plants in lesser amount than Ni and the amount of heavy metals was more in roots than in shoots. The concentration of the heavy metal accumulation was more in inoculated plants than the uninoculated plants. Moreover, the heavy metals were accumulated in greater amounts by plants inoculated with *F. solani* than the plants inoculated with *R. reniformis*. It was further noticed that the accumulation of heavy metals in plants increased with an increase in the concentration of Cr or Ni.

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

Results revealed that the penetration, development and multiplication of reniform nematode, *R. reniformis* were inhibited and delayed by the presence of heavy metals viz. chromium and nickel as compared to control. The penetration of nematodes in control started within 1 day of inoculation which was however delayed by one day in plants grown in pots treated with either Cr or Ni. Females with slight swelling were first observed on 5\(^{th}\) day in control whereas such females were recorded on 8\(^{th}\) and 7\(^{th}\) day in plants treated with Cr and Ni, respectively. The fully swollen females, females with matrix and females with eggmasses were first recorded on 10\(^{th}\), 14\(^{th}\) and 16\(^{th}\) day of
inoculation in the control plants, respectively. The corresponding stages of
development of reniform nematode were first recorded on 12th, 18th and 20th
day, and on 11th, 16th and 18th day of inoculation in plants treated with Cr and
Ni, respectively. The average number of eggs per eggmass was significantly
reduced in both Cr (48) and Ni (52) treated plants as compared to control (69).
The eggs took 4 days to hatch into second stage juveniles in control, while in
Cr and Ni treated soil, eggs hatched in 5 and 4 days respectively. The second
stage juveniles were recorded on 20th day in control as against 25th day in Ni
and 22nd day in Cr treated soil, respectively. The third stage female and male
juveniles were recorded on 23rd day in control, but, these stages of development
were recorded on 29th and 25th day of inoculation in Cr and Ni treated soil,
respectively. Similarly, fourth stage female and male juveniles were recorded
on 25th day in control, while in Cr and Ni treated soil these stages were
recorded on 33rd and 28th day after inoculation, respectively. The immature
females and adult males were recorded on 28th, 39th and 33rd day, respectively
in the corresponding treatments. In this way the life cycle of *R. reniformis* on
chickpea was delayed by 11 days and 5 days in the presence of Cr and Ni
respectively as compared to control. The number of immature females and
adult males were also significantly reduced in plants treated with either Cr or
Ni as compared to control. The total population of the nematode was also
reduced in Cr and Ni treated pots as compared to control on the day of recovery
of immature females. The female and male ratio (female: male) was 1.17:1.00
in control as against 1.00:1.30 and 1.00:1.21 in Cr and Ni treated soil,
respectively.
ABSTRACT

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

The results clearly revealed that plant growth and yield of chickpea was significantly reduced in the pots individually treated with *R. reniformis*, *F. solani*, Cr and Ni. Moreover, these parameters of chickpea plants was synergistically reduced in the pots treated with the test pathogen (*R. reniformis / F. solani*) in combination with the heavy metal (Cr / Ni) except the plants grown in Cr-treated soil and inoculated with *F. solani*, in which the reduction in plant growth was not synergistic. It was found that the growth and yield of chickpea was significantly improved in presence of neem cake, mustard cake, *T. harzianum*, mahua cake, castor cake and sesame cake as compared to untreated-uninoculated plants. However, the application of linseed cake, *P. lilacinus* and Bavistin did not show any significant improvement in the plant growth and yield as against untreated-uninoculated plants. The best protection of chickpea plants against the *R. reniformis* was recorded by the application of *P. lilacinus* followed by Bavistin, neem cake, mustard cake, castor cake, *T. harzianum* and mahua cake. These treatments significantly reduced the reproduction factor of reniform nematode which consequently increased plant growth and yield of chickpea as compared to untreated-inoculated plants. Similarly, the best protection of chickpea plants against *F. solani* was recorded by the application of Bavistin, followed by *T. harzianum*, neem cake, linseed cake, mustard cake, castor cake and mahua cake. These treatments also significantly reduced the disease index of *F. solani* and increased the plant growth and yield of chickpea. The application of neem cake, mustard cake, castor cake, *T. harzianum* and mahua cake also reduced the damage caused by heavy metals (Cr / Ni). The application of neem cake, mustard cake, castor
ABSTRACT
cake, mahua cake, *T. harzianum*, *P. lilacinus* and Bavistin were found to be effective in managing the damage caused by combined effect of heavy metal (Cr / Ni) and *R. reniformis*. Similarly, the application of *T. harzianum*, neem cake, mustard cake, castor cake, mahua cake, linseed cake and Bavistin were also found to be effective in managing the damage caused by combined effect of heavy metal (Cr / Ni) and *F. solani*.

9: SCREENING OF CHICKPEA VARIETIES FOR RESISTANCE AGAINST *ROTYLENCHULUS RENIFORMIS, F. SOLANI, CHROMIUM AND NICKEL:*

There was an adverse effect of the test pathogens and heavy metals on the growth of chickpea varieties, irrespective the level of its resistance against pathogen or heavy metal. Out of 25 chickpea varieties, 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*, and 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*. 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) to heavy metal, chromium, and 2 were highly susceptible (Pragati and XVSCR-
ABSTRACT

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 grown in the soil treated with either Cr or Ni even in the presence of either \textit{R. reniformis} or \textit{F. solani}. The results indicated that the variety Phule-G 8602 showed the resistance towards \textit{R. reniformis}, \textit{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 (\textit{R. reniformis}/\textit{F. solani}) and contaminated with these heavy metals. 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.