**Efficacy of Various Control Measures Against Downy Mildew (Sclerospora graminicola) in Pearl Millet: A Comparative Analysis**

**ABSTRACT**

Pearl millet (*Pennisetum glaucum* (L.) R. Br), commonly known as Bajra, is a staple cereal crop in dry and semi-arid regions of Asia and Africa, valued for its nutritional richness, drought tolerance, and adaptability to poor soils. pearl millet is highly susceptible to downy mildew, a major disease caused by the pathogen Sclerospora graminicola. Integrated approaches combining bio-agents like fluorescent Pseudomonas spp., fungicides, and resistant varieties are gaining importance for sustainable disease control. This research aims to compare the efficacy of different treatments against *Sclerospora graminicola* to identify the most effective and environmentally sustainable strategy for managing downy mildew in pearl millet cultivation. The present study was undertaken during the *Kharif* season of 2024 at the Rainfed Organic Agriculture Research Farm, Bundelkhand University, Jhansi, Uttar Pradesh. To evaluate the progression of downy mildew disease of pearl millet under natural epiphytotic conditions and to assess the efficacy of selected seed treatments and foliar applications. Significant differences were observed among treatments in terms of plant population, seedling emergence, and disease incidence. The highest number of plants per plot (47.67) and seedling emergence percentage (95.33%) were recorded in the treatment comprising seed treatment with Metalaxyl @ 6 g/kg seed combined with foliar spray of Propiconazole 25% EC @ 0.25%. This treatment also exhibited the lowest downy mildew incidence at both 30 DAS (2.00%) and 60 DAS (3.28%). Biocontrol agents such as Trichoderma harzianum @ 6 g/kg seed and Pseudomonas fluorescens @ 8 g/kg seed showed moderate efficacy, recording lower disease incidence than the untreated control. The control plots, which received no seed treatment or spray, showed the poorest performance with the lowest plant count (27.50), lowest seedling emergence (55.00%), and the highest disease incidence at both 30 DAS (33.97%) and 60 DAS (35.12%). These findings clearly demonstrate the superior performance of integrated chemical seed treatment and foliar application in enhancing seedling establishment and reducing downy mildew disease in pearl millet. These findings are consistent with the principles of IDM and advocate for their adoption in downy mildew-prone regions to ensure healthy crop establishment and yield sustainability.

**Keywords**: Downy mildew, Sclerospora graminicola, Pearl millet, Disease progression, chemical fungicides

**INTRODUCTION**

Pearl millet [*Pennisetum glaucum* (L) R.Br], 2n = 14, is an annual C4 coarse-grained crop, ranked as the sixth most important global cereal crop, widely cultivated by the resource-poor farmers in arid and semi-arid regions of Africa and the Indian subcontinent. It can thrive under adverse conditions like drought, salinity, low rainfall and fertility. It has higher potential for biomass production, multiple forage crop characteristics such as rapid regeneration efficiency, high tillering capacity, more leaf area, and greater green fodder yield and pest and disease tolerance 1. (Annamalai et al., 2020). Pearl millet commonly known as Bajra, is a staple cereal crop in dry and semi-arid regions of Asia and Africa, valued for its nutritional richness, drought tolerance, and adaptability to poor soils. Despite its resilience, pearl millet is highly susceptible to downy mildew, a major disease caused by the pathogen Sclerospora graminicola, which leads to significant yield losses by affecting plant growth and grain development. Traditional management strategies such as chemical fungicides and resistant cultivars have shown limited long-term success due to pathogen variability, environmental influences, and emerging resistance. Therefore, integrated approaches combining bio-agents like fluorescent Pseudomonas spp., fungicides, and resistant varieties are gaining importance for sustainable disease control. ‘Biological control’ might be comprehensively characterised as the reduction of harmful activity of one or more organisms, regularly referred to as a natural destroyer. Be that as it may, as far as plant pathology, the meaning of biological control alludes to the deliberate usage of introduced or resident biotic organisms, other than disease-resistant host plants, to minimise the activities and population of one or more plant pathogens. The enthusiasm for choosing beneficial microorganisms, with which to develop biological control agents (BCAs), has expanded because microbial biopesticides are a key and incredible asset in Integrated Pest Management (IPM) (Tariq et al., 2020; Islam et al., 2022). This research aims to compare the efficacy of different treatments against Sclerospora graminicola to identify the most effective and environmentally sustainable strategy for managing downy mildew in pearl millet cultivation.

**MATERIALS AND METHODS**

A field experiment was conducted during the *Kharif* season of 2024 to study the management of downy mildew of pearl millet caused by *Sclerospora graminicola*. The test crop used was a moderately resistant cultivar, Leo-7601. The study was undertaken at the Rainfed Organic Agriculture Research Farm, Narayan Bagh, Institute of Agricultural Sciences, Department of Plant Pathology, Bundelkhand University, Jhansi (Uttar Pradesh). The experimental design followed a Randomised Block Design (RBD) with nine treatments, each replicated thrice. Seeds were treated with selected fungicides and bio-agents to evaluate their effectiveness through seed treatment and foliar sprays. Metalaxyl was used for seed treatment in one of the effective treatments. A non-treated control (without fungicide application) was also maintained for comparison. Each plot measured 2.0 m × 1.0 m, with a plant spacing of 30 cm between rows and 10 cm between plants to ensure uniform plant population. Farmyard manure (FYM) was incorporated at the rate of 10-12 tonnes/ha two to three weeks before sowing. Fertilisers were applied at a rate of 90:30 kg/ha (N: P₂O₅), with nitrogen split into two equal doses-half as basal and half as top dressing at 30 days after sowing. All agronomic practices, including irrigation, weed, and pest management, were uniformly maintained throughout the experimental period. The first spray treatment was applied 21 days after sowing. The virulent isolate of *Sclerospora graminicola* was used for disease inoculation. The objective was to evaluate the long-term efficacy of fungicides and biocontrol agents under natural epiphytotic conditions for sustainable management of pearl millet downy mildew. Treatment details of the experiment are given below.

**Observations recorded**

**Downy mildew incidence (%):** The total number of plants was recorded at the time of thinning, *i.e.,* fifteen days after sowing, while the number of downy mildew-infected plants was recorded at 30 and 60 days after sowing then the downy mildew incidence percentage was calculated with the help of the following formula:

$$Downy mildew incidence (\%)=\frac{Downy mildew infected plants }{Total number of plants}×100$$

**Seedling emergence**

$$Percent seedling emergence=\frac{Number of seeds germinates }{Total number of seeds sown}×100$$

**RESULTS**

**The present investigation was undertaken to evaluate the effect of various chemical, biological, and botanical seed treatments and foliar applications on the incidence of downy mildew disease in pearl millet under natural epiphytotic conditions. The results obtained on seedling emergence, average number of plants per plot, and disease incidence at 30 and 60 days after sowing (DAS) are summarised in Table 1 & Fig.1**

**Seedling Emergence and Average Number of Plants**

**The average number of plants per plot differed significantly among treatments. The highest number of plants per plot was observed in the treatment T4 (Seed treatment with Metalaxyl @ 6 g/kg seed + foliar spray of Propiconazole 25% EC @ 0.25%) with 47.67 plants, followed by *Trichoderma harzianum* @ 6 g/kg seed (44.73 plants) and Metalaxyl @ 0.25% (44.22 plants). The lowest plant count (27.50) was recorded in the control treatment, indicating a poor establishment due to disease pressure and absence of seed protection. The differences among treatments were statistically significant. Seedling emergence percentage was highest in the combined Seed treatment with Metalaxyl (@ 6g/kg seed + Spray of Propiconazole 25% EC @ 0.25% treatment (95.33%), followed by *Trichoderma harzianum*** @ 6g/kg seed **(89.47%), *Pseudomonas fluorescens @* 8g/kg seed (89.13%) and Metalaxyl (88.43%). The lowest emergence (55.00%) was recorded in the control, the adverse effect of seed- and soil-borne pathogens on germination in the absence of treatment.**

**Downy Mildew Incidence at 30 DAS**

**Disease incidence at 30 DAS revealed significant variations. The lowest disease incidence (2.00%) was recorded in the Seed treatment with Metalaxyl (@ 6g/kg seed + Spray of Propiconazole 25% EC @ 0.25% treatment, followed by Metalaxyl alone (2.58%), and Carbendazim (2.60%). Biocontrol agents such as *Trichoderma harzianum* @** 6g/kg seed **(2.87%) and *Pseudomonas fluorescens @* 8g/kg seed (2.93%) were moderately effective. The highest incidence (33.97%) occurred in the untreated control, indicating a high level of early disease development when no protective treatment was applied.**

**Downy Mildew Incidence at 60 DAS**

**At 60 DAS, disease progression followed a similar trend. The combined treatment of Seed treatment with Metalaxyl (@ 6g/kg seed + Spray of Propiconazole 25% EC @ 0.25%again exhibited the lowest incidence (3.28%), followed by Metalaxyl (3.40%), and Carbendazim (3.57%). Among biocontrol agents, *Trichoderma harzianum*** @ 6g/kg seed**and *Pseudomonas fluorescens @* 8g/kg seed showed moderate disease control. Neem oil recorded a higher incidence (5.51%), but still significantly lower than the control treatment, which recorded 35.12% incidence, the highest among all treatments.**

**Table 1: Effectiveness of different treatments against *Sclerospora graminicola*, the causal agent of downy mildew in pearlmillet during *Kharif* 2024 under field conditions.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Average no. of plants/Plots** | **Seedling emergence****(%)** | **Downy mildew incidence (%) at 30 DAS** | **Downy mildew incidence (%) at 60 DAS** |
| Metalaxyl @ 0.25% | 44.22 (6.69) \* | 88.43 | 2.58 (1.74) | 3.40 (1.96) |
| Carbendazim @ 0.25% | 42.15 (6.53) | 84.30 | 2.60 (1.75) | 3.57 (2.01) |
| Mancozeb @ 0.2 %  | 41.70 (6.50) | 83.40 | 2.82 (1.81) | 3.82 (2.07) |
| Seed treatment with Metalaxyl (@ 6g/kg seed + Spray of Propiconazole 25% EC @ 0.25% | 47.67 (6.94) | 95.33 | 2.00 (1.57) | 3.28 (1.92) |
| Seed treatment with *Trichoderma harzianum* @ 6g/kg seed | 44.73 (6.73) | 89.47 | 2.87 (1.82) | 3.93 (2.11) |
| Seed treatment with *Pseudomonas fluorescens* @ 8g/kg seed | 44.57 (6.71) | 89.13 | 2.93 (1.84) | 4.60 (2.26) |
| Seed treatment with *Trichoderma asperellum* @ 6g/kg seed | 44.40 (6.70) | 88.80 | 3.13 (1.89) | 4.87 (2.32) |
| Neem oil | 40.23 (6.38) | 80.45 | 4.11 (2.15) | 5.51 (2.45) |
| Control | 27.50 (6.29) | 55.00 | 33.97 (5.87) | 35.12 (5.97) |
| **S. Em±** | **0.03** | **-** | **0.09** | **0.09** |
| **C.D. @ 5%** | **0.10** | **-** | **0.28** | **0.27** |
| **CV%** | **0.87** | **-** | **7.14** | **6.18** |

\*All Data are means of three replications.

\*Figures in parentheses are angular transformed values.

**Figure 1:** Effectiveness of different treatments against *Sclerospora graminicola*, the causal agent of downy mildew in pearl millet. during *Kharif* 2024 in the field

**DISCUSSION**

The highest seedling emergence (95.33%) and plant stand (47.67 plants per plot) were observed with the combined treatment of seed treatment using Metalaxyl @ 6 g/kg seed along with foliar spray of Propiconazole 25% EC @ 0.25%. This might be due to the systemic and protective action of both fungicides, which protected seedlings from primary infection and delayed disease onset. Metalaxyl seed treatment combined with a foliar fungicide spray effectively controlled downy mildew and improved seedling emergence in pearl millet (Sharma et al., 2018).

 Metalaxyl alone also performed significantly well (88.43% emergence), indicating its systemic activity against oomycetes such as *Sclerospora graminicola*. Metalaxyl-treated seeds showed improved germination and reduced early infection of downy mildew (Singh et al., 1993).

 Minimum disease incidence at 30 and 60 DAS was recorded in the combined Seed treatment with Metalaxyl (@ 6g/kg seed + Spray of Propiconazole 25% EC @ 0.25%treatment (2.00% and 3.28%, respectively). This confirms the synergistic effect of dual fungicide application, offering both protective and curative action against the pathogen. Singh (1995) highlighted the importance of combining seed and foliar fungicide applications for effective management of downy mildew in susceptible crops like pearl millet and sorghum.

 Chemical fungicides like Carbendazim and Mancozeb also performed moderately well. Carbendazim, a systemic benzimidazole fungicide, inhibited fungal mycelial development. Carbendazim significantly suppressed downy mildew development in pearl millet under field conditions (Singh and Shetty, 1990).

 Among the biological treatments, seed treatment with *Trichoderma harzianum* and *Trichoderma aspergillus* demonstrated moderate efficacy in reducing disease incidence. These organisms are known for their antagonistic activity, induced systemic resistance (ISR), and rhizosphere competence. *Trichoderma spp*. produces secondary metabolites and hydrolytic enzymes that suppress soil-borne pathogens. *Trichoderma harzianum* reduced the incidence of several soil-borne diseases through competition and antibiosis (Nayak et al., 2020).

 *Trichoderma harzianum*, a plant growth-promoting rhizobacteria (PGPR), showed promising disease suppression, supporting findings of Kloepper *et al.,* (2004), who stated that PGPR enhance plant immunity and reduce disease incidence by activating ISR mechanisms. However, biological treatments were not as effective as chemical fungicides, possibly due to environmental variability and lower pathogen suppression under high disease pressure.

 Neem oil showed limited efficacy in suppressing downy mildew (5.51% incidence at 60 DAS), but it was significantly better than the control (35.12%). Neem oil contains azadirachtin and other compounds that have antifungal properties. Rawal et al., (2013) reported moderate antifungal activity of neem-based formulations against various plant pathogens.

 Carbendazim and Mancozeb treatments also showed considerable disease suppression, which is in agreement with Ojiambo et al, (2010), who reported the broad-spectrum protective activity of these fungicides against downy mildew pathogens. Among the biological agents, *Trichoderma harzianum* and *Trichoderma aspergillus* showed moderate disease control (around 3.2-3.7% incidence), reflecting their potential in inducing systemic resistance and producing antifungal metabolites, as documented by Gopalakrishnan *et al.,* (2011) and Riera et al., (2023).

 The findings of the present study are in agreement with those of Raj *et al.* (2004), who reported that seed treatment with P. fluorescens significantly reduced downy mildew severity and improved seedling vigour in pearl millet. A substantial reduction in disease incidence and enhancement of plant growth when P. fluorescens was applied as a seed or soil treatment under field conditions (Shetty and Kumar, 2000).

 Neem oil, though slightly less effective than chemical treatments, still demonstrated suppressive effects on disease incidence, supporting earlier work by Bunker and Mathur (2008) that highlighted the antifungal properties of neem-based formulations. The significantly high disease incidence in the untreated control (33.97% at 30 DAS and 35.12% at 60 DAS) confirmed the conducive conditions for natural epiphytotic development of downy mildew and emphasised the necessity of effective disease management strategies.

 The integrated treatment of Seed treatment with Metalaxyl (@ 6 g/kg seed) + Spray of Propiconazole 25% EC @ 0.25% also provided moderate disease suppression (4.33% at 30 DAS and 5.23% at 60 DAS), which agrees with observations made by Narayanamma *et al.,* (2013), advocating for integrated management as a sustainable strategy against downy mildew.Biocontrol agents like *Trichoderma harzianum* and *P. fluorescens* performed well initially but showed higher disease incidence by 60 DAS compared to chemical treatments. This could be attributed to the slower mode of action of bioagents, which often require colonisation and competition to effectively suppress pathogens (Cunniffe and Gilligan, 2011).Neem oil, despite being considered a natural pesticide, was the least effective among the treatments, with disease incidences of 7.83% (30 DAS) and 8.23% (60 DAS). This suggests that while neem oil may offer some level of antifungal activity, it is insufficient for managing systemic diseases like downy mildew in susceptible crops like pearl millet.The untreated control consistently showed the highest incidence of downy mildew (33.97% at 30 DAS and 35.10% at 60 DAS), illustrating the epiphytotic potential of the disease under favourable weather conditions (high humidity and moderate temperatures), as similar reported by Theradi and Juliet (2009) and Kumar *et al.,* (2013).

**Conclusion**:

Overall, the results underscore the importance of integrated disease management (IDM) involving compatible chemical and biological agents. The systemic fungicides, particularly in combination treatments, offer reliable protection, while bioagents and botanicals contribute to sustainable, eco-friendly disease suppression. These findings are consistent with the principles of IDM and advocate for their adoption in downy mildew-prone regions to ensure healthy crop establishment and yield sustainability.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

**REFERENCE**

1. Cunniffe, N. J., & Gilligan, C. A. (2011). A theoretical framework for biological control of soil-borne plant pathogens: identifying effective strategies. Journal of Theoretical Biology, 278(1), 32-43.
2. Riera, N., Davyt, D., Durán, R., Iraola, G., Lemanceau, P., & Bajsa, N. (2023). An antibiotic produced by Pseudomonas fluorescens CFBP2392 with antifungal activity against Rhizoctonia solani. Frontiers in Microbiology, 14, 1286926.
3. Rawal, P., Sharma, P., Singh, N. D., & Joshi, A. (2013). Evaluation of fungicides, neem bio-formulations and biocontrol agent for the management of root rot of safed musli caused by Rhizoctonia solani. J Mycol Plant Pathol, 43(30), 297.
4. Gopalakrishnan, S., Kiran, B. K., Humayun, P., Vidya, M. S., Deepthi, K., & Rupela, O. (2011). Biocontrol of charcoal rot of sorghum by Streptomyces spp. under field conditions. Plant Pathology Journal, 10, 79-86.
5. Kloepper, J. W., Ryu, C. M., & Zhang, S. (2004). Induced systemic resistance and promotion of plant growth by Bacillus spp. Phytopathology, 94, 1259-1266.
6. Narayanamma, V. L., Reddy, K. D., & Reddy, A. V. (2013). Integrated pest and disease management practices in oilseeds–a critical review. Indian Journal of Entomology, 75(1), 34-56.
7. Nayak, D., Mishra, M. K., Pradhan, B., & Sharma, K. K. (2020). Evaluation of some bio-control agents in in vitro control of Fusarium oxysporum f. sp. cubense, an incitant of banana panama wilt. J. Pharmacogn. Phytochem, 9, 751-753.
8. Sharma, R., Gate, V. L., & Madhavan, S. (2018). Evaluation of fungicides for the management of pearl millet [Pennisetum glaucum (L.)] blast caused by Magnaporthe grisea. Crop Protection, 112, 209-213.
9. Raj, S. N., Shetty, N. P., & Shetty, H. S. (2004). Seed bio-priming with Pseudomonas fluorescens isolates enhances growth of pearl millet plants and induces resistance against downy mildew. International Journal of Pest Management, 50(1), 41-48.
10. Singh, S. D., & Shetty, H. S. (1990). Efficacy of systemic fungicide metalaxyl for the control of downy mildew (Sclerospora graminicola) of pearl millet (Pennisetum glaucum). Indian Journal of Agricultural Sciences, 60(9), 575-581.
11. Theradi Mani, M., & Juliet Hepziba, S. (2009). Biological management of pearl millet downy mildew caused by Sclerospora graminicola. Archives of Phytopathology and Plant Protection, 42(2), 129-135.
12. Ojiambo, P. S., Paul, P. A., & Holmes, G. J. (2010). A quantitative review of fungicide efficacy for managing downy mildew in cucurbits. Phytopathology, 100(10), 1066-1076.
13. Singh, S. D. (1995). Downy mildew of pearl millet. Plant Disease, 79(6), 545-550.
14. Bunker, R. N., & Mathur, K. (2008). Evaluation of neem based formulations and chemical fungicides for the management of sorghum leaf blight. Indian Phytopathology, 61(2), 192-196.
15. Singh, S. D., King, S. B., & Werder, J. (1993). Downy mildew disease of pearl millet. Information Bulletin no. 37. International Crops Research Institute for the Semi-Arid Tropics.
16. Kumar, A., Manga, V. K., Gour, H. N., & Purohit, A. K. (2013). Pearl millet downy mildew: challenges and prospects. Ann Rev Plant Pathol, 5, 139.
17. Shetty, H. S., & Kumar, V. U. (2000). Biological control of pearl millet downy mildew: present status and future prospects. Biocontrol Potential and its Exploitation in Sustainable Agriculture: Crop Diseases, Weeds, and Nematodes, 251-265.
18. Annamalai, R., Aananthi, N., Arumugam Pillai, M., & Leninraja, D. (2020). Assessment of variability and character association in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Int. J. Curr. Microbiol. App. Sci, 9(06), 3247-3259.
19. Tariq, M., Khan, A., Asif, M., Khan, F., Ansari, T., Shariq, M., & Siddiqui, M. A. (2020). Biological control: a sustainable and practical approach for plant disease management. Acta Agriculturae Scandinavica, Section B—Soil & Plant Science, 70(6), 507-524.
20. Islam, M. H., Masud, M. M., Jannat, M., Hossain, M. I., Islam, S., Alam, M. Z., ... & Islam, M. R. (2022). Potentiality of formulated bioagents from lab to field: A sustainable alternative for minimizing the use of chemical fungicide in controlling potato late blight. Sustainability, 14(8), 4383.