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Integrated Approaches for Sustainable Management of Fungal Diseases in Chamomile Plants in Hill Country; Sri Lanka

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Abstract – *Matricaria chamomilla* (chamomile) is an important medicinal plant widely used in medicine, cosmetics, and the food industry. Fungal diseases pose a major challenge to chamomile cultivation, particularly in the hilly regions of Sri Lanka. This study focused on management of powdery mildew (*Erysiphe cichoracearum*), a destructive fungal disease affecting chamomile growth. A field experiment was conducted using a bio-fungicide, a vinegar solution, a chemical fungicide (Mancozeb), and an untreated control. The experiment followed a Randomized Complete Block Design (RCBD), with 20 plants per block and a total of 80 plants across four treatments. Plant height, average leaf size, and disease severity were assessed. The bio-fungicide treatment produced the highest plant growth (8.02 ± 0.21 cm) and improved overall plant health. The vinegar treatment also showed promising results (7.45 ± 0.18 cm), outperforming both Mancozeb and the untreated control. Mancozeb effectively reduced disease severity (7.27 ± 0.14 cm) but resulted in comparatively lower plant growth. The untreated plants showed severe disease symptoms, yellowing leaves, and stunted growth. The results highlight the importance of integrated disease management strategies that combine biological and eco-friendly approaches to enhance chamomile productivity while minimizing chemical fungicide use and promoting sustainable cultivation practices under local conditions.

Keywords- Bio-fungicide, Chamomile, Disease management, Powdery mildew, Sustainable agriculture

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Introduction

Chamomile (*Matricaria chamomilla*) is a well-known medicinal herb valued for its anti-inflammatory, antioxidant, and calming properties. Its dried flowers and essential oils are widely used in pharmaceuticals, cosmetics, and the food industry (Meena et al., 2020). With the growing interest in natural remedies, chamomile has gained significant popularity, especially among younger populations seeking relief from stress through herbal teas and wellness products. In 2021, the global market value of chamomile herbal tea was estimated at US$ 226.9 million, and it is expected to reach US$ 504.35 million by 2029, growing at an annual rate of 10.50%. (FlairInsights, 2025). This increasing demand presents the opportunities for expanding chamomile cultivation and trade in both local and international markets. Despite its economic and medicinal value, chamomile cultivation is often challenged by fungal diseases such as powdery mildew (*Erysiphe cichoracearum*) and root rot caused by *Fusarium* species.

These infections negatively impact plant yield, stunt growth, damage foliage, and reduce the quality and quantity of essential oils. Traditionally, chemical fungicides are used to control these pathogens. While they can be effective, over-reliance on synthetic chemicals poses environmental and health risks, including soil degradation, water contamination, and the development of resistant fungal strains (S. Kumar et al., 2021). Due to these concerns, there is growing interest in sustainable and eco-friendly disease management practices. Recent research highlights the potential of biological fungicides, plant extracts, and beneficial microorganisms in disease control. For instance, *Trichoderma* based products and neem-derived compounds have shown promising antifungal effects with minimal environmental impact (Bora et al., 2015).

Additionally, organic farming techniques and cultivating disease-resistant varieties offer sustainable ways to protect chamomile crops and enhance long-term productivity. Among these diseases, powdery mildew is particularly widespread in chamomile cultivation worldwide. Caused by fungi from the *Erysiphe* group, it is easily identified by white or gray powdery patches on leaves, stems, and flowers. As the disease progresses, it leads to leaf curling, yellowing, premature leaf drop, and overall plant weakening (Agrios, 2005). Unlike many other fungal pathogens, powdery mildew thrives in dry climates with high humidity, making it especially problematic in hilly regions that experience warm days and cool, damp nights conditions ideal for its rapid spread. Effective management of powdery mildew requires early detection, accurate identification, and the implementation of suitable control strategies. These include integrated disease management approaches that combine good agricultural practices, the use of resistant plant varieties, biological controls, and the careful application of chemical fungicides when necessary.

This study focuses on identifying the primary fungal threats affecting chamomile and evaluating the efficacy of environmentally friendly treatment methods under diverse field conditions. The findings aim to support the development of cost-effective, sustainable solutions that minimize environmental harm and promote long-term viability of organic chamomile cultivation.

Materials and Methods

Experimental Site

This research was conducted at the Sustainability, Research and Development Division, Bogawantalawa Tea Estates PLC, in a timber nursery of about one acre adjacent to the Castle reach Reservoir in the Hatton Dickoya area of the hilly region of Sri Lanka, a region with a temperate climate and favourable conditions for the cultivation of medicinal plants. The research site is situated at an elevation of roughly 1,100 meters above sea level in the Hatton neighbourhood of the Nuwara Eliya district. The Hatton region is renowned for its humid and

chilly weather throughout the year. In this region, the average temperature is between 18 °C and 26 °C, while the annual rainfall is between 1,850 and 2,200 mm. These conditions create a moderately humid environment in Sri Lanka that supports the healthy growth of medicinal plants such as chamomile and also increases the likelihood of fungal infections in many plants. This location provides a suitable environment for chamomile cultivation due to its cool climate, moderate humidity, and well-drained soils, conditions that mimic optimal chamomile growing regions worldwide.

Research Design and Layout

A RCBD was used to structure the field trial experiment, allowing all experimental units within each block to be exposed to similar environmental conditions. A total of 80 chamomile seedlings were used, divided into four treatments (T1 to T4). Each treatment was replicated across four blocks (B1 to B4), with 20 plants per treatment and 5 plants per treatment in each block. This layout ensured proper randomization and replication, minimizing the impact of variability across the field.

The seedlings were planted in elevated beds, arranged in three rows per bed. Plant spacing and row spacing were both maintained at 30 cm, while bed spacing was set at 50 cm to promote sufficient air circulation and to follow standard chamomile cultivation practices, as recommended by Mounir and Gilles (2011). Uniform soil moisture was maintained as needed by careful irrigation, ensuring water was applied sparingly without over-saturating the leaves (Giannoulis et al., 2011). All other standard crop management practices, including weeding and pest control, were carried out to maintain optimal growing conditions throughout the experiment.

Planting and Crop Maintenance Practices

Healthy chamomile seedlings were initially raised under controlled nursery conditions before being transplanted into the main field. Seeds were sown in seedling trays filled with a sterilized mixture of equal parts coconut coir, compost, and sand. The trays were watered daily to maintain adequate moisture for germination. Seedlings were nurtured for approximately four weeks until they reached a height of 4 - 5 cm and developed at least three true leaves. Prior to transplanting, a hardening process was conducted over a one-week period by gradually exposing the seedlings to outdoor conditions. This step minimized transplant shock and enhanced survival rates during field establishment (Spruce, 2008). Transplanting was carried out manually during the morning hours to avoid heat stress. Each seedling was placed in pre-prepared raised beds, with planting holes dug slightly deeper than the root ball. Light irrigation was applied immediately after transplanting to help settle the soil around the roots.

Post-transplantation care included weekly fertilization with 5 kg of pure organic compost per tunnel. Watering was carried out in the morning, as excessive moisture during this time can reduce the risk of fungal disease outbreaks (Ma et al., 2001). Hand weeding was conducted every 7 to 10 days to minimize competition for nutrients and conserve soil moisture. During routine inspections, wilted or diseased leaves were pruned using sterilized scissors to prevent the spread of pathogens. Daily visual monitoring was performed for common pests such as aphids, thrips, mealybugs, and black ants, which may facilitate the transmission of fungal infections. These management practices ensured healthy growth and minimized biotic stress in the chamomile plants.

Isolation and Identification of Fungal Pathogens

Symptomatic leaf samples were cut and collected to confirm fungal infections and identify the causal pathogens. Sampling was performed early in the morning to avoid moisture stress in the plants. Random symptomatic leaf samples were collected from each treatment

group and placed into sterilized, labelled polythene bags for immediate transport to the laboratory. Upon arrival, the samples were disinfected to remove surface debris by submerging them in a 1% Clorox solution for one minute, followed by immersion in 70% ethanol for 30 seconds, and finally rinsed with sterilized distilled water (Deepak & Virk, 2022).

After surface sterilization, small segments (approximately 5 mm × 5 mm) were cut from the margins of infected areas under sterile conditions. This procedure, including cutting and subsequent inoculation, was carried out inside a laminar flow cabinet to maintain aseptic conditions and avoid contamination. The prepared segments were inoculated onto Potato Dextrose Agar (PDA) plates. The plates were incubated at 25 ± 2 °C for 15 to 25 days and monitored daily for fungal colony development. Observations focused on colony morphology, pigmentation, growth rate, and spore formation, as described by Khan and Ali (2019). Fungal colonies were examined using a compound light microscope at 400× magnification for detailed identification (El-Mohamedy et al., 2021).

In instances where powdery mildew symptoms were observed, additional root rot samples were processed using the same disinfection and inoculation protocols. These samples were specifically examined for vascular browning and root-associated pathogens. Where multiple fungal species were identified from a single sample, sub-culturing was performed under sterile conditions to obtain pure colonies for further examination.

Data Collection

The data collection was initiated one week after the application of the first treatment and was carried out weekly over a seven-week treatment period. Several growth and health parameters were recorded to assess the effects of the treatments. Plant height (cm) was measured weekly using a ruler, from the soil surface to the tip of the highest point on the main stem. The height of all plants was recorded following the method described by Reddy and Rao (2020). Leaf size (cm) was measured by selecting three random leaves per plant, recording their length and width, and calculating the average for analysis.

In addition to growth measurements, the Disease Severity Index (DSI) was evaluated to determine the extent of fungal infections. A visual scoring scale from 0 to 5 was used. Visual assessments were performed weekly by the researcher to ensure consistency in disease severity evaluations.

0: No visible symptoms
1: Very light infection (<10% of leaf area)
2: Light infection (10–25% of leaf area)
3: Moderate infection (26–50% affected)
4: Severe infection (51–75% affected)
5: Very severe infection (>75% of leaf area affected or plant death)

Statistical Analysis

All quantitative field data were statistically analyzed using IBM SPSS Statistics software (Version 25). A one-way Analysis of Variance (ANOVA) was conducted to evaluate the significance of differences among treatment at the 5% probability level ($p < 0.05$). Data were graphically represented by using MS Excel.

Results

Identification of Fungal Pathogens

The primary fungal pathogen isolated from symptomatic chamomile leaf samples was *Erysiphe cichoracearum*, the causal agent of powdery mildew. Laboratory cultures displayed characteristic white, powdery mycelial growth, with barrel-shaped, hyaline conidia borne on

erect conidiophores, consistent with morphological descriptions provided by Agrios (2005) and Amano (1986). Accurate identification of *E. cichoracearum* is essential, as the pathogen spreads rapidly under warm and humid environmental conditions (Glay, 2008). The isolates were successfully cultured on PDA, and morphological characterization confirmed their identity as *E. cichoracearum* (Figure 1; Figure 2).

Figure 1. *Macroscopic mycelial view of Erysiphe cichoracearum*

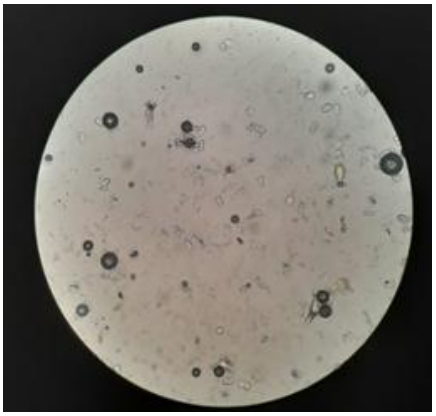

Figure 2. *Microscopic spore view of Erysiphe cichoracearum*

Visual Index

For each of the four treatments, T1 (*Trichoderma harzianum*), T2 (mancozeb), T3 (vinegar), and T4 (untreated control) the severity of disease symptoms was visually assessed using a standardized numerical rating scale ranging from 0 to 5. Evaluations were conducted both prior to treatment application and at regular intervals following treatment. The DSI was used to quantify the extent of infection, with higher values indicating greater severity. A comparative bar chart illustrates the differences in DSI across treatments, highlighting the efficacy of each intervention in reducing fungal symptoms (Figure 3).

Disease Severity After Treatment

The application of the four treatments (T1: bio fungicide, T2: mancozeb, T3: vinegar, and T4: control) revealed clear differences in disease severity reduction. Among all, T1 (bio fungicide) showed the most significant control of fungal infections. The number of plants exhibiting no visible symptoms increased notably, while those previously showing light, moderate, severe, or very severe symptoms decreased considerably. These findings align with previous studies (Harman et al., 2004) supporting the potential of bio fungicides as an environmentally friendly and sustainable strategy in plant disease management.

T2 (mancozeb), a synthetic fungicide, also provided effective disease suppression. Plants initially classified under moderate and severe infection categories showed improvement, with a shift towards no symptoms or only very light infection. However, the effectiveness was comparatively less than that of the bio fungicide, possibly due to the limitations and long-term risks associated with synthetic chemical use.

T3 (vinegar) produced moderate disease control effects. Several plants moved from severe or very severe disease categories to lighter forms of infection. A minor increase in the number of healthy, symptom-free plants was also observed, indicating a degree of antifungal activity. However, its efficacy was lower than both T1 and T2, suggesting vinegar might be suitable only for small-scale or organic farming contexts where low-cost and readily available solutions are prioritized. In contrast, T4 (control) exhibited no improvement. Instead, disease symptoms worsened in many plants, with several shifting into the severe and very severe categories. This highlights the progressive nature of fungal infections when left unmanaged, emphasizing the importance of timely and effective treatment interventions.

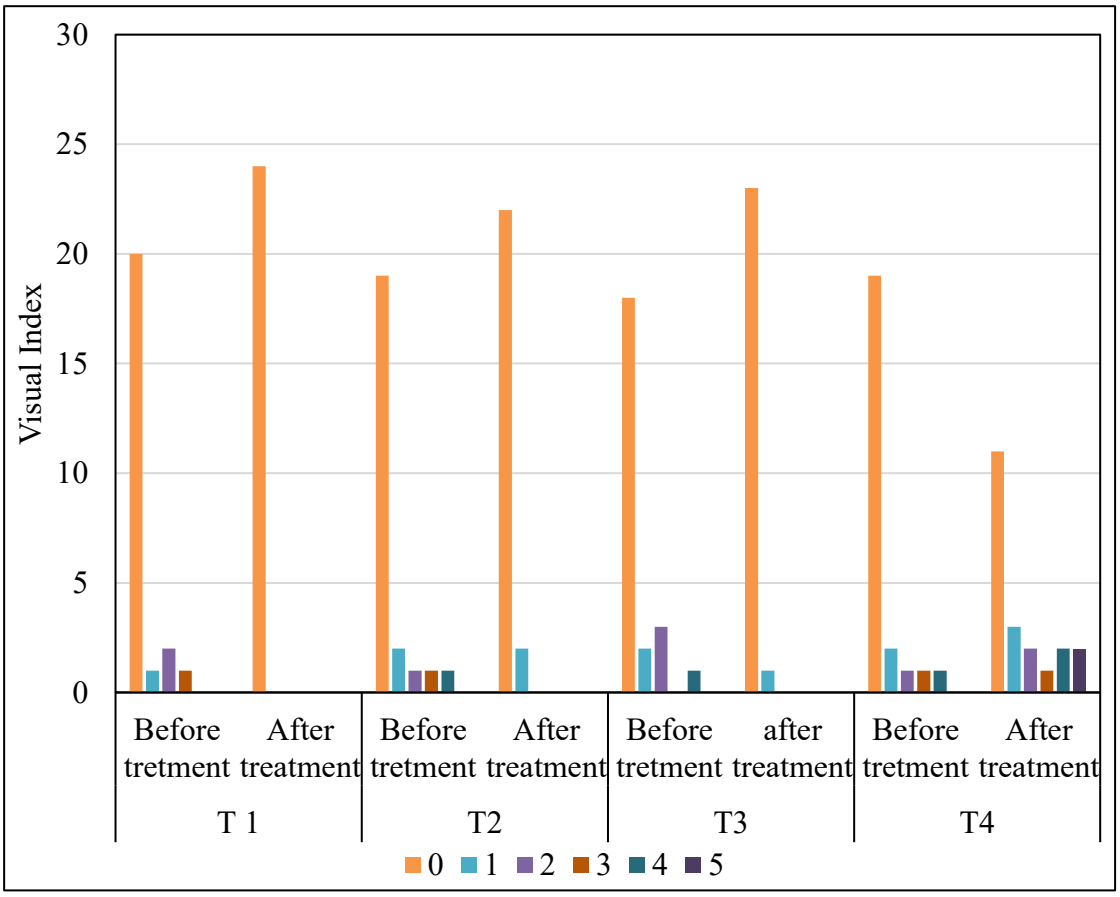

Figure 3. *Visual index of disease severity scale*

Plant Height

Plant height was monitored weekly over a 7-week period to assess the influence of the four treatments on growth. During the initial growth phase (weeks 1 to 3), there was little variation in plant height across treatments. All groups recorded similar average heights, ranging from 5.4 cm to 5.9 cm. The statistical analysis showed no significant differences ($p > 0.05$), with p-values of 0.960, 0.826, and 0.791 for weeks 1, 2, and 3 respectively. This early uniformity can be attributed to the slow initial growth stage of chamomile, where genetic factors and seed quality predominantly influence development.

Between weeks 4 and 5, slight differences in plant height began to emerge. T1 showed a steady increase from 6.36 ± 0.15 cm at week 4 to 6.77 ± 0.16 cm at week 5. Similar trends were observed in other treatments, though less pronounced in T2 and T4. Nevertheless, statistical analysis still indicated no significant differences among treatments during this period ($p = 0.835$ and 0.957 for weeks 4 and 5, respectively). This suggests that the treatments had started to influence plant growth, though the effects were still in the early stages of manifestation.

From week 6 onward, more distinct differences became apparent. Although the p-value at week 6 (0.201) remained above the significance threshold, the increasing F-value (1.582) and a reduced coefficient of variation (CV < 10%) indicated a trend towards more reliable and consistent data. T1 again had the tallest plants (7.42 ± 0.16 cm), followed by T3, while T2 and T4 showed comparatively lower growth, hinting at less effective or delayed treatment responses.

By week 7, treatment effects became statistically significant ($p = 0.002$; F = 5.456). T1 maintained the highest average height (8.02 ± 0.21 cm), demonstrating its superiority in promoting plant growth. T3 also performed well with an average of 7.45 ± 0.18 cm. T2 and T4, which followed similar growth patterns throughout the experiment, recorded the lowest final plant heights at 7.27 ± 0.14 cm and 7.11 ± 0.13 cm, respectively. These results suggest that while T2 and T4 were sufficient for supporting basic growth, they lacked the capacity to enhance plant development to its full potential.

Table 1

Plant height

	1 Week	2 Week	3 Week	4 Week	5 Week	6 Week	7 Week
T1	5.43 ± 0.18^{a}	5.67 ± 0.17^{a}	5.81 ± 0.16^{a}	6.36 ± 0.15^{a}	6.77 ± 0.16^{a}	7.42 ± 0.16^{a}	8.02 ± 0.21^{a}
T2	5.54 ± 0.16^{a}	5.88 ± 0.15^{a}	5.81 ± 0.17^{a}	6.30 ± 0.16^{a}	6.70 ± 0.14^{a}	7.08 ± 0.14^{a}	7.27 ± 0.14^{b}
T3	5.42 ± 0.19^{a}	5.75 ± 0.19^{a}	5.8 ± 0.19^{a}	6.48 ± 0.16^{a}	6.81 ± 0.18^{a}	7.13 ± 0.18^{a}	7.45 ± 0.18^{bc}
T4	5.48 ± 1.54^{a}	5.81 ± 0.16^{a}	5.81 ± 0.17^{a}	6.30 ± 0.72^{a}	6.7 ± 0.14^{a}	6.93 ± 0.14^{a}	7.11 ± 0.13^{c}
p value	0.960	0.826	0.791	0.835	0.957	0.201	0.002
F value	0.100	0.299	0.347	0.286	0.105	1.582	5.456
CV (%)	13.91	12.93	12.83	11.74	10.49	9.89	10.544

Leaf Size

Among the treatments, the bio-fungicide (T1) recorded the highest average leaf area (4.78 ± 0.17), indicating enhanced leaf development and improved plant vigor. The vinegar treatment (T2) showed moderate effectiveness, with an average leaf area of 4.15 ± 0.13. Mancozeb (T3) resulted in a slightly lower leaf area (4.02 ± 0.11) compared to T2. The untreated control (T4) exhibited the smallest leaf area (3.21 ± 0.19), reflecting the adverse effects of uncontrolled powdery mildew infection.

The bio-fungicide treatment not only achieved the highest mean leaf area but also showed lower variability among replicates, demonstrating consistent plant performance. Overall, the results confirm that biological disease management approaches are more effective in promoting leaf growth and maintaining plant health compared to chemical and untreated conditions.

Discussion

The results of the present study clearly demonstrate the differential effects of disease management strategies on fungal suppression and growth performance of *Matricaria chamomilla*. Among the treatments evaluated, the bio-fungicide (T1) consistently outperformed the chemical fungicide, vinegar treatment, and untreated control across disease severity, plant height, and leaf area parameters.

The superior performance of T1 can be attributed to the presence of *Trichoderma harzianum*, a well-established biocontrol agent known for its multiple modes of action. *Trichoderma* spp. suppresses fungal pathogens through mycoparasitism, competition for nutrients and space, and the production of antifungal enzymes and secondary metabolites (Bora et al., 2015; Harman et al., 2004). This explains the significant reduction in powdery mildew severity observed in T1-treated plants. In addition to disease suppression, *Trichoderma* is recognized for its plant growth promoting effects, which likely contributed to the enhanced plant height and larger leaf area recorded in this treatment.

The increased growth observed under T1 may also be associated with the activity of Plant Growth Promoting Rhizobacteria (PGPR) such as *Azospirillum* and *Azotobacter*, which improve nitrogen fixation and nutrient availability in the rhizosphere (Chaudhary et al., 2022). Furthermore, bio-fungicides often contain phytohormones including auxins, gibberellins, and cytokinins that stimulate root elongation, cell division, and leaf expansion, leading to improved overall plant vigor (Mukherjee, 2022). The presence of amino acids and vitamins may have further enhanced metabolic efficiency and stress tolerance, particularly during later growth stages (Daniel et al., 2022).

Mancozeb (T2) effectively reduced disease severity but showed comparatively lower improvements in plant height and leaf area. This supports previous findings that while synthetic fungicides are efficient in pathogen control, they do not contribute to plant physiological enhancement and may disrupt beneficial soil microflora with prolonged use (V. Kumar et al., 2021). The vinegar treatment (T3) provided moderate disease suppression and growth improvement, likely due to the antifungal action of acetic acid, which reduces surface pathogen load when applied at appropriate concentrations (Zhang et al., 2013). However, its lack of systemic activity limits long-term growth benefits.

The untreated control (T4) consistently exhibited the highest disease severity and poorest growth performance, highlighting the progressive nature of powdery mildew infection under favorable environmental conditions. Reduced leaf area and plant height in T4 can be attributed to impaired photosynthetic capacity, nutrient stress, and physiological damage

caused by fungal infection, as reported in earlier studies on fungal stress in medicinal plants (Agrios, 2005).

The gradual reduction in the coefficient of variation from 13.91% in week 1 to 10.544% in week 7 indicates increasing experimental consistency and reliability over time. This trend strengthens confidence in the treatment effects observed during the later stages of plant development, particularly the statistically significant differences recorded at week 7. The findings emphasize that effective disease management combined with biological growth promotion offers a more sustainable and productive approach for chamomile cultivation than disease control alone.

Conclusion

This study evaluated sustainable methods for controlling fungal diseases in chamomile cultivated in Sri Lanka's hill regions. Powdery mildew (*Erysiphe cichoracearum*) was identified as the dominant disease, significantly affecting plant growth. Among the treatments, the *Trichoderma harzianum* based bio fungicide was the most effective, reducing disease severity and promoting healthy plant growth. The vinegar treatment showed moderate control and is a viable, low-cost, eco-friendly option. Mancozeb, a chemical fungicide, reduced disease symptoms but did not enhance plant growth and poses environmental risks. The untreated control group had the highest disease severity, with visible yellowing and stunted growth. These results highlight the importance of integrated, eco-friendly disease management practices, particularly in moisture-prone highland areas, to ensure sustainable chamomile production.

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