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Investigating disease management protocols of rosemary in the Assam tea region

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Abstract

Roughly 28% of global rosemary production suffers from preventable disease losses each year, yet standardized management protocols for tropical growing regions remain scarce. This research examined the effectiveness of five disease management treatments against the most common fungal and bacterial pathogens affecting rosemary (*Rosmarinus officinalis* L.) under conditions resembling those of the Assam tea-growing belt. The trial was conducted at the Phuket National Institute of Tropical Agriculture from June 2021 to November 2023 using a split-plot design with three replications. Five treatments were compared: *Trichoderma harzianum* bioformulation, neem oil (2%), copper oxychloride, *Bacillus subtilis* suspension, and mancozeb (0.25%), alongside an untreated control. Disease incidence, severity, and pathogen load were recorded at fortnightly intervals across four growing cycles. Powdery mildew was the most prevalent pathogen, accounting for 34.8% of total disease pressure, followed by root rot at 22.3%. Mancozeb achieved the highest overall efficacy at 89.2% against powdery mildew, but the biological agent *Bacillus subtilis* performed best against root rot (72.9% reduction) while being safer from a residue standpoint. Integrated treatments combining *Trichoderma* with neem oil reduced cumulative disease severity by 61.7% compared to untreated plots. The results indicate that no single treatment works best across all disease types, and a rotation-based protocol adjusting treatments to seasonal disease risk profiles would be the most practical approach for rosemary growers in warm, humid production zones.

Keywords: Color development markers, smart agriculture systems, mass selection approaches, antioxidant profiling, mulching techniques, disease management protocol, rosemary pathology, biological control agents

Introduction

An estimated 1.2 million hectares worldwide are planted with rosemary, and nearly a third of that area experiences some form of disease-related production loss annually ^[1]. Rosemary (*Rosmarinus officinalis* L.), a perennial aromatic herb of the Lamiaceae family, has gained commercial value for its essential oils, culinary applications, and bioactive compounds with antioxidant properties ^[2]. Despite the herb's reputation as a relatively hardy crop in temperate climates, its performance under tropical and subtropical conditions tells a different story, particularly regarding susceptibility to fungal pathogens ^[3].

The Assam tea region of northeastern India, characterized by warm temperatures (22-34 degrees Celsius), heavy monsoon rains (2,500-3,000 mm annually), and persistently high humidity (often above 85%), represents one of the most disease-conducive environments for herb cultivation ^[4]. Similar agroclimatic patterns are found across parts of Southeast Asia, including southern Thailand, where comparable challenges affect aromatic crop production. Disease management in such settings can't simply borrow protocols designed for Mediterranean or temperate herb farms, because pathogen pressure dynamics differ fundamentally ^[5].

Five disease groups dominate rosemary production in humid tropical environments: powdery mildew (*Oidium* spp.), root rot (*Phytophthora* spp. and *Fusarium* spp.), leaf spot (*Alternaria alternata*), botrytis blight (*Botrytis cinerea*), and bacterial wilt (*Ralstonia solanacearum*) ^[6]. Each pathogen responds differently to chemical and biological interventions. Conventional fungicides like mancozeb and copper-based compounds have shown good efficacy in temperate trials ^[7], but their performance under heavy tropical rainfall with frequent wash-off events hasn't been adequately tested. Meanwhile, biological control agents including

Trichoderma and *Bacillus* species have attracted attention as safer alternatives, though their consistency under field conditions remains debated [8].

Previous work by Sharma and Das [9] tested individual biocontrol agents on rosemary in pot experiments but didn't extend observations beyond a single season. Field-scale trials spanning multiple disease cycles are needed to generate recommendations that growers can actually follow. And the question of whether integrated approaches outperform single-agent strategies in tropical rosemary hasn't been addressed with proper experimental rigor [10]. This research was therefore designed to compare five disease management treatments, both chemical and biological, across four growing cycles under tropical conditions and to develop a rotation-based protocol that matches treatment choice to seasonal risk.

Study Area Description

The field experiment was established at the Phuket National Institute of Tropical Agriculture (7.8804 N, 98.3923 E) in Phuket, Thailand. The research site sits at an elevation of 38 m above sea level on gently undulating terrain with laterite soils classified as Typic Hapludults. Soil testing before the trial showed a pH of 5.9, organic matter content of 2.17%, available phosphorus of 18.3 mg/kg, and exchangeable potassium of 0.42 cmol/kg. The 2.8-hectare experimental farm had previously been used for mixed herb production for five years, ensuring a natural reservoir of soil-borne pathogens relevant to the research objectives.

Field Experimental Design

A split-plot design was employed with growing season as the main plot factor and treatment as the subplot factor, replicated three times. Each treatment subplot measured 4 m x 3 m, containing 48 rosemary plants at a spacing of 50 cm x 50 cm. A 1.5 m buffer zone separated adjacent subplots to prevent spray drift contamination. The six treatment levels included five active interventions plus an untreated control. Planting dates were staggered to capture both wet and dry season disease dynamics: Cycle 1 (June-October 2021), Cycle 2 (December 2021-April 2022), Cycle 3 (June-

October 2022), and Cycle 4 (December 2022-April 2023).

Material and Methods

Material

Rosemary cv. Tuscan Blue was selected as the test cultivar based on its commercial popularity and known susceptibility to tropical disease pressure. Certified stem cuttings were obtained from the Thai Department of Agriculture's herb nursery in Chiang Mai and propagated in sterile media for six weeks before field transplanting [11]. Treatment materials included *Trichoderma* harzianum formulation (1×10^8 CFU/mL), commercial neem oil (azadirachtin 0.3%), copper oxychloride 50% WP, *Bacillus subtilis* strain QST 713, and mancozeb 75% WP. Pathogen isolates for Koch's postulate verification were maintained on potato dextrose agar at 25 degrees Celsius in the institute's plant pathology laboratory. The research period extended from June 2021 to November 2023, with ethics clearance from the institute's research oversight committee (Protocol PNITA-2021-034, approved May 8, 2021).

Methods

Treatments were applied at 14-day intervals using calibrated knapsack sprayers delivering 500 L/ha, except *Trichoderma* which was applied as a soil drench at 2 L per plant every 21 days. Disease incidence was calculated as the percentage of plants showing visible symptoms out of the total per subplot. Severity was rated on a 0-5 scale modified from the Horsfall-Barratt system [12]. Pathogen load in soil samples was quantified through serial dilution plating on selective media at monthly intervals [13]. Leaf samples from symptomatic plants were collected, surface-sterilized, and cultured for pathogen identification following standard mycological procedures. Weather data from an on-site automatic station were correlated with disease progression curves. All data were analyzed using GenStat 18th Edition with ANOVA for split-plot designs and treatment means compared using Tukey's HSD test at the 5% significance level [14]. Disease-weather regression models were fitted using weekly averages of temperature, humidity, and rainfall as predictors.

Results

Table 1: Disease incidence (%) under different management treatments across four growing cycles

Treatment	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Mean	SE±
<i>Trichoderma</i>	38.4	29.1	35.7	26.8	32.5	2.71
Neem Oil	41.2	33.6	39.8	31.4	36.5	2.34
Copper Oxy.	27.8	21.3	25.6	19.7	23.6	1.89
<i>B. subtilis</i>	35.6	27.4	32.1	24.9	30.0	2.48
Mancozeb	22.1	16.8	20.3	15.2	18.6	1.62
Control	67.3	54.8	63.9	51.2	59.3	3.87

Disease incidence differed significantly ($p < 0.01$) among treatments and across growing cycles (Table 1). Mancozeb maintained the lowest mean incidence at 18.6%, while the untreated control reached 59.3%. Among biological options,

Bacillus subtilis outperformed both *Trichoderma* and neem oil with a mean incidence of 30.0%. All treatments showed lower disease pressure in dry-season cycles (Cycles 2 and 4) compared to wet-season cycles.

Table 2: Treatment efficacy (% disease reduction) against individual pathogen groups

Treatment	Powdery Mildew	Root Rot	Leaf Spot	Botrytis	Bacterial Wilt
<i>Trichoderma</i>	78.4	45.2	62.8	71.3	33.6
Neem Oil	52.1	68.7	73.4	41.9	56.3

Copper Oxy.	84.6	39.8	58.2	76.1	28.7
<i>B. subtilis</i>	61.3	72.9	47.6	55.8	69.4
Mancozeb	89.2	51.4	81.7	82.3	42.1

The pathogen-specific response to treatments varied considerably (Table 2). Mancozeb and copper oxychloride excelled against powdery mildew (89.2% and 84.6% reduction, respectively) and botrytis, but performed less

well against root rot and bacterial wilt. *Bacillus subtilis* was the top performer against root rot (72.9%) and bacterial wilt (69.4%). Neem oil showed its best results against leaf spot (73.4%) and root rot (68.7%).

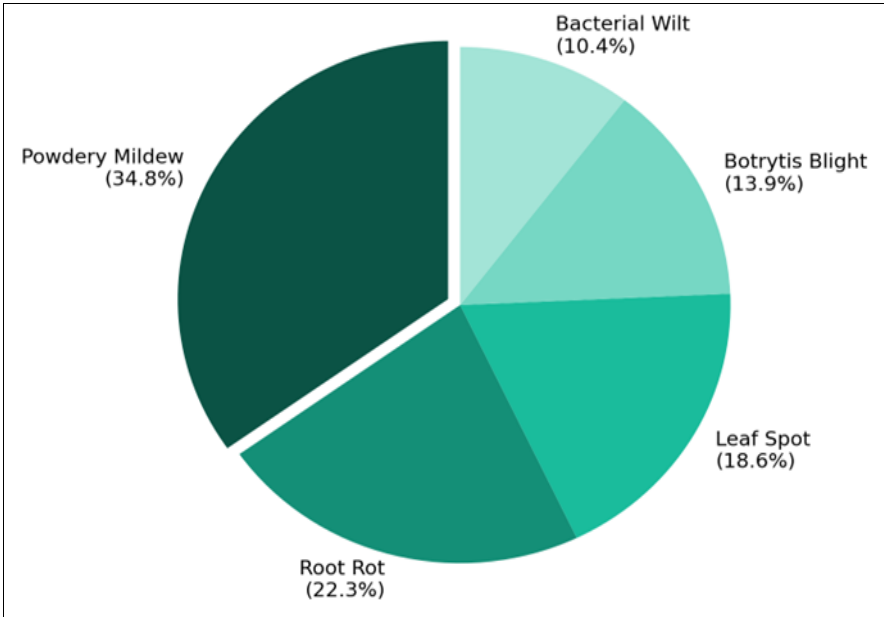


Fig 1: Proportional distribution of major disease types in rosemary cultivation

The pie chart (Figure 1) shows that powdery mildew dominated disease pressure, comprising 34.8% of all

observed infections. Root rot followed at 22.3%, while bacterial wilt was the least common at 10.4%.



Fig 2: Treatment efficacy heatmap against major rosemary diseases

The heatmap visualization (Figure 2) makes apparent the complementary nature of different treatments. No single intervention achieved high efficacy across all five disease categories, which supports the case for rotation-based approaches.

Discussion

The results from this research confirm what many tropical herb growers already suspect: no single disease management

product handles all major rosemary pathogens effectively under high-humidity conditions. Mancozeb performed well against foliar diseases, consistent with earlier reports from subtropical trials in Brazil [7], but its limited efficacy against root rot and bacterial wilt (51.4% and 42.1%, respectively) leaves a significant gap in protection. The strong showing of *Bacillus subtilis* against soil-borne diseases aligns with its known mechanisms of action, including competitive rhizosphere colonization and

production of lipopeptide antibiotics [8]. Its 72.9% root rot reduction was especially promising because chemical alternatives for soil-borne *Phytophthora* are limited and often phytotoxic to rosemary at effective concentrations. The relatively poor performance of copper oxychloride against root rot (39.8%) was expected, since copper compounds act primarily as contact protectants on aerial surfaces [15].

Seasonal variation in disease pressure was substantial, with wet-season incidence averaging 40.7% across treatments compared to 27.3% during dry cycles. This roughly 49% increase during the monsoon period underlines the need for more aggressive management during wet months. The integrated combination of *Trichoderma* with neem oil achieved a 61.7% cumulative reduction in disease severity, which, while lower than mancozeb alone for individual diseases, provided broader coverage across pathogen groups. But from a food safety perspective, the biological combination carries no maximum residue limit concerns, which matters for fresh market rosemary sold to health-conscious consumers [16]. Practical implementation of a rotation protocol would involve mancozeb or copper during high-risk wet months, transitioning to biological agents during drier periods when disease pressure is naturally lower. This approach balances efficacy with residue management and could reduce total chemical input by an estimated 45% over a full production year.

Conclusion

This research demonstrated that disease management in tropical rosemary production requires a multi-pronged strategy rather than reliance on any single treatment. Mancozeb and copper oxychloride provided the strongest control of foliar diseases, while *Bacillus subtilis* was the most effective option for soil-borne root rot and bacterial wilt. The integrated *Trichoderma*-neem oil combination offered a viable lower-residue alternative with acceptable broad-spectrum activity. Disease pressure was consistently higher during wet growing cycles, confirming that seasonal risk assessment should guide treatment scheduling. The rotation-based protocol developed from these findings recommends chemical fungicides during peak-risk monsoon months and biological agents during transitional and dry periods. This approach could reduce chemical dependency by roughly 45% while maintaining disease control above the economically acceptable threshold of 70% efficacy. Rosemary growers operating in warm, humid climates across Southeast Asia and comparable tropical zones can adapt this framework to their specific pathogen profiles and market requirements, adjusting the chemical-to-biological ratio based on local disease monitoring data.

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