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Research Article

In vitro efficacy of oomycete-specific fungicides and pH-modulated Bordeaux mixture against *Phytophthora meadii* of arecanut fruit rot

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Abstract

Fruit rot disease or Koleroga, caused by *Phytophthora meadii*, is a serious disease of arecanut (*Areca catechu* L.) in the Western Ghats of India, causing major economic losses. The study evaluated the curative efficacy of selected oomycete-specific fungicides and the effect of pH on Bordeaux mixture against *P. meadii* using a detached nut assay in farmer's participatory mode. Healthy 'Sagara Local' nuts were inoculated with a zoospore suspension of *P. meadii* and treated with Bordeaux mixture (1%) at pH 6, 7 and 10, Metalaxyl (4%) + Mancozeb 64% WP (0.25%), Mandipropamid 23% SC (0.1%) and Copper oxychloride 50% WP (0.25%). An untreated inoculated control was maintained. After seven days of incubation under high humidity, disease incidence was recorded. The untreated control showed 100 per cent disease incidence, while all other treatments significantly reduced fruit rot disease. Metalaxyl + Mancozeb was found to be most effective (10% incidence; 90% reduction), followed by Mandipropamid (20% and 80% reduction). Bordeaux mixture at pH 7 found superior (24% incidence), compared to pH 6 (36% incidence) and pH 10 (60% incidence). The results highlighted the effectiveness of Metalaxyl + Mancozeb, Mandipropamid and emphasize maintaining neutral pH in Bordeaux mixture for improved management of arecanut fruit rot.

Keywords: *Areca catechu*, Detached nut assay, Fungicide efficacy, *Phytophthora meadii*

Introduction

Arecanut (*Areca catechu* L.) is an economically and culturally important plantation crop in South and South-East Asia. India is the largest producer and consumer, with 10.40 lakh ha under cultivation producing 14.91 lakh tons (DASD, 2024). The Malnad region of Karnataka in the Western Ghats is the traditional center of arecanut cultivation due to its favorable agro-climatic conditions. However, expansion into new areas and intensive practices have created favorable microclimates for serious pests and diseases, threatening long-term sustainability (Balanagouda *et al*., 2021).

Among various diseases affecting arecanut, fruit rot disease (FRD), traditionally called Koleroga or *Mahali*, is the most destructive. It is caused by the oomycete *Phytophthora meadii*, first scientifically described in arecanut by Coleman (1910). The disease is closely linked to South-West monsoon conditions in the Western Ghats. Under heavy rainfall and high humidity, they release motile zoospores that infect nuts through the perianth region. The pathogen rapidly colonizes the fruit, producing white mycelial growth and abundant secondary inoculum, leading to severe epidemics. Infected nuts drop prematurely and further, severe infection may reach the crown causing bud rot. Yield losses often range from 50-90 per cent in unmanaged plantations (Jose *et al*., 2019; Patil *et al*., 2022).

Because of non-availability of resistant cultivars, FRD management mainly depends on fungicides. For over a century, copper-based fungicides, especially 1% Bordeaux mixture recommended after Coleman's work, have been widely used (Ravikumar *et al*., 2019). Although its effectiveness and performance mainly depends on ingredient quality, pH and long-term use raises concerns about copper accumulation and residues (Mathew *et al*., 2015). These limitations have encouraged the use of modern oomycete-specific systemic fungicides like Metalaxyl and Mandipropamid which provides strong systemic activity and rain-fastness (Patil *et al*., 2024).

There is a significant research gap in the quantitative assessment of how pH variations affect the efficacy of Bordeaux mixture against *P. meadii*. Therefore, this study was designed as a farmer-participatory study aimed to compare the curative efficacy of Metalaxyl + Mancozeb and Mandipropamid with traditional copper fungicides for FRD control and to evaluate how acidic, neutral and alkaline pH levels influence the effectiveness of Bordeaux mixture against *P. meadii*. The results aim to provide practical recommendations for effective management of arecanut fruit rot.

Materials and Methods

Experimental site and collection of nuts

The study was conducted as farmer-participatory research mode in Kattinakere village (14.30.61 N, 75.14.85 E), Soraba taluk, Shivamogga district, Karnataka, India, located in the Malnad region of the Western Ghats, an endemic zone for arecanut fruit rot disease. About 70 mature nuts showing typical fruit rot symptoms with white mycelial growth of *Phytophthora* were collected from an unsprayed plantation for inoculum preparation. Healthy, uniform immature nuts of the cultivar 'Sagara Local' were harvested from disease-free palms for the bioassay. Local farmers assisted in collecting diseased nuts, preparing inoculum and maintaining incubation conditions, allowing demonstration of fungicide performance under practical conditions.

Preparation of pathogen inoculum

A crude suspension of *Phytophthora meadii* sporangia and zoospores was prepared by soaking the infected nuts in 10 L sterile distilled water for 30 minutes with intermittent agitation. The suspension was filtered through double-layer muslin cloth to remove debris, producing a viable inoculum containing infective propagules for the assay.

Fungicide treatments and preparation

Based on the survey feedback of 526 arecanut farmers, the treatments were finalized with graded pH levels of Bordeaux mixture and other effective chemicals with an idea of demonstrating the effectiveness of Bordeaux mixture (1%) with pH 7. These seven treatments were evaluated, including six fungicides and an untreated control. Bordeaux mixture (1%) was prepared at pH 6, 7 and 10 using copper sulphate and hydrated lime solutions, with pH adjusted using a digital pH meter. Other fungicides were prepared according to recommended concentrations: Metalaxyl 4%+Mancozeb 64% WP (0.25%), Mandipropamid 23% SC (0.1%) and Copper oxychloride 50% WP (0.25%) (Table 1).

Inoculation and fungicide application

Healthy nuts were surface sterilized with 0.1% sodium hypochlorite for one minute and rinsed with sterile distilled water. Nuts were then submerged in the *P. meadii* inoculum suspension for 30 minutes. The inoculated nuts were divided into seven groups (50 nuts per treatment) and sprayed with the respective fungicide solutions using a hand atomizer. Control nuts were sprayed with sterile distilled water. The treatments were replicated thrice. After seven days of incubation, the results were demonstrated to 65 farmers. Treated and untreated nuts were displayed side-by-side, clearly showing differences in disease development.

Incubation and disease assessment

After treatment, nuts were placed in separate labeled polythene bags and incubated for seven days under high humid conditions (≈95%) between wet gunny bags in 90 per cent dark conditions to simulate monsoon microclimate. After incubation, each nut was examined for fruit rot symptoms. Disease incidence was calculated as:

Disease Incidence (%) = (Number of infected nuts/ Total number of nuts assessed) × 100

Statistical analysis

Percent disease reduction relative to the control was calculated using Abbott's formula (Abbott, 1925). Descriptive statistics were computed and treatment effects were analyzed using one-way ANOVA with the model $Y_{ij} = \mu + \tau_i + \varepsilon_{ij}$. When significant differences were detected, Tukey's HSD test was applied for pairwise comparisons at $\alpha = 0.05$. All analyses were performed using the R statistical software version 4.2.1 (R Core Team, 2022).

Results and discussion

Effective management of arecanut fruit rot requires reliable chemical control due to the rapid spread and severe yield losses caused by *Phytophthora meadii*. The present farmer-participatory research compared modern systemic fungicides with traditional copper-based formulations and provided practical insights for improving effective management.

Disease incidence and fungicide efficacy

Artificial inoculation and controlled incubation successfully induced fruit rot disease. The untreated control showed 100 per cent disease incidence, confirming high infection pressure. All fungicide treatments significantly reduced the disease incidence compared to control (Table 2). Metalaxyl 4% + Mancozeb 64% WP provided the highest control with only 10 per cent disease incidence followed by Mandipropamid 23% SC recorded 20 per cent incidence. The effectiveness of Bordeaux mixture depended strongly on pH, the neutral formulation (pH 7) showed 24 per cent incidence, followed by the acidic formulation (pH 6) with 36 per cent. The alkaline Bordeaux mixture (pH 10) was least effective among the Bordeaux treatments, with 60 per cent incidence. Copper oxychloride showed moderate control with 50 per cent disease incidence (Figure 1).

Comparative disease reduction

Disease reduction relative to the untreated control confirmed the superiority of Metalaxyl + Mancozeb (90% reduction), followed by Mandipropamid (80%). Neutral Bordeaux mixture achieved 76 per cent reduction, performing better than acidic Bordeaux mixture (64%) and alkaline Bordeaux mixture (40%). Copper oxychloride provided 50 per cent reduction, indicating moderate efficacy under high disease pressure. Visual observations of incubated nuts supported these quantitative results (Figures 2 & 3). The high efficacy of Metalaxyl + Mancozeb is attributed due to its complementary modes of action. Metalaxyl is a

Table 1: Fungicide treatments used in the detached nut assay for the management of arecanut fruit rot

Treatment Code	Fungicide/Active Ingredient	Formulation	Concentration (%)
T_1	Bordeaux mixture (pH 6)	Soluble Liquid (SL)	1.00
T_2	Bordeaux mixture (pH 7)	Soluble Liquid (SL)	1.00
T_3	Bordeaux mixture (pH 10)	Soluble Liquid (SL)	1.00
T_4	Metalaxyl 4% + Mancozeb 64%	Wettable Powder (WP)	0.25
T_5	Mandipropamid 23%	Suspension Concentrate (SC)	0.10
T_6	Copper oxychloride 50%	Wettable Powder (WP)	0.25
T_7	Untreated control	-	-

Table 2: Mean disease incidence of arecanut fruit rot under different fungicide treatments seven day's post-inoculation

Treatments	Fungicides	Disease Incidence (%)	Disease Reduction (%)
T_1	Bordeaux mixture (pH 6)	36.0* (36.89)	64.0
T_2	Bordeaux mixture (pH 7)	24.0 (29.35)	76.0
T_3	Bordeaux mixture (pH 10)	60.0 (50.79)	40.0
T_4	Metalaxyl 4% + Mancozeb 64% WP	10.0 (18.44)	90.0
T_5	Mandipropamid 23% SC	20.0 (26.58)	80.0
T_6	Copper oxychloride 50% WP	50.0 (45.02)	50.0
T_7	Untreated Control	100.0 (90.05)	0.0
SEm±		4.42	-
CD (5%)		13.38	-

*Note: Mean of three replications, values in the parenthesis are angular transformed values

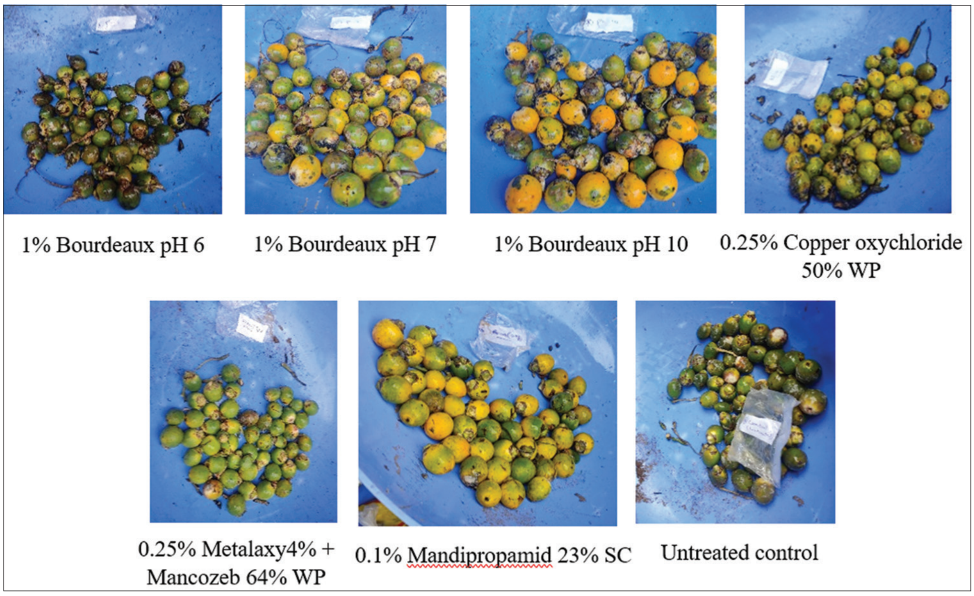

Figure 1: Comparison of disease symptoms in treated and untreated arecanut nuts after incubation

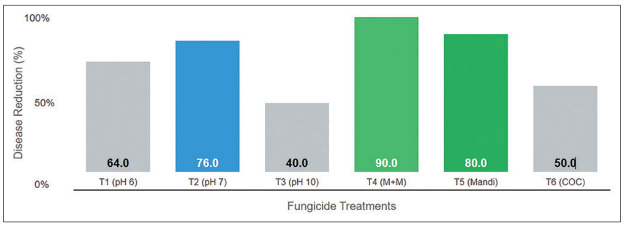

Figure 2: Curative efficacy of fungicides, expressed as percent disease reduction relative to the untreated control

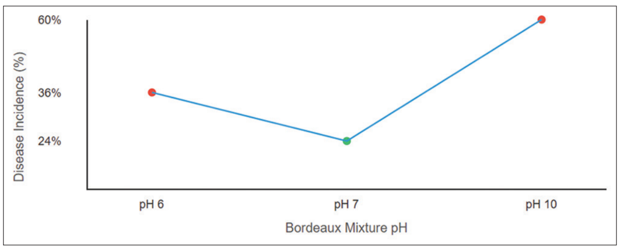

Figure 3: The effect of pH on the efficacy of 1% Bordeaux mixture against arecanut fruit rot

systemic phenylamide fungicide that inhibits ribosomal RNA synthesis in oomycetes, suppressing mycelial growth and providing curative activity. Mancozeb is a multi-site contact fungicide that disrupts multiple metabolic processes in pathogen spores. Together, they provide both protective and curative action while reducing the risk of resistance. Similar findings have been reported in field studies where Metalaxyl + Mancozeb fungicide consistently reduced fruit rot severity under natural conditions (Patil *et al*., 2024). On the other hand, Mandipropamid, a carboxylic acid amide fungicide, inhibits cellulose synthase involved in oomycete cell wall formation. Its translaminar movement and strong affinity for the plant cuticle enable prolonged protection and effective suppression of pathogen development even after infection has begun.

Statistical analysis of treatment efficacy

One-way ANOVA showed a highly significant difference among treatments ($F(6,343)=405.1$, $p<0.001$). Tukey's HSD test separated the treatments into five significance groups. Metalaxyl + Mancozeb was statistically superior compared to all other treatments. Mandipropamid and neutral Bordeaux mixture formed the second group and were significantly more effective than the remaining treatments. Acidic Bordeaux mixture showed intermediate efficacy, while copper oxychloride and alkaline Bordeaux mixture had comparatively lower effectiveness. The untreated control differed significantly from all fungicide treatments (Table 3).

The study clearly demonstrated that the effectiveness of Bordeaux mixture is strongly influenced by pH. The

Table 3: Pairwise comparison of mean disease incidence using Tukey's HSD post-hoc test [*Means of same superscript letter are not significantly different at the α = 0.05 level]

Treatment Code	Fungicide Treatment	Mean Incidence (%)*
T_1	Metalaxyl+Mancozeb	10^a
T_2	Mandipropamid	20^b
T_3	Bordeaux mixture (pH 7)	24^b
T_4	Bordeaux mixture (pH 6)	36^c
T_5	Copper oxychloride	50^d
T_6	Bordeaux mixture (pH 10)	60^d
T_7	Untreated Control	100^e

neutral formulation (pH 7) performed significantly better than acidic or alkaline preparations. The chemical reaction between copper sulphate and lime produces a precipitate whose stability, adhesiveness and fungitoxicity are all governed by pH. At neutral pH, the precipitate remains stable and adhesive, allowing gradual release of copper ions that inhibit pathogen spores. Acidic mixtures contain excess soluble copper sulphate, which may cause phytotoxicity and reduce stability. Highly alkaline mixtures contain excess lime, forming crystalline copper hydroxide that reduces the availability of active copper ions. It is widely believed that a neutral to slightly alkaline pH is optimal for creating a stable precipitate that allows for the sustained release of fungitoxic copper ions (Anandaraj & Saraswathy, 1986). Multi-site fungicide Bordeaux mixture remain important due to their low resistance risk and suitability for prophylactic applications before the monsoon (Ravikumar *et al*., 2019).

Systemic fungicides such as Metalaxyl+Mancozeb and Mandipropamid can be used strategically during periods of high disease pressure. Rotational use of fungicides with different modes of action, reduces selection pressure and delays resistance development. Combining the protective action of copper fungicides with the curative activity of modern systemic fungicides provides a balanced and sustainable strategy for long-term management of arecanut fruit rot in the Malnad region.

Conclusions

Fruit rot disease caused by *P. meadii*, remains one of the most devastating diseases of arecanut. The findings of the present study indicate that use of fungicides such as Metalaxyl + Mancozeb, Mandipropamid and 1% neutral Bordeaux mixture during peak disease pressure will help in controlling the disease. Even though systemic fungicides showed higher efficacy, exclusive reliance on them is not sustainable because site-specific fungicides can promote resistance development in pathogen populations. Therefore, integrated disease management strategies are necessary. This farmer-participatory research clearly evaluated the effectiveness of key fungicides for managing arecanut fruit rot and provided practical recommendation to the growers.

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