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RESEARCH ARTICLE

Novel fungicidal management for basal stem rot disease of coconut: *In vitro* and *in vivo* perspectives

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Abstract

Basal stem rot (BSR) disease, a lethal disease of coconut crop, induced by *Ganoderma lucidum* is prevalent and endemic in the East Coast region of the Tamil Nadu. The prolonged use of a single fungicide and the emerging issue of fungicide resistance raised concerns regarding disease control in this region. An integrated disease management strategy, incorporating new generation fungicides could help resolve these challenges. The Indian Council of Agricultural Research-AICRP on Plantation Crops (All India Co-ordinated Research Project) investigated different fungicides of single along with combination types against *G. lucidum* at three different concentrations (100, 250 and 500 ppm) in an *in vitro* study. Thirteen fungicides were screened and was found that hexaconazole 4 % + carbendazim 16 % SC, hexaconazole 5 % + validamycin 2.5 % SC as well as azoxystrobin 11 % + tebuconazole 18.3 % SC W/W were most effective in controlling *G. lucidum* even at lower concentrations. In field trial, two novel combination fungicides azoxystrobin 11 % + tebuconazole-18.3 % SC W/W and hexaconazole 5 % + validamycin 2 % SC, were utilized. In comparison to other treatments, treatment (T_6), which consists of root feeding hexaconazole 5 % + validamycin-2.5 % SC @ 4 mL in 100 mL of water as well as drenching the soil with hexaconazole 5 % + validamycin-2.5 % SC @ 2 mL/L (15 L/palm) every three months, was the most successful in controlling the disease. This treatment reduced the BSR disease index by 12.43 % compared to the initial disease index and resulted in a 58.49 % increase in nut yield compared to the control.

Keywords: basal stem rot; coconut; disease management; fungicide; *Ganoderma lucidum;* hexaconazole; tebuconazole

Introduction

Coconut (*Cocos nucifera* Linn.) is a tropical perennial plantation crop known for its variety of commercial importance. The major coconut growing countries include Philippines, Indonesia, Sri Lanka and India. In India, coconut cultivation in an area of 2.28 million hectares produces 20535.88 million nuts (1). The coconut under cultivation in the state of Tamil Nadu in an area of 0.44 million hectares produces 4097.23 million nuts (2).

Coconut is affected by various fungal diseases, including bud rot (*Phytophthora palmivora)*, grey blight (*Pestalotiopsis palmarum*), Thanjore Wilt (or) basal stem end rot (*G. lucidum)*, stem bleeding disease (*Thielaviopsis paradoxa*) occurring in Tamil Nadu. Among these, BSR disease caused by *G. lucidum* (Leys.) Karst. poses a significant threat to production and productivity (3). Also known as Thanjavur wilt this disease predominantly affects in traditional coconut growing regions along the East Coastal. As per estimates, the disease incidence in the area was nearly about 31 % (4). Recently, the cyclone-Gaja aggravated the disease incidence by up to 50 % in east coastal region that continuously reminds the threat of the disease to the coconut farmers in this region (5).

The symptoms of BSR disease include yellowing, drooping and drying of leaves from lower to upper portion followed by button shedding and barren nuts and excessive root rot, stem bleeding with the exudation of reddish-brown viscous fluid and dried leaves fall-off with crown collapse and decay leads to death of palm (6). Severely infected palms become wilt and unproductive with the formation of sporophores at the base of the palm (7). This disease spreads quickly in the ill-maintained coconut gardens.

BSR disease primarily affects coconut plantations in East Coastal areas with sandy loam soils particularly under rainfed conditions and in poorly maintained coconut gardens (8). The coastal soil type and soils with poor drainage and flooded conditions of the field during rainy season are highly conducive to the disease (9). Soil borne nature of the fungus disseminates through soil, irrigation water and rainwater and seedlings from sick soil from one field to others. The severe spread and lethal nature of the disease urgently necessitates sustainable disease management. Combining cultural, chemical, along with biological approaches can help to manage BSR disease in coconuts (10). Fungal pathogens are effectively controlled by chemical fungicides (11).

In disease management scenario, failure of fungicides due to fungicidal resistance and banning of existing fungicides in the market is highly challenging. Extending the scope of screening for new chemicals is a practical need for the disease control. In this context, the performance of *in vitro* screening of new fungicide molecules is continuously encouraged that ensuring the complete inhibition of the pathogen.

Several studies have investigated the *in vitro* efficacy of novel fungicidal molecules against *G. lucidum,* with promising results for various chemical treatments. The effectiveness of Tridemorph (500 ppm) against *G. lucidum* was tested by (11, 12). tridemorph 80 EC effectively suppressed the *G. lucidum* of arecanut (13).

The combination fungicide *tebuconazole* 50 % +trifloxystrobin was tested for the *in vitro* suppression of *Lasiodiplodia theobromae* of coconut (14). Carbendazim 50 WP was a potent fungicide for the suppression of *Lasiodiplodia theobromae* under *in vitro* (15). Difenoconazole was used for the *in vitro* suppression of coconut grey leaf spot pathogen of coconut (16). Study indicated that difenoconazole inhibited the mycelia growth and sporulation of *Thielaviopsis punctulate* (17). Difenoconazole and cyflufenamid were used for the significant inhibition of the *Fusarium solani* growth causing sudden decline disease of date palms *in vitro* (18).

The present study tried to evaluate 13 novel systemic fungicides against the virulent isolate of *G. lucidum* (CRSVPM-3) causes BSR disease. Subsequently, field evaluation of potential fungicide molecules was done by adopting the soil drenching and root feeding methods for the fullest practical utility to combat the soil borne disease. Therefore, the field study laid out with different treatments of potent fungicides and essentially integrated the soil drenching and root feeding methods for these fungicides made fruitful for future disease control strategies.

In this context, the present study tried to review the different systemic chemicals used by several workers for the control of BSR disease in coconut: Root feeding with carboxin and quintozene fungicides (19) were effective in controlling BSR disease in coconut.

To ensure the lowest BSR disease index in the coconut gardens, palms were treated with 2 % tridemorph root feeding + 0.3 % soil drenching and demonstrated the combined effect of 1 % hexaconazole root feeding and 0.2 % soil drenching: soil drenching with 0.3 % tridemorph and 0.2 % hexaconazole in comparison with root feeding 2 % tridemorph or else 1 % hexaconazole alone (20). In the Kerala, soil drenching with 0.4 % copper oxychloride at 15 L/ tree and root feeding with 2 % tridemorph and 0.1 % soil drench in conjunction with neem cake successfully prevented the BSR disease of coconut (21). Hexaconazole, tridemorph, propiconazole, tridemefon, cyproconazole and penconazole were used as soil drenching in the control of white root disease of rubber in the newly infected trees or trees at mild infection level (22). The root feeding of hexaconazole 5 EC 1 % along with the potential biocontrol agent at four monthly intervals helped in controlling the BSR disease in coconut (23).

Although many investigations on the field application of disease management practices were tried against this disease, the use of systemic chemicals is highly promising. Recently, the aggravation of the disease after the cyclone - Gaja caused severe yield reduction and the quest for new systemic chemicals was viewed seriously by the state agriculture research and extension system and coconut growers. This necessitates the laboratory screening and field study of fungicides to find out the effective new fungicide against *G. lucidum* for field utility. Accordingly, the present study focused on the effective management of BSR of coconut.

Materials and Methods

The inhibitory effect of thirteen systemic fungicides includes five combination fungicides and eight single fungicides at 100, 250 and 500 ppm concentrations on *G. lucidum's* mycelial growth under *in vitro* condition was evaluated by poisoned food technique (24). Each treatment was replicated three times with proper control.

Five combination fungicides *viz.,* famoxadone 16.6 %+ cymoxanil 22.1 % SC, hexaconazole 4 %+ carbendazim 16 % SC, azoxystrobin 11 %+ tebuconazole 18.3 % SC W/W, azoxystrobin 18.2 % w/w+ difenoconazole 11.4 % w/w SC, hexaconazole 5 %+ validamycin 2.5 % SC were used against the *G. lucidum*.

Eight single fungicides *viz.,* cyazafamid 34.5 % SC, mancozeb 35 % SC, "kitazin 48 % EC, thifluzamide24 % SC, carbendazim 46.27 % SC, isoprothiolone 40 % EC, difenoconazole 25 % EC, pencycuron 23.9 % SC were also used for the *in vitro* studies.

The sterile Potato Dextrose Agar (PDA) medium was amended with required concentrations of fungicides and dispensed into individual sterile Petri plates for each concentration under sterile environment. The fungal mycelial disc (8mm) from 7days old culture of the virulent isolate of *G. lucidum* (CRSVPM-3) (mycelial disc) was used for the inoculation and the Petri plates were incubated at 28±2 ºC. For each concentration, a control had been maintained by simultaneous inoculation of well grown target fungus in the Petri plate without amending the fungicide in the PDA medium. Nine days after the fungus's inoculation, measurements of the target fungus's mycelial growth diameter were taken. The following formula was used for the calculation of percent inhibition of mycelial growth of target fungus:

$$PI=(C-T)/C*100 \qquad \text{(Eqn. 1)}$$

Where,

PI=Per cent inhibition over control

C=Mycelial growth of pathogen in control

T=Mycelial growth of pathogen in treatment

Under a CRD (completely randomized design), 3 replications of each treatment were kept. Duncan's Multiple Range Test (DMRT) was used to compare treatment means and the data were statistically analyzed (25).

Field evaluation of potential fungicides

The following eight treatments were adopted for the conduct of field evaluation of potential fungicides against coconut's BSR disease at Coconut Research Station, Veppankulam during 2021-2022 under RBD (Randomized Block Design) with 3 replications (4 palms/replication).

Coconut palms (variety East Coast Tall) aged 15-20 years and infected with BSR were selected for the trial. The disease index of the palms was calculated before and after imposition of treatments.

Treatments

- **T_1**-Root feeding of azoxystrobin 11 %+ tebuconazole 18.3 % SC @ 4 mL in 100 mL of water
- **T_2**- Soil drenching of azoxystrobin 11 %+ tebuconazole 18.3 % SC (@ 2 mL/L of water) 15 L of water/palm
- **T_3**-T_1+T_2
- **T_4**-Root feeding of hexaconazole 5 %+validamycin 2.5 % SC@4 mL in 100 mL of water
- **T_5**- Soil drenching of hexaconazole 5 %+validamycin 2.5 % SC (@ 2 mL/L of water) 15 L of water/palm
- **T_6**-T_4+T_5
- **T_7**-Root feeding of hexaconazole @ 4 mL in 100 mL of water
- **T_8**-Control

Calculation of Disease Index (DI)

The DI was calculated by taking note of the height of the bleeding patch, the quantity of functional leaves, as well as the decline in leaf size in infected palms. The disease-infected palms were identified based on the visible symptoms on leaves as well as bleeding on basal portion of stem (6).

DI formula for BSR disease in coconuts was provided using the equation (26).

$$DI=23.6+17.7\,h+3.6r-0.61 \qquad \text{(Eqn. 2)}$$

where "h" stands for the height of the bleeding spread on stem, "l" for number of functional leaves in crown, as well as "r" represents reduction of terminal leaf size.

The calculated DI score for a mild disease attack of BSR was 15 or less than 15, for a moderate attack of BSR the score was between 15 and 40 and for a highly diseased one was above 40. This approach allows for disease assessment in palms while the severity does not surpass 100.

Statistical analysis

ANOVA for a Completely Randomized Design for *in vitro* research and RBD for *in vivo* studies with three replicates were applied to the data collected for different parameters in the current investigation. The critical difference was calculated for the mean values of different parameters with standard errors for the significance at P values <0.05. Microsoft Excel (2019) was used for the creation of graphs. The ICAR software WASP version 2.0 was used for the data analysis.

Results

In vitro screening of new fungicides against *Ganoderma lucidum*

Thirteen fungicides were tested against *G. lucidum* the *in vitro* by poisoned food technique at 100, 250 and 500 ppm concentrations and the mycelial growth of *G. lucidum* and the inhibition were checked with the control plate.

The results revealed that among thirteen fungicides tested under *in vitro*, hexaconazole 4 %+carbendazim 16 % SC, "azoxystrobin 11 % + tebuconazole-18.3 % SC W/W as well as hexaconazole 5 %+ validamycin 2.5 % SC" had been found superior over the other fungicides by recording 100 % inhibition of *G. lucidum* at 250 ppm and 500 ppm concentrations (Table 1, Fig.1, Fig. 2a - 2e). Treatments were statistically significant. There was no 100 % mycelial inhibition of pathogenic fungi by the fungicide azoxystrobin 11 %+ tebuconazole-18.3 % SC W/W at lower concentration of 100 ppm. On the other hand, "hexaconazole 5 %+ validamycin 2.5 % SC and hexaconazole 4 %+ carbendazim 16 % SC showed 100 % mycelial inhibition at lower concentration of 100 ppm.

Management of basal stem rot disease in coconut through fungicides

To control BSR in coconut during 2021-2022, an *in vitro* investigation evaluated two novel systemic combination fungicides: hexaconazole 5 %+ validamycin 2.5 % SC and azoxystrobin 11 % + tebuconazole-18.3 % SC W/W". A field study was conducted using eight treatments in a randomized block design with three replications. Three coconut trees infected with BSR were chosen for each replication. The treatments including the new systemic fungicides were applied through root feeding and soil drenching at quarterly intervals. Additionally, a treatment involving root feeding with hexaconazole 5 % alone was included for comparison. Pre and post treatments imposition were implemented and the DI for coconut BSR was recorded (Table 2a, 2b).

In comparison to other treatments in 2022, outcome of the present investigation showed that treatment (T_6), that consists of root feeding hexaconazole 5 %+ "validamycin-2.5 %S C@ 4 mL in 100 mL water as well as soil drenching of hexaconazole 5 %+ validamycin-2.5 % SC@ 2 mL/L (15 L/ palm) at quarterly intervals, was most efficient in managing BSR disease". This treatment resulted in a 12.43 % reduction in the BSR DI compared to the initial DI (Table 2b). Additionally, the same treatment showed the increased per centage of nut yield of 40.2 % over the control (Table 3).

Discussion

Earlier, *in vitro* screening of different fungicides against *G.*

Table 1. *In-vitro* evaluation of new fungicides molecules against *Ganoderma* sp

S. No	Fungicides	Mycelial growth of *Ganoderma lucidum* 9 days after inoculation (in mm)			Percentage inhibition over control
		100 ppm	250 ppm	500 ppm	
1	Famoxadone16.6 % + Cymoxanil 22.1 % SC	90 (71.67)	90 (71.67)	89.68 (71.26)	0.361
2	Cyazafamid 34.5 % SC	90 (71.67)	90 (71.67)	90 (71.67)	0
3	Mancozeb 35 %SC	68.75 (56.01)	68.13 (55.63)	66.38 (54.56)	26.25
4	Kitazin 48 % EC	15.38 (23.09)	11.20 (19.55)	10.39 (18.80)	88.46
5	Hexaconazole 4 % + Carbendazim 16 % SC	0 (00.00)	0 (00.00)	0 (00.00)	100
6	Azoxystrobin 11 % + Tebuconazole-18.3 % SC W/W	1.50 (7.03)	0 (0)	0 (0)	100
7	Thifluzamide24 % SC	18.06 (25.15)	10.31 (18.73)	12.31 (20.54)	86.32
8	Carbendazim 46.27 % SC	6.13 (14.33)	4.13 (11.73)	0.81 (5.16)	99.10
9	Isoprothiolone 40 % EC	35.13 (36.35)	23.43 (28.95)	15.19 (22.94)	83.13
10	Difenoconazole 25 % EC	56.44 (48.70)	46.49 (42.99)	35.50 (36.57)	60.56
11	Azoxystrobin 18.2 % w/w + difenoconazole 11.4 % w/w SC	25.19 (30.13)	21 (27.27)	3.78 (11.21)	95.81
12	Hexaconazole 5 % + validamycin 2.5 % SC	0 (0)	0 (0)	0 (0)	100
13	Pencycuron 23.9 % SC	90 (71.67)	90 (71.67)	90 (71.67)	0
14	Control	90 (71.67)	90 (71.67)	90 (71.67)	0
	CD(p=0.05)	**5.465**	**0.391**	**0.437**	

Figures in parenthesis are arc sine transformed values

Table 2a. Effect of fungicides against BSR of coconut at CRS, Veppankulam during 2021

Treatments	BSR DI (%)				
	Pre-tmt Oct 20	January 21	April 21	July 21	October 21
T1	16.21 (23.74)	16 (23.58)	16.01 (23.59)	16.01 (23.59)	15.85 (23.46)
T2	16.08 (23.64)	16.20 (23.73)	16.20 (23.73)	16.26 (23.78)	16 (23.58)
T3	24.38 (29.59)	23.50 (29)	23.48 (28.98)	23.44 (28.95)	23 (28.66)
T4	30.61 (33.59)	30 (32.21)	30 (33.21)	29.82 (33.10)	29 (32.58)
T5	35.87 (36.79)	36 (36.87)	35.89 (36.80)	35.62 (36.64)	35.50 (36.57)
T6	14.12 (22.07)	13 (21.13)	12.99 (21.13)	12.85 (21)	12.72 (20.89)
T7	18.94 (25.80)	18 (25.10)	18 (25.10)	18 (25.10)	17.98 (25.09)
T8-Control	40.92 (23.74)	43.70 (41.38)	43.72 (41.39)	44.22 (41.68)	44.30 (41.73)
SEM	3.57	12.10	3.88	12.01	3.92
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**

Figures in parenthesis are arc sine transformed values

Table 2b. Effect of fungicides against BSR of coconut at CRS, Veppankulam during 2022

Treatments	BSR DI (%)				Percentage disease reduction over initial
	January 22	April 22	July 22	October 22	
T1	15.82 (23.44)	15.80 (23.42)	15.50 (23.18)	15.09 (22.86)	6.91
T2	15.67 (23.32)	15.95 (23.54)	15.90 (23.50)	15.82 (23.44)	1.59
T3	22.95 (28.62)	22.80 (28.52)	22.50 (28.32)	22.25 (28.14)	8.73
T4	28.60 (32.33)	28.25 (32.11)	28 (31.95)	27.70 (31.76)	9.49
T5	35.45 (36.54)	35.40 (36.51)	35 (36.27)	34.96 (36.25)	2.54
T6	12.70 (20.88)	12.50 (20.70)	12.50 (20.70)	12.36 (20.58)	12.43
T7	17.85 (24.99)	17.75 (24.92)	17.70 (24.88)	17.44 (24.68)	7.90
T8-Control	44.46 (41.82)	44.56 (41.88)	44.65 (44.93)	45.10 (42.19)	-10.22
SEM	0.235	0.360	0.352	0.40	
CD (p=0.05)	**0.714**	**1.093**	**1.07**	**1.21**	

Figures in parenthesis are arc sine transformed values

Table 3. Effect of fungicides against BSR of coconut and nut yield at CRS, Veppankulam during 2021-22

Treatments	Mean nut yield/Year						Percent increase over control
	July 2021	October 2021	December 2021	March 2022	July 2022	Total	
T1	24.03	14.37	10.43	10.1	24.03	82.97	10.04
T2	24.83	15	14.23	16.3	20	90.37	19.85
T3	21.83	26.17	13.30	24.1	32.10	117.47	55.79
T4	10	15	16	20.5	24	85.53	13.44
T5	13.53	14	15	24	25	91.53	21.40
T6	16.50	18	24	26	35	119.50	58.49
T7	18.63	14.40	30.83	22.2	32.53	118.57	57.25
T8-Control	17.87	13	15.53	14	15	75.40	0
SEM	6.777	0.170	0.287	0.331	0.467		
CD (p=0.05)	**NS**	**0.517**	**0.872**	**1.005**	**1.417**		

lucidum was done with the conventional fungicidal molecules *viz.,* carbendazim, tridemorph and aureofunginsol. The current study focused on new generation fungicidal molecules for managing BSR disease caused by *G. lucidum* palm species. The fungicide Tridemorph at 500 ppm inhibited *G. lucidum* under *in vitro* (27, 28). *In vitro* suppression of *G. lucidum* and *G. applanatum* by some fungicides *viz*., Bordeaux mixture, tridemorph, copper oxychloride and hexaconazole (12). Study revealed that difenoconazole+propiconazole, hepridion and carbendazim inhibited the growth of *Phytophthora palmaram* grey leaf spot of coconut even at low concentrations (16). Six fungicides were evaluated against BSR of Arecanut and tridemorph 80 EC was reported as superior fungicide in controlling the disease and followed by carbendazim 50 WP (13). difenoconazole inhibited the mycelia growth and sporulation of *Thielaviopsis punctulate* pathogen of Date palm (17). A study confirmed that *Botrydiplodia theobromae was* significantly inhibited by the fungicide tebuconazole 50 % + trifloxystrobin 25 % WG over other fungicides *in vitro* (29). The fungicide tebuconazole +trifloxystrobin was found to inhibit *Lasiodiplodia theobromae* growth at 100 ppm (14). The inhibitory effect of fifteen fungicides on *L. theobromae* growth was showed at different concentrations and systemic fungicide carbendazim showed 100 % inhibition the over control even at lower concentration of 50 ppm under room temperature (15).

The present *in vitro* study revealed the effectiveness of the new combination fungicide against *G. lucidum* under *in vitro* experiment and 100 % mycelial inhibition of *G. lucidum* was achieved by three new fungicides *viz.,* hexaconazole 4 % + carbendazim 16 % SC, azoxystrobin 11 % + tebuconazole-18.3 % SC W/W as well as hexaconazole 5 % + validamycin 2.5 % SC at 250 ppm and 500 ppm (Table 1, Fig. 1 & Fig. 2 (a, b, c, d, e)). While slight fungal growth was observed at 100 ppm, the new fungicide combinations remain promising for further field evaluations.

The screening of twelve fungicides and new combinations of fungicides against *G. lucidum* was done and found that tebuconazole 25.9 EC, tetraconazole 3.8 EW, tebuconazole + trifloxystrobin 50 + 25 WG, hexaconazole 5 EC, difenoconazole 25 % EC, thiram + carboxin 37.5 + 37.5 WS and propiconazole 25 EC were showed similar results (29). Recently, the work related to the suppression of *G. lucidum* under *in vitro* by the fungicide hexaconazole 5 EC @ 125 ppm (23) and trifloxystrobin 25 %+tebuconazole 50 % WG was used in the control of tomato leaf blight and obtained the reduced disease incidence 32.40 % as compared to control (54.21 %) (30). In solid plate assay, triflumizole 42.14 % SC and azoxystrobin 18.2 % + difenoconazole 11.4 % SC at 2000 ppm, 4000 ppm completely suppressed the *Ganoderma* causes BSR disease in oil palm (31). The confirmation of the inhibitory effect of propiconazole and tebuconazole against *Lasiodiplodia theobromae* was also done under *in vitro.* The sequential root feeding of propiconazole and tebuconazole fungicide (100 mL / palm) at three months interval reduced the leaf blight disease incidence up to 5.66 % over control (32).

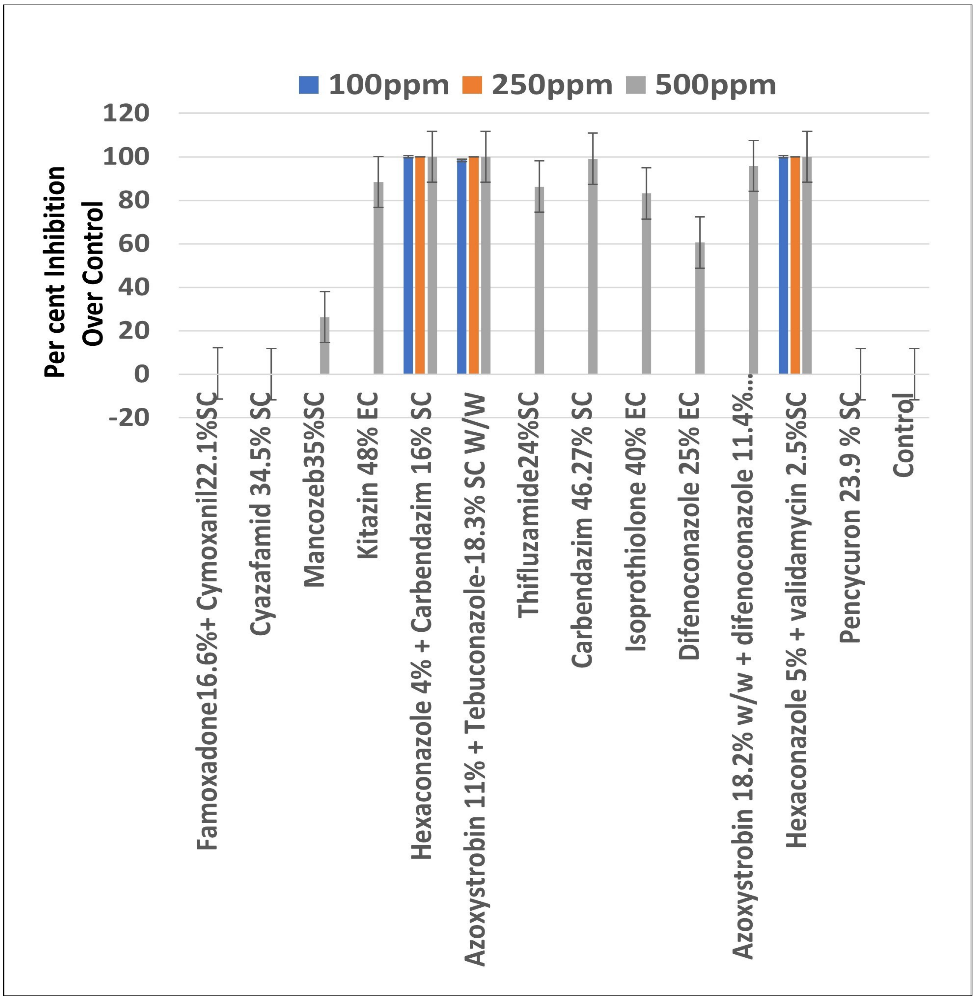

Fig. 1. *In vitro* effect of different fungicides against *Ganoderma lucidum* at varying concentrations, observed 9 days after inoculation on Potato Dextrose Agar (PDA) medium.

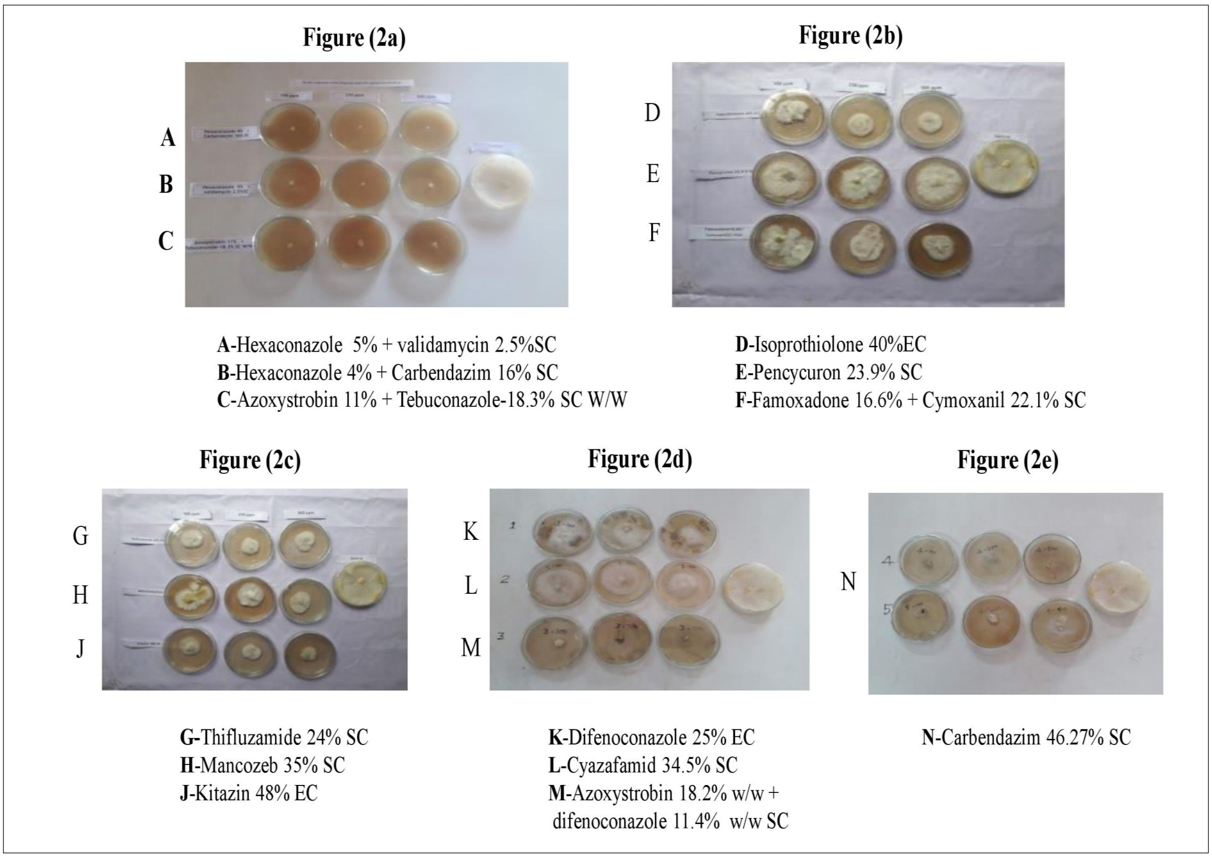

Fig. 2. *In vitro* effect of different fungicides against *Ganoderma lucidum* at varying concentrations, observed 9 days after inoculation on PDA medium. (a, b, c, d, e).

Many investigations on fungicidal management against BSR disease in various field studies were initiated with different fungicides. tridemorph (2 %) root feeding combined with 0.3 % soil drenching treated palms showed the lowest DI subsequent by 1 % hexaconazole root feeding+ soil drenching (20). Half yearly application of 1 % bordeaux mixture as soil drenching @ 20 L / Palm contributed least increase of DI (10.57 %) over pre-treatment in the Integrated disease management of *Ganoderma* wilt of coconut (28). Fungicide tridemorph treated palms in integrated disease management trial controlled the BSR disease in coconut with low infection levels within seven months (33). An attempt was made to utilize 5 kg of neem cake as well as 50 g of *Trichoderma harzianum* per palm to the soil in 6 months intervals, along with quarterly root feedings of 1 % hexaconazole in controlling BSR. They were able to minimize disease by 70.31 % over the control. 2 % tridemorph root feeding, as well as 5 kg of neem cake/palm/year, demonstrated a 64.02 % disease reduction over control. On the other hand, 1 % hexaconazole root feeding and 5 kg of neem cake/palm/year demonstrated a 56.93 % disease reduction over control (34). While soil drenching with 0.3 % Calixin at the rate of 10 L /palm at quarterly intervals and the most effectiveness of the fungicidal treatment in controlling BSR was documented (13). In field investigations, application of 40L of 1 % bordeaux mixture as a soil soaking once every 3 months and feeding tridemorph roots (2 mL in 100 mL of water) at quarterly intervals was effective in controlling coconut BSR disease in coconut (35). Diseased coconut seedlings treated with difenoconazole, escaped from the attack of *Thielaviopsis punctulata* for 4 weeks after inoculation (17). The coconut leaf blight disease was controlled in two different locations by the root feeding with carbendazim 50 % WP @ 10 g in the 100 mL water with minimizing the disease by approximately 20.72 % (15).

The present field study revealed the effectiveness of "treatment (T_6) root feeding of hexaconazole 5 % + validamycin 2.5 % SC@ 4 mL in the 100 mL water combined with soil drenching of same fungicide at the rate of 2 mL/L (15 L/palm) at quarterly interval. This treatment contained the BSR disease by registering 12.43 % decline of DI over the initial DI in contrast to alternative treatments in 2022 (Table 2b). and the same treatment showed the increased percentage of nut yield of 40.2 % over the control (Table 3). BSR disease in the coconut was successfully managed with application of talc formulation of potential *Trichoderma viride* and *Pseudomonas fluorescens* each at the rate of 5 kg/ha), neem cake at 5 kg/ha/tree and *in situ* ploughing of sunnhemp at 50 kg/ha in 45 days after sowing (36). In their investigation of the impact of root feeding 2 % tridemorph and applying 5 kg of neem cake per palm annually, as well as root feeding 1% hexaconazole and applying 5 kg of neem cake per palm annually against *G.lucidum* in arecanut was recorded. The integrated treatments had lower disease spread rates (64.02 %) than the control (56.93 %) (37). Hexaconazole @3 mL/100 mL of water/palm was employed as root feeding at quarterly intervals for coconut BSR disease's field management (38).

The reduced BSR DI from 32.2-17.1 % after 3 years in coconut while combining the soil application of 1 % hexaconazole 5 EC with *T. harzianum* enriched neem cake @ 5 kg/palm at the 4 months interval (23).

Recently, to control BSR of arecanut, adopted a soil drenching treatment with 10 L of hexaconazole 5 % EC @ 2mL/L water/palm twice a year and applied *Trichoderma virens* enriched with 2 kg neem cake/palm 15 days after chemical application. Integration of biocontrol agents with fungicide hexaconazole and neem cake was advocated (39). The sequential root feeding of propiconazole and tebuconazole against coconut leaf blight disease and registered significant disease reduction and increased nut yield (135 nuts) as compared to control (99 nuts) confirmed the results of the present study (33). Recently, the effectiveness of hexaconazole 5 %+ validamycin 2.5 % SC and azoxystrobin 11 % + tebuconazole 18.3 % SC, famaxadone 16.6 % + cymaxanil 22.1 % SC, carbendazim 12 % + mancozeb 63 % WP and hexaconazole 4 % + zineb 68 % in suppressing *G. lucidum* under *in vitro* with the inhibition range of 97 % to 99 % at 100 ppm, 250 ppm and 500 ppm and at par with single fungicide formulations that is, hexaconazole 5 % EC, thifluzamide 24 % SC along with mancozeb 75 % WP having conformity with the results (40).

In the last two decades, the work on new systemic fungicidal molecules and combination fungicides for the control of BSR pathogen of coconut under in *vitro* and *in vivo* conditions has been limited. Considering the futuristic view, the present investigation identified the potential new systemic combination fungicides *viz.,* Hexaconazole 5 % + Validamycin-2.5 % SC as well as Azoxystrobin 11 % + Tebuconazole-18.3 % SC and tested their field efficacy in individual and combination mode of treatments. The present field study confirmed effectiveness of treatment (T_6), which involved root feeding with hexaconazole 5 % + validamycin-2.5 % SC (4 mL in the 100 mL water) combined with soil drenching (2 mL/L of water, 15 L of water/palm) at quarterly interval to evaluate the disease's further spread in endemic location to sustain nut yield. The findings of this study provide valuable insights for integrating new fungicide formulations into future BSR disease management strategies in coconut.

Conclusion

The present study validated the efficacy of new combination fungicides in both *in vitro* as well as *in vivo* against the lethal pathogen *G. lucidum* causes BSR disease in coconut. Two potential combination fungicides *viz.,* hexaconazole 5 % + validamycin-2.5 % SC and azoxystrobin 11 % + tebuconazole 18.3 % SC had been identified and the efficacy of soil drenching method and root feeding method and their integration for these two potential fungicides were tested in the field trial for two years. The findings of the study boost the judicial usage of new promising chemicals with the merits of novel mode of action, less residual toxicity, less persistence of chemical in soil and minimal effect on non-target organisms for tackling fungal disease management. The exploitation of field efficacy of new fungicidal molecules with appropriate delivery can improve the plant uptake and reduces the runoff of fungicides and manage the fungicide resistance.

In this context, the present study will ultimately support the development of Integrated Disease Management (IDM) module for tackling BSR disease in coconut.

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Authors' contributions

Idea, *in vitro* screening, field work, writing-original draft writing-original draft review of literature search, collection of data conceptualization, visualization, review, supervision, analysis was done by SM. Graphs, calculation and table construction was prepared by SC, SKN, KK, PM, AKS. Idea, checking review, abstract construction, supervision and editing was done by VH, SS, JBA. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Coconut Development Board. Coconut statistics 2022–23. India: CDB; 2023. http://www.coconutboard.gov.in/presentation/statistics
2. Saxena M. Horticultural statistics at a glance - 2015. New Delhi: Oxford University Press. 2017:463.
3. Snehalatharani A, Maheswarappa HP, Devappa V, Malhotra SK. Status of coconut basal stem rot disease in India – a review. Indian J Agric Sci. 2016;86(12):1519–29. https://doi.org/10.56093/ijas.v86i12.65347
4. Bhaskaran R, Ramanathan T. Occurrence and spread of Thanjavur wilt disease of coconut. Indian Coconut J. 1984;15(6):12–4. http://doi.org/10.37833/cord.v9i01.263
5. Surulirajan M, Arunkumar R, Mathirajan VG, Babu R, Hegde V, Bhat R. Promising combination systemic fungicides in combating basal stem rot disease of coconut. Int J Plant Soil Sci. 2023;35(14):316–20. https://doi.org/10.9734/ijpss/2023/v35i143052
6. Vinayaka H, Prathibha. Integrated disease management in coconut. Indian Coconut J. 2013;56(3):16–21. https://www.cabidigitallibrary.org/doi/full/10.5555/20133332541
7. Bhaskaran R, Rethinam P, Nambiar KKN. Thanjavur wilt of coconut. J Plant Crops. 1989;17:69–79. https://www.cabidigitallibrary.org/doi/full/10.5555/19912312920
8. Rethinam P. Thanjavur wilt disease of coconut in Tamil Nadu. Indian Coconut J. 1984;15(2):3–11. https://epubs.icar.org.in/index.php/IJAgS/article/view/65347
9. Bhaskaran R. Management of basal stem rot disease of coconut caused by *Ganoderma lucidum*. In: Flood J, Bridge PD, Holderness M, editors. *Ganoderma* diseases of perennial crops. CABI. 2000:121–8. https://www.cabidigitallibrary.org/doi/abs/10.1079/9780851993881.0121
10. Karunanithi KL, Sarala G, Manickam S, Rajarthinam Khan H. Management of basal stem rot of coconut. Indian Coconut J. 2005;35(9):10–11. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173103568
11. Da Silva PAV, Martins RB, Michereff SJ, Da Silva MB, Câmara MPS. Sensitivity of *Lasiodiplodia theobromae* from Brazilian papaya orchards to MBC and DMI fungicides. Eur J Plant Pathol. 2021;13:489–98. http://doi.org/10.1007/s10658-011-9891-2
12. Srinivasulu B, Aruna K, Krishna Prasadji J, Rajamannar, Sabitha Doraisamy, Rao DVR, et al. Prevalence of basal stem rot disease of coconut in coastal agro-ecosystem of AP. Indian Coconut J. 2002;XXXIII:23–6. https://www.cabidigitallibrary.org/doi/full/10.5555/20023194984
13. Chakrabarty R, Acharya GC, Sarma TC. Management of basal stem rot of arecanut (*Areca catechu* L.) under Assam condition. Bioscan. 2013;8(4):1291–4. https://thebioscan.com/index.php/pub/article/view/292
14. Baloch A, Abro MA, Jatoi GH, Abro NA, Dad S, Rafique M, et al. In vitro evaluation of different fungicides and the bio-control agent *Trichoderma harzianum* against *Botryodiplodia theobromae* the cause of guava decline. Pak J Biotechnol. 2017;14:491–6. https://pjbt.org/index.php/pjbt/article/view/834
15. Ushamalini P, Ashok Kumar S, Parthasarathy S. Efficacy of fungicides for the management of coconut leaf blight. Plant Dis Res. 2019;34(1):29–35. http://doi.org/10.5958/2249-8788.2019.00005.2
16. Rahman S, Adhikary SK, Sultana S, Yesmin S, Jahan N. In vitro evaluation of some selected fungicides against *Pestalotia palmarum* (Cooke.) causal agent of grey leaf spot of coconut. J Plant Pathol Microb. 2013;4:197. http://doi.org/10.4172/2157-7471.1000197
17. Saeed E, Sham A, El-Tarabily K, Abu Elsamen F, Iratni R, AbuQamar SF. Chemical control of black scorch disease on date palm caused by the fungal pathogen *Thielaviopsis punctulata* in United Arab Emirates. Plant Dis. 2016;100:2370–6. https://doi.org/10.1094/PDIS-05-16-0645-RE
18. Khawla J, Alwahshi, Esam Eldin, Saeed, Arjun Sham, Aisha A Alblooshi, et al. Molecular identification and disease management of date palm sudden decline syndrome in the United Arab Emirates. Int J Mol Sci. 2019;20:923. https://doi.org/10.3390/ijms20040923
19. George P, Gupta A, Gopal M, Chandra Mohanan R, Thomas L, Thomas GV. In vitro antagonism of rhizospheric fluorescent pseudomonads of coconut against *Ganoderma applanatum* and *Thielaviopsis paradoxa*, fungal pathogens of coconut. J Plantation Crops. 2012;40(2):75–81.
20. Naik RG. Chemical control of basal stem rot of coconut. Agric Sci Digest. 2001;21(4):249.
21. Naik G, Venkatesh R. Management of basal stem rot of coconut. Indian J Agric Res. 2001;35(2):115–7.
22. Mohd Farid A, Lee SS, Maziah Z, Rosli H, Norwati M. Root rot in tree species other than *Acacia*. In: Potter K, Rimbawanto A, Beadle C, editors. Heart rot and root rot in tropical *Acacia* plantations. Proceedings of a workshop held in Yogyakarta. Canberra: ACIAR; 2006:124.
23. Prathibha VH, Hegde V, Monisha M, Vipin K. Management strategies for *Ganoderma* wilt disease of coconut. Int J Agric Sci. 2020;12(11):9890–3. https://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217
24. Schmitz H. Poisoned food technique. Ind Eng Chem Analyst. 1930;2:361. https://doi.org/10.5897/SRE2015.6198
25. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley & Sons; 1984. https://pdf.usaid.gov/pdf_docs/pnaar208.pdf
26. Bhaskaran R, Karthikeyan A. Method for assessing severity of basal stem rot disease of coconut. J Plantn Crops. 1994;22(2):93–6. https://www.cabidigitallibrary.org/doi/full/10.5555/19952312743
27. Anbalagan R, Shanmugam N. Studies on *Ganoderma lucidum* (Leys) Karst. associated with Thanjavur wilt of coconut. In: Proceedings of All India Thanjavur wilt of coconut; 1984:24–9. http://doi.org/10.9734/ijpss/2023/v35i153106
28. Palanna KB, Narendrappa T. Integrated disease management of *Ganoderma* wilt of coconut in dry tracts of southern Karnataka. Mysore J Agric Sci. 2016;50(2):416–20. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20173103568

29. Thangeswari S, Karthikeyan A, Maheswarappa HP. Management of basal stem rot disease in coconut through fungicides. J Plantation Crops. 2019;47(3):207–10. https://doi.org/10.25081/jpc.2019.v47.i3.6058

30. Gurudatt MH, Hegde, Nagaraj BT. Combi fungicide trifloxystrobin 25% + tebuconazole 50 % WG against early blight disease of tomato. Int J Curr Microbiol App Sci. 2020;9(5):1402–8. https://doi.org/10.20546/ijcmas.2020.905.159

31. Amrutha Lakshmi M, Indraja M, Challa G, Arutselvan R, Suresh K. Evaluation of new generation fungicides against *Ganoderma*-induced basal stem rot of oil palm. J Mycol Plant Pathol. 2024;54(2):101–10. https://doi.org/10.59467/JMPP.2024.54.101

32. Latha P, Sudhalakshmi C, Suresh J, Karthikeyan M, Sumitha S, Austine Jerard A. Field evaluation of fungicides for management of *Lasiodiplodia* leaf blight of coconut. J Plantation Crops. 2024;52(1):28–36. https://updatepublishing.com/journal/index.php/JPC/article/view/9173

33. Karthikeyan M, Radhika K, Bhaskaran R, Mathiyazhagan S, Velazhahan R. Rapid detection of *Ganoderma lucidum* and assessment of inhibition effect of various control measures by immunoassay and PCR. Afr J Biotechnol. 2009;8(10):2202–8. http://www.academicjournals.org/AJB

34. Palanna KB, Naik RG, Basavaraju TB, Boraiah B, Thyagaraj NE. Etiology and management of coconut basal stem rot (*Ganoderma* wilt) in sandy soils of Karnataka. J Plantation Crops. 2009;37(1):26–9. https://doi.org/10.56093/ijas.v86i12.65347

35. Surulirajan M, Rajappan K, Kumar NS, Annadurai K, Kumar KJ, Asokhan M. Management of basal stem rot disease in coconut through bio-inoculants and chemicals. Indian J Trop Agric. 2014;32(3–4):407–14. https://www.cabidigitallibrary.org/doi/full/10.5555/20153318085

36. Shanmugam PS, Indhumathi K, Sangeetha M. Management of wilt diseases in coconut through integrated disease management strategies. Int J Agric Sci. 2018;10(7):5652–4. https://doi.org/10.9735/0975-3710

37. Narayanaswamy H, Raju J, Jayalakshmi K, Syed Sannaulla, Shesragiri KS, Dinesh Kumar M. Integrated management of basal stem rot disease of arecanut. Int J Chem Stud. 2018;6(5):530–1. https://www.chemijournal.com/archives/2018/vol6issue5/PartJ/6-4-622-651.pdf

38. Neeraja B, Snehalatharani A, Maheswarappa HP, Ramanandam G, Chalapathi Rao NBV, Padma E. Management of basal stem rot (*Ganoderma* wilt) in coconut with effective bio agents under field condition. Int J Curr Microbiol App Sci. 2018;7(9):1051–60. https://doi.org/10.20546/ijcmas.2018.709.125

39. Bachu Raghavendra B, Gangadhara Naik MK, Naik HP, Maheswarappa R, Ganesha Naik KM, Satish KM. Integrated disease management of basal stem rot of arecanut caused by *Ganoderma* spp. under field conditions. Biol Forum Int J. 2021;13(4):196–9.

40. Govardhan Rao V, Neeraja VB, Chalapathi Rao NBV, Kireeti A, Anoosha V, Hegde V, et al. Fungicidal management of basal stem rot - a soil borne disease in coconut. Biol Forum Int J. 2023;15(10):447–53.

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