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A comparative study of bio-intensive pest-disease management modules in small-cardamom agro ecosystems

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Abstract
Small cardamom (*Elettaria cardamomum*), often called the "queen of spices," occupies a distinctive niche in the global spice market and is ranked as the third most valuable spice after cinnamon and clove. Repeated pest incursions and associated yield reductions have prompted growers to rely heavily on broad-spectrum insecticides, which can destabilise cardamom ecosystems and leave residues in the harvested product. To address these concerns, a three-year study (2021-2024) was carried out in Idukki district, Kerala, to evaluate the conservation and sustainability impacts of several bio-intensive pest-management (BIPM) modules relative to conventional farmer practices (FP). Four BIPM regimes were tested: BIPM-1 combined cultural practices (trash removal to reduce thrips and root-grub damage) with foliar application of plant-derived growth promoters (PPFM, 3 ml L^{-1}) for drought mitigation, soil amendment with ICAR-IIHR-AMC (10 g L^{-1}) for nutrient management, and soil inoculation with entomopathogenic nematodes (EPN, 2.5 kg ha^{-1}) to control root grubs. BIPM-2 employed soil-applied entomopathogenic fungus *Metarhizium anisopliae* (2 % w/v) for root-grub suppression. BIPM-3 involved spraying a natural product, spinosad (0.0135 % a.i., derived from *Saccharopolyspora spinosa*), to manage thrips, shoot borers and capsule borers. BIPM-4 used Bacillus thuringiensis (2 ml L^{-1}) applied at the early-instar stage (within 20 days of adult moth emergence) to target capsule, panicle and bud larvae. Two farmer-practice treatments were included: FP-1-need-based insecticide applications, and FP-2-calendar-based sprays, alongside an untreated control (UC) receiving no interventions. Pest and disease incidence were recorded by visual counts at 15-day intervals throughout the cropping seasons. The study aimed to quantify the ecological and production benefits of the BIPM approaches compared with conventional chemical-based strategies.

Keywords: BIPM, *Bacillus subtilis*, farmers practices, *Pseudomonas fluorescens*, *Trichoderma harzianum*

Introduction

Small cardamom (*Elettaria cardamomum*), often called "green gold," originates from the evergreen rainforests of the Western Ghats. The Cardamom Hills, which run through southern India and the southern Western Ghats, are the primary cultivation zone. Among the three Indian states that grow cardamom—Kerala, Tamil Nadu and Karnataka-Kerala contributes roughly 88 % of national output. Within Kerala, the Cardamom Hill Reserves of Idukki district cover about 7 488 ha and account for nearly 70 % of India's total cardamom production. The perennial, succulent nature of the plant, together with the humid, partially shaded environment, creates ideal conditions for pathogens to persist year-round. This combination makes profitable cardamom cultivation in the Cardamom Hill Reserves particularly challenging. Key pests include shoot and capsule borer, thrips, root grub, whitefly and nematodes, while major diseases comprise capsule and panicle rot, clump rot, Fusarium rot, leaf blight and various viral infections. Indiscriminate use of synthetic pesticides to control these organisms has led to high residue levels in export-oriented produce, prompting increasing scrutiny and affecting the international reputation of the "king" and "queen" of spices. Consumer demand for organic spices is rising at about 20 % per year, and there is a pressing need for India to regain its position as the world's spice hub by delivering safer products.

Achieving sustainable, higher yields will require the adoption of good agricultural practices that emphasize eco-friendly pest and disease management. Physical, cultural and biological/botanical approaches can promote the presence of natural enemies and beneficial microorganisms, thereby restoring ecosystem balance in small-cardamom systems. The present study was designed to evaluate the effects of several bio-intensive pest-management (BIPM) packages on pest populations, natural-enemy communities and crop yield, comparing these outcomes with those obtained under conventional farmer practices (FP).

Materials and Methods

A two-year field trial was carried out on a 5-ha small-cardamom plantation in Idukki district, Kerala, to test the performance of several bio-intensive pest-management (BIPM) packages. Four distinct BIPM modules were designed, each combining cultural, biological and botanical interventions, and were compared with two conventional farmer practices (FP 1 = need-based insecticide sprays, FP 2 = calendar-based sprays) and an untreated control (UC).

BIPM 1 integrated trash removal to suppress thrips and root-grub, foliar application of plant-derived growth promoter (PPFM, 3 ml L^{-1}) for drought relief, soil amendment with ICAR-IIHR-AMC (10 g L^{-1}) for nutrient supply, entomopathogenic nematodes (EPN, 2.5 kg ha^{-1}) against root-grub, and the fungus *Lecanicillium psalliotae* (50 g $plant^{-1}$) for thrips control. Neem oil (0.5 %) was sprayed to manage whitefly, while *Trichoderma* spp. and *Paecilomyces lilacinus* were applied to the soil to curb nematodes. A prophylactic spray of Pseudomonas fluorescens (2 %) together with basal inoculation of the *arbuscular mycorenchymal* fungus *Glomus fasciculatum* (50 g) and *Trichoderma viride* (100 g $plant^{-1}$) was used to protect against capsule and panicle rot. Three applications of 1 % Bordeaux mixture were made in May, June and July to control Fusarium, root rot, capsule rot and panicle rot.

BIPM 2 focused on potassium silicate (3 g L^{-1}) for drought mitigation, a liquid NPK consortium (5 ml L^{-1}) for nutrient management, and soil inoculation with *Metarhizium anisopliae* (2 %) to target root-grub. Foliar sprays of *Beauveria bassiana* (20 g L^{-1} talc formulation) were scheduled every 15 days to manage shoot and capsule borers. Yellow sticky traps (20 per ha) were installed for whitefly monitoring, and organic manures plus neem cake (250-1 000 g $plant^{-1}$) were applied twice yearly to suppress nematodes. Basal applications of *T. harzianum* and *P. fluorescens* were made in May, June and July to reduce Fusarium, root rot, capsule rot and panicle rot.

BIPM 3 employed a Pseudomonas spray (5 ml L^{-1}) for drought relief and a novel biocapsule system (5 capsules ha^{-1}) delivering PGPR/microbes for nutrient supply. A 0.2% “poneem” mixture (pungam oil + neem oil, 1:1) was used against shoot borer, while spinosad (0.0135%) targeted thrips, shoot borer and capsule borer. Light traps and mass-trapping devices (4 ha^{-1}) were deployed for adult beetle control, and Jeevamrutha (10 L) combined with *Azospirillum* and *T. viride* (10 g each per plant) was applied to manage nematodes. A bacterial consortium (*P. fluorescens* + *Bacillus subtilis*) was used to suppress Fusarium, root rot, capsule rot and panicle rot.

BIPM 4 combined fish-oil insecticidal soap (2.5%) with tobacco extract (2.5%) to control thrips, and released Chrysoperla zastrowi sillemi larvae (2 per plant early, 4 per plant later) for biological suppression. *Bacillus thuringiensis* (2 ml L^{-1}) was applied within 20 days of adult moth emergence to target early-instar larvae on capsules, panicles or buds. A chitin-based biopesticide (Eco-1, 0.5%) was sprayed for thrips and whitefly management. Soil amendment with a mixture of cow dung, neem cake, marotti cake, AMF and *P. lilacinus* (90 kg : 5 kg : 2 kg : 2 kg : 1 kg, 1 kg $plant^{-1}$) addressed nematodes, and basal applications of *T. harzianum*, *P. fluorescens* and *B. subtilis* were used against Fusarium, root rot, capsule rot and panicle rot.

Observations were recorded at 15-day intervals throughout the study period. The trial aimed to assess how each BIPM strategy influenced pest populations, natural-enemy communities and cardamom yield relative to the conventional and untreated controls.

Statistical analysis

The data for pest and natural enemy abundance was suitably transformed and analyzed using ANOVA-RBD with 6 treatments having 4 replications each. The mean incidence was ranked using Dunken’s mean range test through the OP-STAT online tool (Sheoran *et al.*, 1998) [21]. The data was analyzed for Diversity and Evenness using the online Biodiversity calculator BPMSG.

Results

Insect pest abundance

The incidence of key pests *viz.*, stem and capsule borer, thrips, root grub, nematodes and scales was recorded throughout the trial. In all cases, pest numbers remained below the economic threshold level (ETL) and were markedly lower in the BIPM plots. Stem and capsule borer larvae were lowest in BIPM 1 (5.70 individuals per quadrat) and BIPM 3 (8.45 individuals per quadrat), which were statistically similar. They were followed by BIPM 2 (9.25), BIPM 4 (7.00), FP 1 (16.95) and the untreated control (19.20). Thrips counts were lowest in BIPM 1 (7.20 individuals per quadrat) and BIPM 2 (8.25 individuals per quadrat), again statistically on par. They were followed by BIPM 4 (9.00), BIPM 3 (9.45), FP 1 (14.25) and the untreated control (17.31). Root grub, nematode and scale populations were also below the ETL in all treatments, with the BIPM modules generally outperforming the conventional and control plots.

Table 1: Insect pest incidence in different treatments

Treatments	BIPM 1	BIPM 2	BIPM 3	BIPM 4	FP 1	UC	CD (0.05)
Stem and Capsule borer	5.70 (2.44) d	9.25 (3.21)b	8.45 (3.42) b	7.00 (2.73) c	16.95 (4.22) a	19.20 (4.51) a	0.35
Thrips	7.20 (2.44) d	8.25 (2.75)b	9.45 (3.52) b	9.00 (3.73) c	14.25 (3.12) a	17.31 (3.51) a	0.41
Root grub	7.45 (2.51) b	8.47 (3.21)b	8.70 (2.44)d	8.00 (2.73) c	12.61 (3.22) a	14.20 (4.51) a	0.39
Nematode	7.70 (2.96) d	7.25 (3.10)b	9.45 (3.81)	9.00 (2.97) c	15.95 (4.02) a	16.20 (4.20) ab	0.45
Scales	6.80 (3.44) d	8.25 (2.89)	6.45 (3.42) b	7.00 (2.73) c	15.40 (3.51) a	17.95 (3.22) a	0.49

*Mean of four observations (visual counts from quadrat) Figures in parenthesis are square root transformed values of insect pest abundance. Values in the row with the same alphabet superscript are not statistically different (BIPM = Bio Intensive Pest Management; FP = Farmer's Practice; UC = Untreated Control; CD = Critical Difference at p <0.05; N/A = Not Applicable).The BIPM 1 and BIPM 4 were on par and recorded the lowest incidence of Root grub with a mean population of 7.45 and 8.00 individuals per quadrat followed by BIPM 2, BIPM 3, FP 1, and least in UC with a mean population of 8.47, 8.70, 12.61 and 14.20 respectively. The BIPM 2 and BIPM 1 were on par and recorded the lowest incidence of Nematode with a mean population of 7.25 and 7.70 individuals per quadrat followed by BIPM 4, BIPM 3, FP 1, and least in UC with a mean population of 9.00, 8.70, 15.95 and 16.20 respectively. The BIPM 3 and BIPM 1 were on par and recorded the lowest incidence of Scales e with a mean population of 6.45 and 6.80 individuals per quadrat followed by BIPM 4, BIPM 2, FP 1, and least in UC with a mean population of 7.00, 8.25, 15.40 and 17.95 respectively. Different treatments modules data showed that the percentage of pest damage recorded was far below the Economic Threshold Levels (ETL) and comparatively less abundant in BIPM1, followed by BIPM4, BIPM3, and BIPM2.

Evaluation of disease severity in small cardamom plantation:

A study was conducted in Idukki district, Kerala, to document the incidence and severity of diseases in small-cardamom and to evaluate several bio-intensive disease-management (BIDM) modules. As part of the research, various biocontrol agents were isolated and their antagonistic activity was examined to develop an environmentally friendly, sustainable disease-control strategy for the region. The lowest Fusarium disease severity was observed in BIDM 1 and BIDM 3, which were statistically similar and limited disease incidence to 25-30% and 21-30% respectively. In contrast, the conventional practice (FP 1) and the untreated control (UC) suffered the greatest yield reductions, with losses ranging from 40-42% and 45-50%. Overall, the most effective treatments for Fusarium were ranked as BIDM 3 > BIDM 1 > BIDM 2 > BIDM 4. For Pythium, BIDM 3 and BIDM 2 performed comparably, restricting disease severity to 24-28% and 29-31% respectively. The conventional and control plots again showed the highest yield losses, at 35-36% for FP 1 and 42-57% for UC. The order of efficacy against Pythium was BIDM 3 > BIDM 2 > BIDM 1 > BIDM 4. These findings suggest that the bio-intensive modules, particularly BIDM 3 and BIDM 1, can substantially reduce disease severity and associated yield losses in small-cardamom, offering a viable alternative to synthetic pesticide-based practices.

The study examined the performance of four bio-intensive disease-management (BIDM) modules against a range of fungal pathogens in small-cardamom plots in Idukki, Kerala.

Table 2: Average disease incidences and severities and their ranges in different treatments

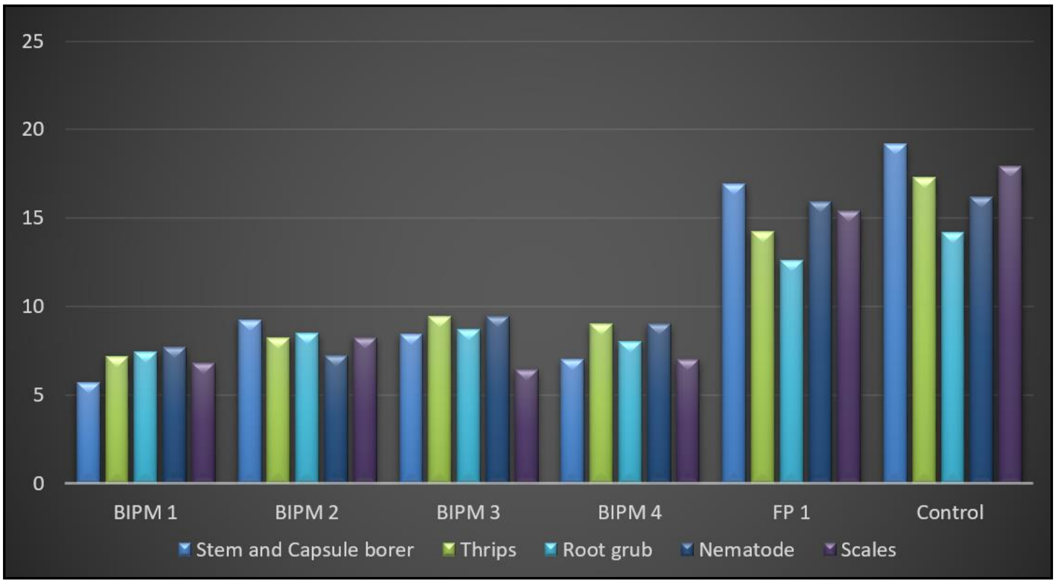
Treatments	BIDM 1	BIDM 2	BIDM 3	BIDM 4	FP 1	UC	Average disease incidence (%) ± SD
Fusarium DI (%)	25-30	26-30	21-30	30-38	40-42	45-50	24.6 ± 8.4a
Pythium DI (%)	31-32	29-31	24-28	31-35	35-36	42-57	28.6 ± 6.7ab
Phytophthora DI (%)	21-25	27-29	20-24	34-38	41-45	50-52	29.83 ± 9.8ab
Phoma DI (%)	18-21	18-27	25-29	25-34	39-41	28-32	25.30 ± 12.4b
Complex fungus DI (%)	21-24	21-24	29-30	31-34	35-40	40-45	21.3 ± 23.1ab
Colletotrichum DI (%)	16-19	17-21	24-26	20-25	34-45	35-37	13.7 ± 8.1b

* Disease incidence range (%), Values in the same letters are not significantly different (p<0.05)

For Phytophthora, Pythium, Phoma, a complex of fungi and *Colletotrichum*, the lowest disease severity was recorded in BIDM 3 and BIDM 1, which were statistically similar and limited the disease index (DI) to 20-24% and 21-25%, respectively. In contrast, the conventional practice (FP 1) and the untreated control (UC) suffered the greatest yield reductions, with losses of 41-45% and 50-52%, respectively. The order of overall effectiveness was BIDM 3 > BIDM 1 > BIDM 2 > BIDM 4. When Phoma was considered alone, BIDM 1 and BIDM 2 performed equally well, holding the DI to 18-21% and 18-27%, while FP 1 and UC incurred yield losses of 28-32% and 39-41%. The ranking for Phoma control was BIDM 1 > BIDM 2 > BIDM 3 > BIDM . A similar pattern emerged for the complex fungal disease, with BIDM 1 and BIDM 2 again on par, achieving DI values of 21-24% and 21-24%, whereas FP 1 and UC experienced losses of 28-32% and 39-41%. Effectiveness followed the order BIDM 1 > BIDM 2 > BIDM 3 > BIDM 4. For *Colletotrichum*, BIDM 1 and BIDM 2 were comparable, limiting the DI to 16-19% and 17-21%, while FP 1 and UC showed yield losses of 35-37% and 34-45%. The most effective treatments for *Colletotrichum* were ranked BIDM 1 > BIDM 2 > BIDM 4 > BIDM 3. Overall, the bio-intensive modules, particularly BIDM 3 and BIDM 1, consistently reduced disease severity and associated yield losses compared with conventional and untreated controls, offering a sustainable alternative for managing key fungal diseases in small-cardamom production.

Natural enemy abundance

Two native parasitoids-*Apanteles taragamae* Vierick (Hymenoptera: Braconidae), a larval parasitoid, and *Agrypon* sp. (Hymenoptera: Ichneumonidae), a larval-pupal parasitoid were observed in the BIDM 1, BIDM 2, BIDM 3, BIDM 4 and FP 1 treatments aimed at controlling the stem borer in small-cardamom. *A. taragamae* was most frequently found parasitising *Conogethes* larvae in capsules, with lower levels on shoots and panicles. Earlier work (Ansar Ali *et al.*, 2014) [10] reported *A. taragamae* and *Glyptapanteles* sp. attacking cardamom capsule-harboring *Conogethes*. *Agrypon* sp. was recorded only from *Conogethes* larvae on shoots and did not parasitise larvae in panicles or capsules. In the present trial, the combined activity of these parasitoids resulted in up to 17% natural parasitism of *Conogethes* on cardamom, which corresponded with a reduction in shoot-borer damage from 19.46% to 14.04% during June across BIDM 1-4 and FP 1.



Conclusion

Many studies have indicated that the in-situ conservation of natural enemy populations will lead to enhanced biological control. The BIPM strategies followed in our study have a great impact on improving natural enemy abundance and diversity which in turn led to harnessing the ecological services in a better way to obtain higher output with minimal investments. Further, the application of plant growth-promoting microbes like Pseudomonas sp., Bacillus sp. etc., were known to improve the below-ground biodiversity thus improving the soil health and had contributed to increased yield in the BIPM modules. A shift from conventional crop production to BIPM methods which are eco-friendly and sustainable can only assure the stability of farming communities in the long run.

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