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RESEARCH ARTICLE

Optimization of fibre yield and pest management: Evaluating integrated pest management modules for disease and insect pest reduction in jute (*Corchorus olitorius*)

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Abstract

The field experiments were conducted to optimize fiber yield and pest management to evaluate integrated pest management (IPM) strategies for jute (*Corchorus olitorius*) cultivation during 2020-2022. The study employed a split-plot design (SPD) with four replicates, testing two sowing methods (line sowing and broadcasting) and three treatment modules: chemical (T1), biological (T2) and untreated control (T3). The chemical module (T1) included seed treatment with Carbendazim 50WP, followed by sprays of Spiromesifen 240 SC, Tebucanazole and λ-cyhalothrin, whereas the biological module (T2) involved seed treatment with *Trichoderma viride*, soil drenching with *Pseudomonas fluorescens* and azadirachtin sprays. The results showed a significantly lower incidence of stem and root rot and reduced infestations of Bihar hairy caterpillar (BHC), semilooper and yellow mite in T1 compared to T2 and T3, with pest reduction ranging from 55 % to over 75 %. The highest fiber yield (25.79 q ha^{-1}) was recorded in T1. Although line sowing had no significant effect on disease incidence, it did influence pest populations. The highest benefit-cost ratio (1.87) was observed in T1, compared to 1.43 in T3, highlighting the effectiveness of chemical treatments in maximizing yield and economic returns. The scoring of different pests and diseases revealed that 45-54 % of the areas exceeded the 5 % disease infestation level for root and shoot rot, while 75 % experienced a high level of mite infestation. Regular monitoring and assessment of pest and disease levels in jute fields are crucial for effective management strategies. These findings emphasize the importance of integrating chemical and biological control methods for sustainable jute production.

Keywords: BHC; fungicide; insecticide; jute; mite; root rot; semilooper and stem rot

Introduction

Common diseases affecting jute in India include stem and root rot caused by *Macrophomina phaseolina* and anthracnose caused by *Colletotrichum* spp. Major pests in jute-growing areas are the Bihar hairy caterpillar (BHC) (*Spilosoma obliqua*), semilooper (*Anomis sabulifera*) and yellow mite (*Polyphagotarsonemus latus*). These pests and diseases not only reduce fiber yield but also degrade fiber quality. *Macrophomina phaseolina* is a soil-borne pathogenic fungus that causes stem and root rot in jute (1). This fungus, belonging to the phylum anamorphic Ascomycetes, produces pycnidia and sclerotia in host tissues (2- 4). It can attack any part of the plant at any growth stage, leading to damping-off, seedling blight, leaf blight, collar rot and stem and root rot (5). While the average yield loss is 10 %, severe infections can increase this to 35 -40 %, particularly under hot, humid conditions (6). The primary sources of inoculum include seeds, soil and plant residues. Studies have indicated that insect pest attacks can cause 31-34 % fibre loss (7). Among the most harmful pests is the jute semilooper, which can damage up to 90 % of jute plant leaves, leading to poor plant growth and reduced fiber yield (8). In 81 % of cases, the upper 7-9 leaves of standing jute crops were damaged and pre-monsoon rains followed by drought can exacerbate semilooper outbreaks, causing up to 50 % yield loss.

Another pest, *Apioncorchori*, is a stem weevil that primarily targets *C. Olitorius* rather than *C. capsularis* (9). Oviposition holes created by the weevil compromise fiber quality. Females create numerous holes in their stems to lay eggs, thereby damaging multiple stems. *Polyphagotarsonemus latus*, a yellow mite, also poses a significant threat, feeding on the sap from young leaves and causing discoloration and curling (10). The natural green color of leaves turns brown and young plants suffer stunted growth due to nutrient loss, significantly reducing yield (11). Female insects make holes in their stems to lay eggs, whereas yellow mites feed on young leaves, causing them to change color and curl. These pests harm plants by stunting their growth and reducing crop yield. Female insects and yellow mites present substantial challenges to jute cultivation, specifically affecting stems and leaves, respectively.

However, the implementation of integrated pest and disease management strategies offers promising approaches to mitigate these biotic stresses and enhance crop productivity in Bihar (12). Although various components of integrated pest management (IPM) have been recommended for jute, there remains a critical knowledge gap regarding the performance of complete, field-validated IPM modules that simultaneously target major pests and diseases under the specific agro-climatic conditions of Bihar. Existing studies largely focus on individual control measures rather than integrated module-based approaches.

The present study addresses this gap by evaluating location-specific IPM modules for *C. olitorius* under field conditions in Bihar (13), to identify effective combinations of practices for reducing biotic stress and improving fibre yield. The novelty of this work lies in its comprehensive, module-level assessment of coordinated pest and disease management strategies tailored to local production systems.

Materials and Methods

Experimental site

Field experiments for integrated disease and pest management in *C. Olitorius* (jute) were conducted from 2020 to 2022 at the experimental plots of the Jute Research Station, Tingachhia, Katihar, Bihar, India. An integrated approach to managing *M. phaseolina* (stem and root rot), mite, semilooper and BHC infestations and fiber yield in jute was evaluated during the kharif seasons of 2020, 2021 and 2022 at the Jute Research Station (JRS), Katihar. The study area falls under a sub-tropical humid climate. In Katihar, the mean maximum and minimum temperatures are approximately 42.0 °C and 4.1 °C, respectively. The district receives an average annual rainfall of 1281 mm, with most falling during the monsoon season. The soils of the region are predominantly alluvial, with textures ranging from sandy loam to clay loam. Although generally non-calcareous, patches of salinity and alkalinity occur in certain parts of the district and adjoining areas. Soil pH typically ranges from moderately acidic to neutral. The soils are poor in nitrogen and low to medium in available phosphorus and potassium, with widespread deficiencies of zinc and boron. The predominant cropping systems in the region include jute – wheat, jute – potato, jute – mustard and jute – maize.

However, the threshold levels for mites, BHC, stem rot, root rot and semilooper in jute are crucial for effective pest and disease management. Consequently, a preliminary survey was conducted before initiating trials in farmers' fields across 37 locations in various villages in the Katihar block. Jute crops were then categorized into low, moderate and high infestation levels based on their threshold levels. Control measures are recommended following analysis of 3 years of pooled data on pests and diseases affecting the test crop. The experiment was laid out in a split-plot design (SPD) with four replications. The sowing method was assigned to the main plots, while the different treatment modules were allocated to the sub-plots, using the jute variety JRO-204. The main plot size was 9 × 4 m^2, whereas the sub-plot size was 3 × 4 m^2, with a row-to-row spacing of 30 cm and plant-to-plant spacing of 10 cm after thinning at 20-25 days after sowing. The recommended package of practices was followed as needed.

Treatment details and IPM module

The treatments were divided into two main plot-sowing methods: P1 (line sowing) and P2 (seed broadcasting). The sub-plot treatments were as follows:

T1: Seed treatment with Carbendazim 50 Wettable Powder (WP) (2 g kg^{-1} seed) followed by spraying of Spiromesifen 240 SC (0.7 mL L^{-1} at 35 days after sowing (DAS)), Tebucanazole (0.15 % at 45 DAS) and λ-cyhalothrin 5 Emulsifiable Concentrate (EC) (0.6 mL L^{-1} at 55 DAS). The chemical module was formulated based on earlier efficacy reports indicating that carbendazim effectively suppresses seed- and soil-borne pathogens such as *M. phaseolina*; Spiromesifen is highly effective against yellow mites due to its lipid biosynthesis inhibition mechanism; Tebuconazole shows strong activity against foliar fungal pathogens; and λ-cyhalothrin has been widely validated for controlling defoliators such as the BHC and semilooper in fibre crops.

T2: Seed treatment with *T. viride* (10 g kg^{-1} seed), soil drenching with *P. fluorescens* (100 g L^{-1} at 15 DAS) and spraying with azadirachtin (10000 ppm, 3 mL L^{-1} at 35 and 55 DAS). This biological module was selected based on previous field trials demonstrating that *T. viride* enhances seedling vigour and provides antagonistic activity against *M. phaseolina*, while *P. fluorescens* suppresses soil-borne diseases through antibiotic production and induces systemic resistance. Azadirachtin, a well-established botanical insecticide, has shown strong oviposition deterrence and feeding inhibition against jute pests, including the jute borer and mites.

T3: Control (no treatment).Seed treatments with Carbendazim 50 WP (2 g kg^{-1} seed) and *T. viride* (10 g kg^{-1} seed) were applied in their respective treatments, whereas *P. fluorescens* and Azadirachtin (10000 ppm, 3 mL L^{-1}) were applied by spraying in T2 (Table 1). Fertilizers were applied to the jute field at the recommended soil dose. Data on mite infestations were recorded at 30, 40 and 50 days after sowing (DAS), whereas data on BHC infestations were recorded as percentages at 55 and 70 DAS. Yellow mite infestations were observed on the young, second-unfolded leaves of 10 randomly selected plants per plot, as yellow mites typically inhabit the lower surfaces of young apical leaves and flowers, where they deposit their eggs. Pre-treatment observations were obtained from all plots at 35 and 50 DAS. Post-treatment observations of mite populations were recorded at 3 and 7 days after both spray applications (35 and 50 DAS). The number of mites per cm ^{2} leaf, regardless of developmental stage (egg, larva, pupa, male, or female), was counted using a 10x magnifying lens.

Table 1. The detailed description of treatment details

Sr. No	Treatments	Treatment details
Main plot		
1.	P1	line sowing
2.	P2	Seed broadcasting.
Sub-plot		
3.	T1	Seed treatment with Carbendazim 50WP (2 g kg^{-1} seed) followed by spraying of Spiromesifen 240 SC (0.7 mL L^{-1} at 35 DAS), Tebucanazole (0.15 % at 45 DAS) and λ-cyhalothrin 5 EC (0.6 ml/L at 55 DAS).
4.	T2	Seed treatment with *Trichoderma viride* (10 g kg^{-1} seed), soil drenching with *Pseudomonas fluorescens* (100 g L^{-1} at 15 DAS) and spraying with azadirachtin (10000 ppm, 3 mL L^{-1} at 35 and 55 DAS).
5.	T3	Control (no treatment).

The data were recorded and square-root-transformed for statistical analysis to test for significance (14). The percentage reduction in pests under field conditions was calculated using the following formula:

$$\% \text{ Reduction} = (N\text{-}N1/N) \times 100 \qquad \text{(Eqn. 1)}$$

where N = Number of mite-infested plants in the control plot and N1 = Number of mite-infested plants in the treated plot.

The fungicides and insecticides were applied to both the abaxial and adaxial leaf surfaces of the jute, whereas the control plot received no fungicide or insecticide. Disease incidence and severity, expressed as Percent Disease Index (PDI), for root rot and stem rot diseases were recorded at the harvesting stage. The following ratings were used for calculating PDI of stem rot disease of jute: 'size of lesion', 'position of lesion on stem' and 'lesion type', where three characteristic symptoms were considered for the calculation of numerical rating.

The disease severity of jute stem rot was calculated by (PDI), in which actual damage in the individual plant was assessed. The numerical rating was performed to determine the actual damage to the individual plant, like other crops. The following ratings were used to calculate the PDI of Stem rot disease in jute: 'Size of lesion, position of lesion on stem' and 'lesion type' where three characteristic symptoms were considered for the calculation of numerical rating (4) (Fig. 1). This scoring system was used because it captures multiple dimensions of disease expression—lesion size, vertical progression and extent of stem tissue involvement—which together provide a more accurate and biologically meaningful assessment of stem rot severity. Previous studies have shown that combining these parameters improves discrimination among disease levels and enables more reliable comparisons of treatments under field conditions.The maximum score value of an affected plant will be 4+4+8 = 16 and the minimum value will be 1+1+1 =3 while an unaffected plant will be assigned '0'. In the case of multiple lesions on a single plant, the value will be added, subject to a maximum of 16.

$$\text{PDI} = \text{Sum of numerical ratings} \times 100/\ (\text{number of plants observed} \times \text{highest value}) \qquad \text{(Eqn. 2)}$$

Root rot was measured as the Disease Incidence percentage (DI %), while stem rot was measured as the (PDI). The study recorded the following disease observations and calculations: (a) Stem rot was measured 30 days after sowing (DAS) and at an interval of 15 days and expressed as a PDI. (b) Root rot in % to be recorded at the time of harvesting. (c) B: C ratio. The incidence and severity of root rot were recorded before and after fungicide spraying. Disease incidence (DI) was calculated using the following formula:

$$\text{DI} = \text{Number of plants infected} \times 100/\ \text{Total number of plants observed} \qquad \text{(Eqn. 3)}$$

The experimental data were subjected to ANOVA using statistical software and the results were considered statistically significant at P 0.05 %.

Results and Discussion

Monitoring and management of mites, Bihar hairy catterpilar, stem rot, root rot and semilooper in jute production

Threshold levels for mites, BHC, stem rot, root rot and semilooper in jute are crucial for effective pest and disease management. These levels can vary based on factors such as the jute species, plant growth stage, environmental conditions and the specific infested species involved (15). Generally, early detection and intervention are essential. To this end, a preliminary survey was conducted before establishing trials, in farmers' fields across 37 locations in various villages in the Katihar block. These areas were then categorized into low, moderate and high infestation levels in jute crops based on their threshold levels. After analyzing three years of pooled data on various pests and diseases affecting the

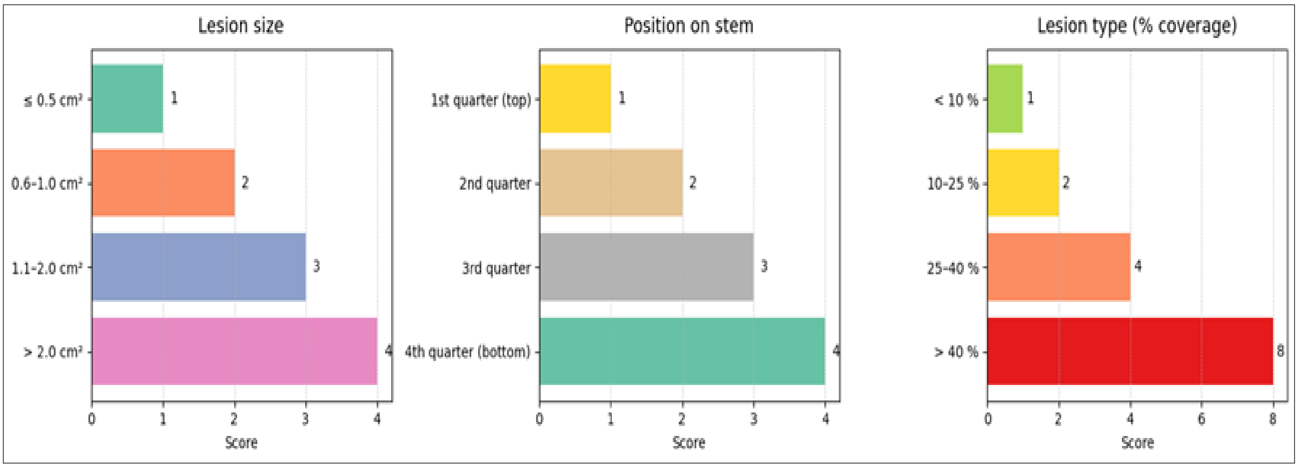

Fig. 1. The ratings chart of the size of lesion, position of lesion on stem, lesion type and PDI of stem rot disease in the test crop.

test crop, control measures must be recommended. The scoring of different pests and diseases revealed that 45 % of the areas exceeded the 5 % % disease incidence level, while 55 % of the areas were at the disease incidence level for root rot in jute crops. For BHC, 48 % of the areas were at the economic threshold level (ETL) level and 52 % were above it (Fig. 2). Regarding mite infestation, 23 % of the areas experienced a moderate level, 75 % a high level and only 2 % a low level. The root rot disease incidence were depicted in the Fig. 3 and in the case of stem rot, 46 % of the area was above 5 percent disease incidence and 54 % was above it (Fig. 4). For semilooper, 28 % of the areas were above the ETL level, whereas 72 % were below it (Fig. 5). These findings confirm the need for regular pest monitoring and farmer training in early detection. Integrated pest management combining cultural, biological and chemical strategies remains essential to keep pest and disease levels below economic thresholds (16, 17).

Effect of fungicides and biocontrol agents on *Macrophomina phaseolina* (stem and root rot)

The efficacy of fungicides and biocontrol agents as part of an integrated approach, involving seed treatment, soil drenching and foliar applications, was evaluated against *M. phaseolina*, the pathogen responsible for stem and root rot in jute. Fig. 6 & 7 represent data on root and stem rot in plants across three years (2020-2022) for different treatments labelled P1T1 to P2T3. Stem rot severity was assessed by calculating the PDI 90 DAS. These findings indicate that the plant population had no significant effect on disease incidence or severity. However, the disease management module T1, which included seed treatment with carbendazim 50 WP (2 g kg^{-1} seed) and spraying of tebucanazole (0.15 % at 45 DAS) along with insecticides, was the most effective treatment for controlling stem and root rot under field conditions. This chemical management module showed consistent, superior performance over the years compared to the biological control module (T2) and the untreated control (T3). Treatment module T1, involving carbendazim seed treatment and tebuconazole foliar spray, consistently produced the lowest disease severity across years. Carbendazim, a benzimidazole fungicide, acts by binding to β-tubulin and inhibiting mitotic spindle formation, thereby preventing fungal cell division and hyphal growth. This mode of action explains its strong suppressive effect on *M. phaseolina*, which relies heavily on rapid mycelial colonization and sclerotial formation. In contrast, the biological control module T2 (seed treatment with *T. viride* and soil drenching with *P. fluorescens*) showed moderate and inconsistent efficacy. In one year, T2 was performed on par with T1; however, in other years, it was less effective. While *Trichoderma* antagonizes soil pathogens through mycoparasitism and the secretion of lytic enzymes, its performance varies with soil moisture, temperature and microbial competition. The chemical module T1, therefore, demonstrated superior stability under field conditions. These results are consistent with earlier studies showing that seed treatment combined with foliar tebuconazole application at 45 DAS effectively suppresses jute diseases (18). The superior performance of the chemical treatment module in controlling *M. phaseolina* highlights the potential of fungicides, particularly in areas with a high disease burden.

Effect of insecticides and botanicals against major pests affecting jute

The efficacy of insecticides and botanicals in an IPM approach, involving foliar applications for controlling mites, semilooper and BHC, was evaluated during the study period. Data on mite infestations were collected from the second unfolded leaf of 10

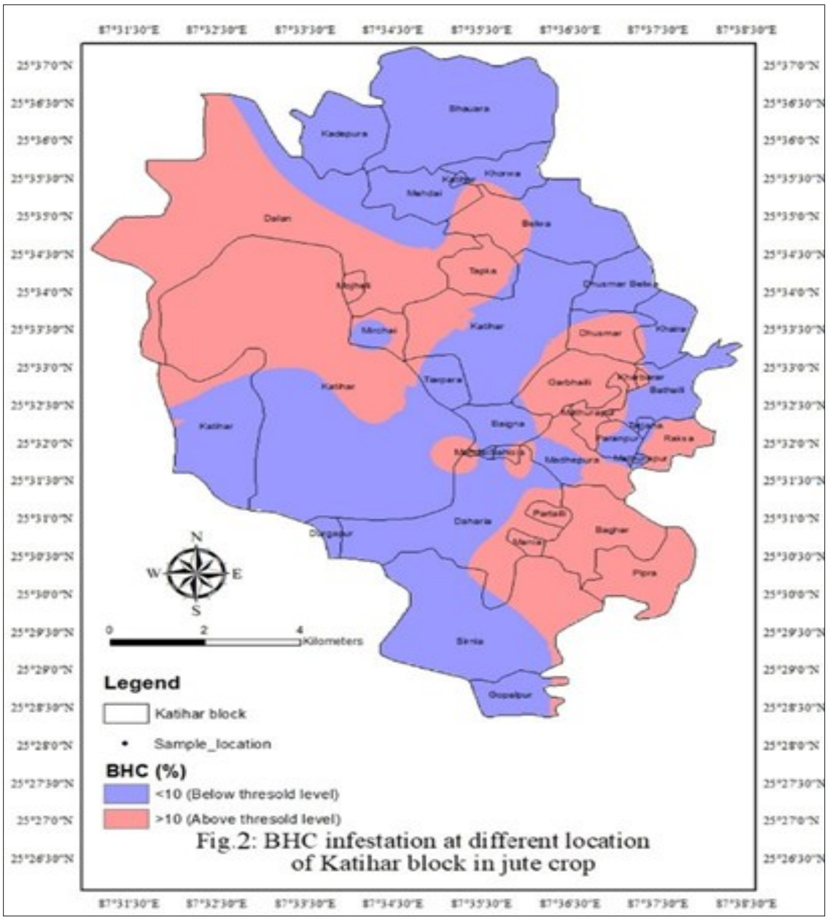

Fig. 2. BHC infestation at different locatopn of Katihar block in jute crop.

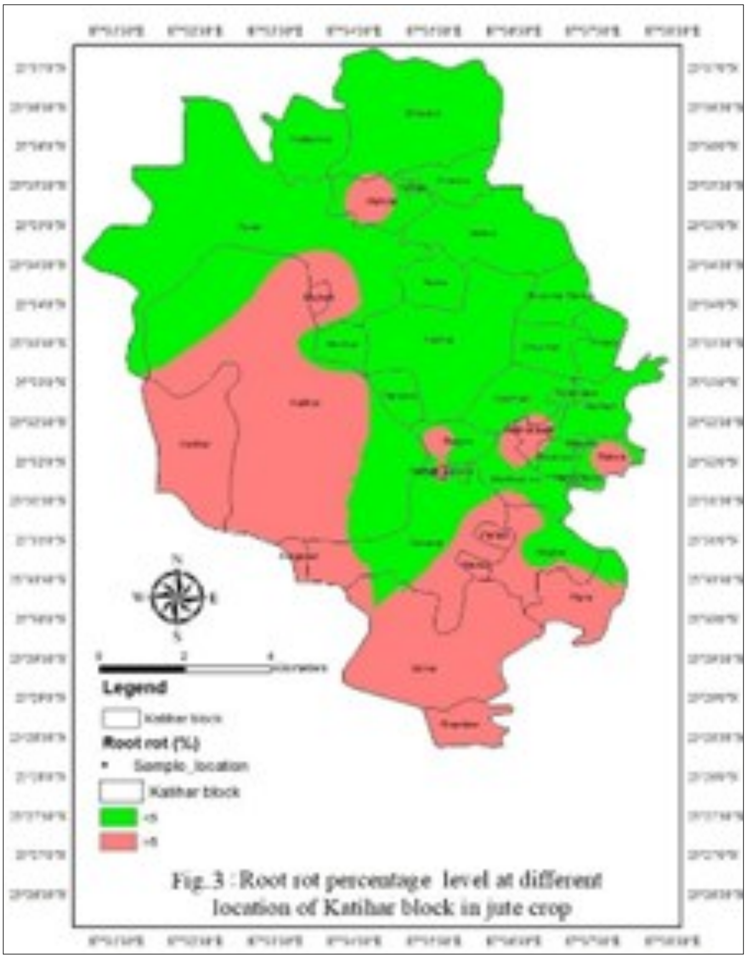

Fig. 3. Root rot percentage level at different location of Katihar block in jute crop.

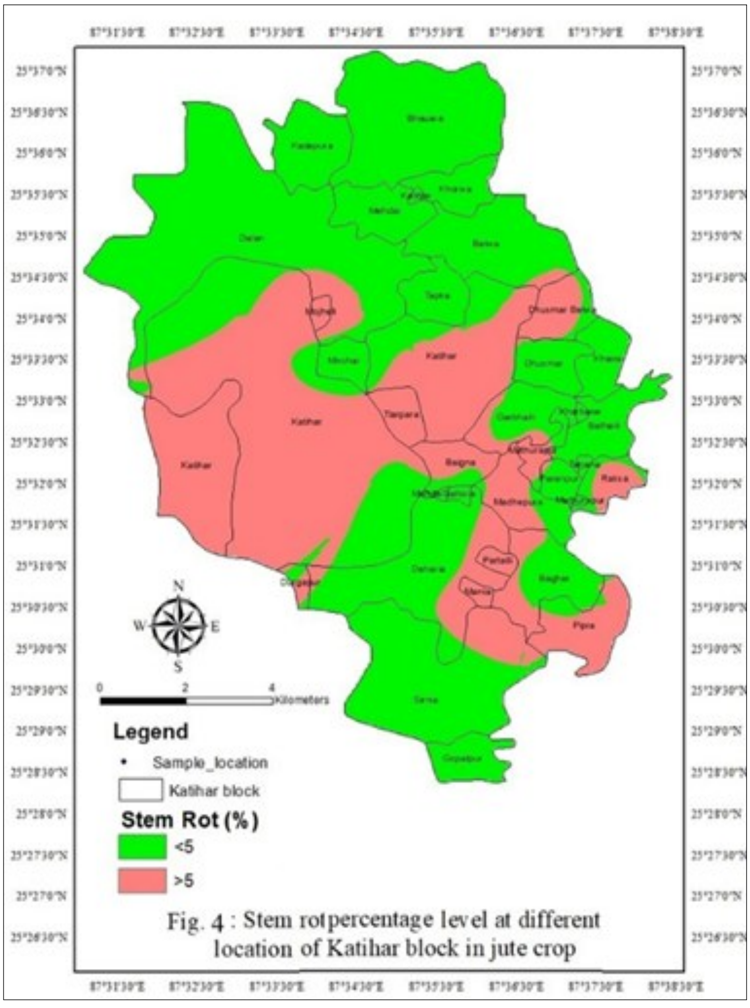

Fig. 4. Stem percentage level at different location of Katihar block in jute crop.

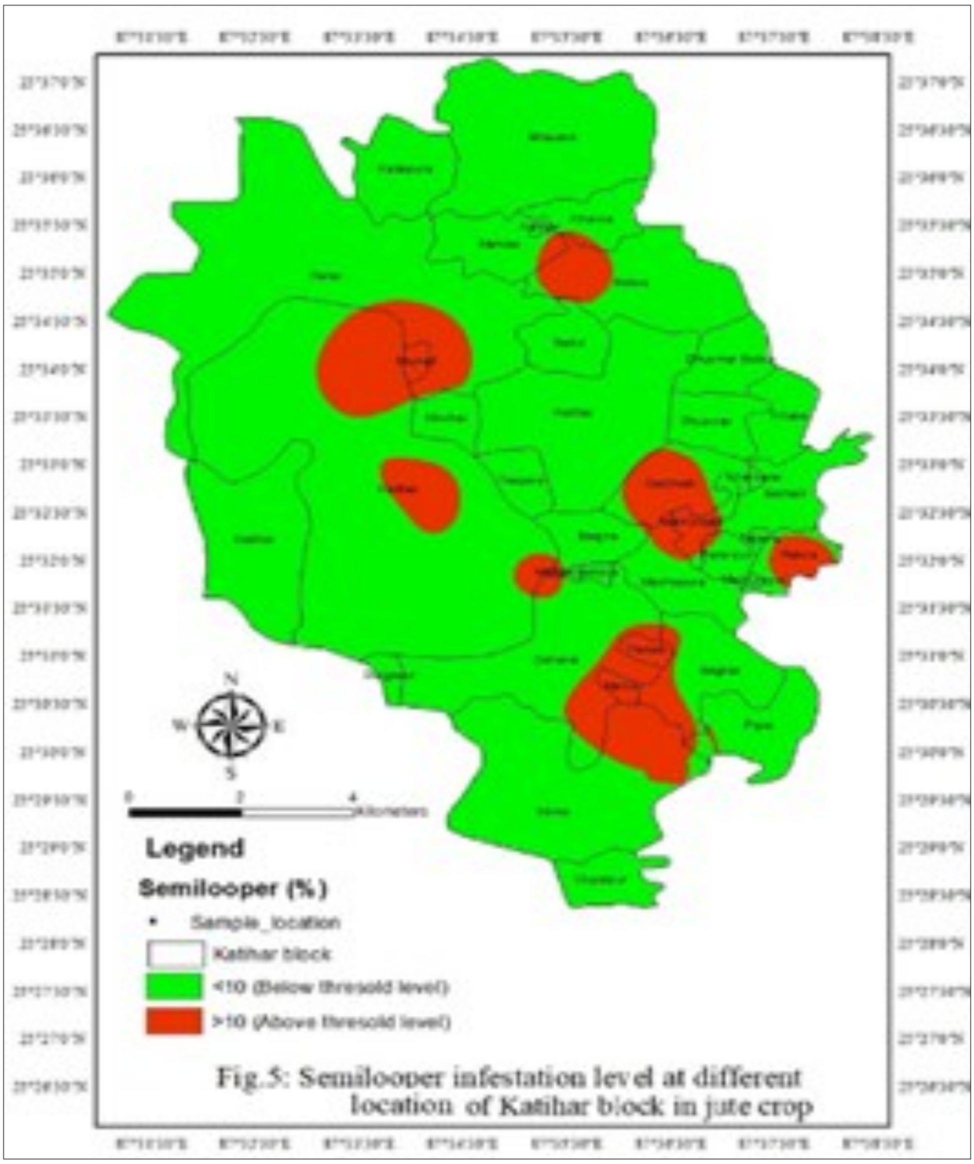

Fig. 5. Semilooper infestation level at different location of Katihar block in jute crop.

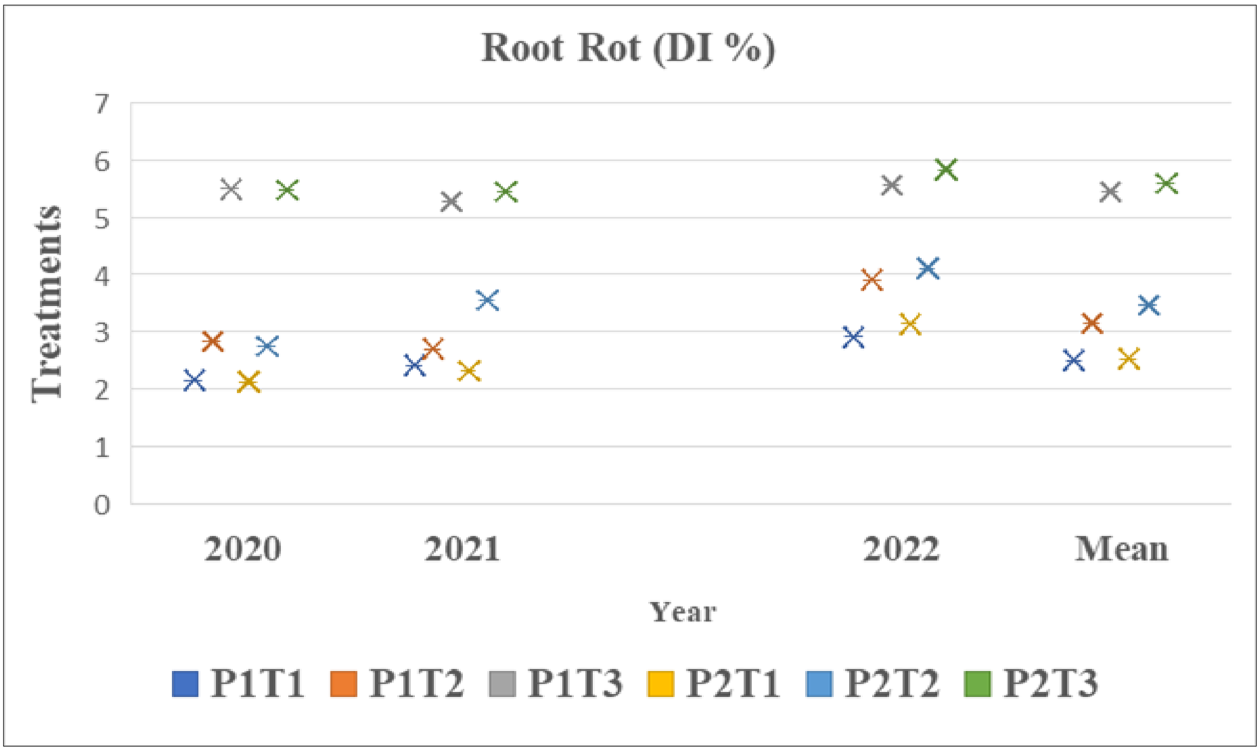

Fig. 6. Impact of fungicides and biocontrol agents against root rot disease in jute.

CD (Year)=0.387. and CD (Treatments)=2.63

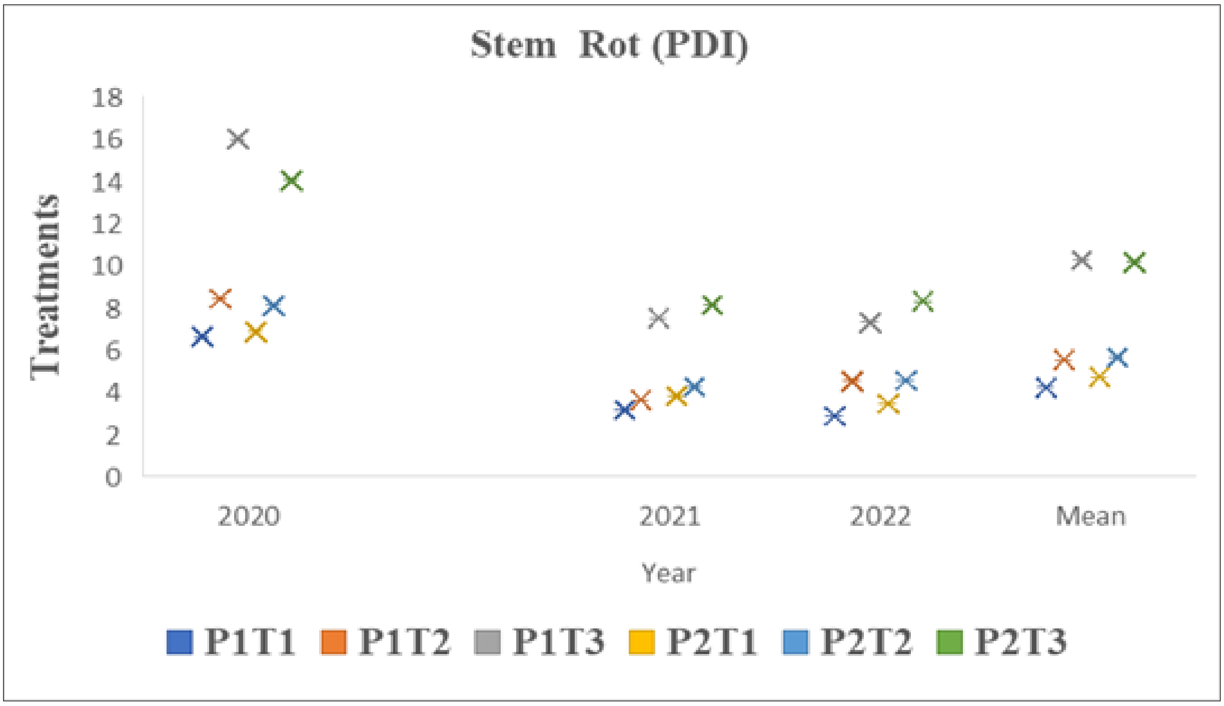

Fig. 7. Impact of fungicides and biocontrol agents on stem rot disease in jute.

CD (Year)=0.61 and CD (Treatments)=0.63

randomly selected plants per plot at 30, 40 and 50 DAS, whereas data on semilooper and BHC infestations were recorded at 55 and 70 DAS, respectively. Fig. 8 shows how different insecticide treatments affected mite infestations on jute plants at 30, 40 and 50 DAS. Different treatments (P1, P2, T1, T2 and T3) resulted in varying levels of mite infestation over time. Fig. 9 shows how different insecticides affected BHC infestations in jute plants. It compares the effectiveness of three treatments (T1, T2 and T3) on two different plant populations (P1 and P2) at 55 and 70 DAS. Fig. 10 shows how different insecticide treatments (T1, T2 and T3) affected semilooper insect infestations on jute plants. We compared the effectiveness of these treatments across two plant populations (P1 and P2) at 55 and 70 days after sowing. The results suggest that treatment effectiveness varied over time and across plant populations (P1 and P2). The results indicated that the efficacy of insecticide treatments against semilooper infestation in jute plants varied with the timing of assessment and plant population. At 55 DAS, the differences between treatments were less pronounced; however, by 70 DAS, the variations became more apparent, with T1 showing the lowest infestation rates and T3 showing the highest across both plant populations. The plant population P2 consistently showed higher semilooper infestation percentages than P1 across all treatments and time points, suggesting that factors related to plant density or other P2 characteristics may influence susceptibility to semilooper attacks. The findings revealed that the plant population had no significant effect on mites, semilooper, or BHC. However, the pest management module T1,

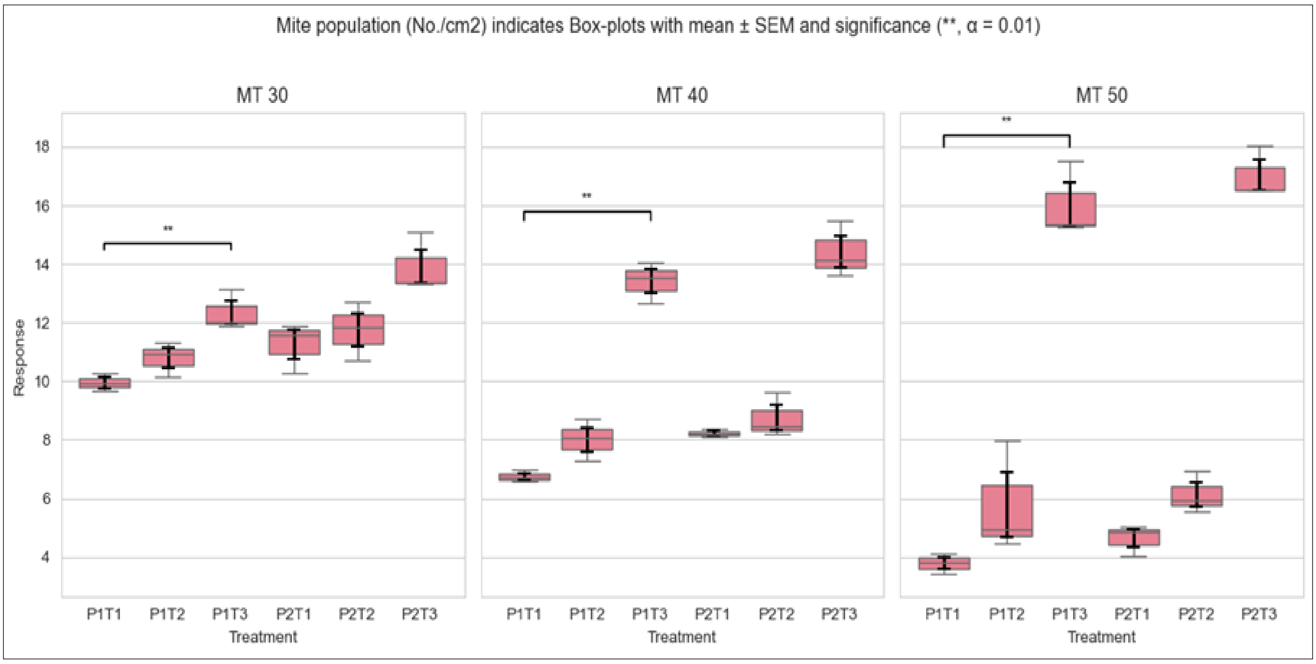

Fig. 8. Mite population (No cm^{-2}) (MT) represents three side-by-side vertical box plots corresponding to 30, 40 and 50 DAS (days after sowing), each displaying three yearly observations per treatment. Black ticks indicate the mean ± SEM for each treatment group. Dark brackets labelled with double asterisks (**) denote pairs within the same MT level that are significantly different at the 1 % level according to Tukey's HSD test.

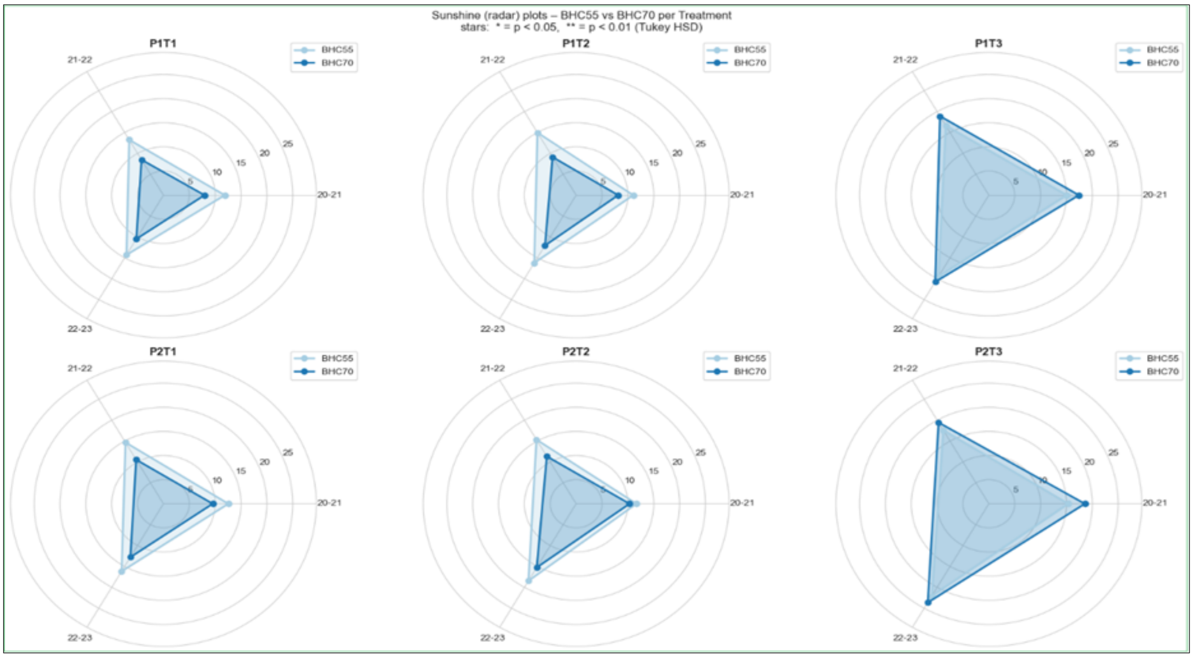

Fig. 9. The six-panel radar (sunshine) plot illustrates the interaction between BHC 55 and BHC 70 across three annual cycles (20-21, 21-22, 22-23) by representing each factorial cell (Period × Treatment) as a pentacle with vertices corresponding to temporal strata; the closed polygons depict the multivariate yield response, with radial distance proportional to yield magnitude and translucent halos indicating±1 standard error as a non-parametric confidence interval. Significant differences at each vertex, identified by Tukey's HSD tests, are marked with asterisks (* $p < 0.05$, ** $p < 0.01$). The plot reveals a crossover interaction where BHC 55 performs better under suboptimal or short-duration conditions, while BHC 70 achieves a higher yield potential when temporal and input constraints are less restrictive.

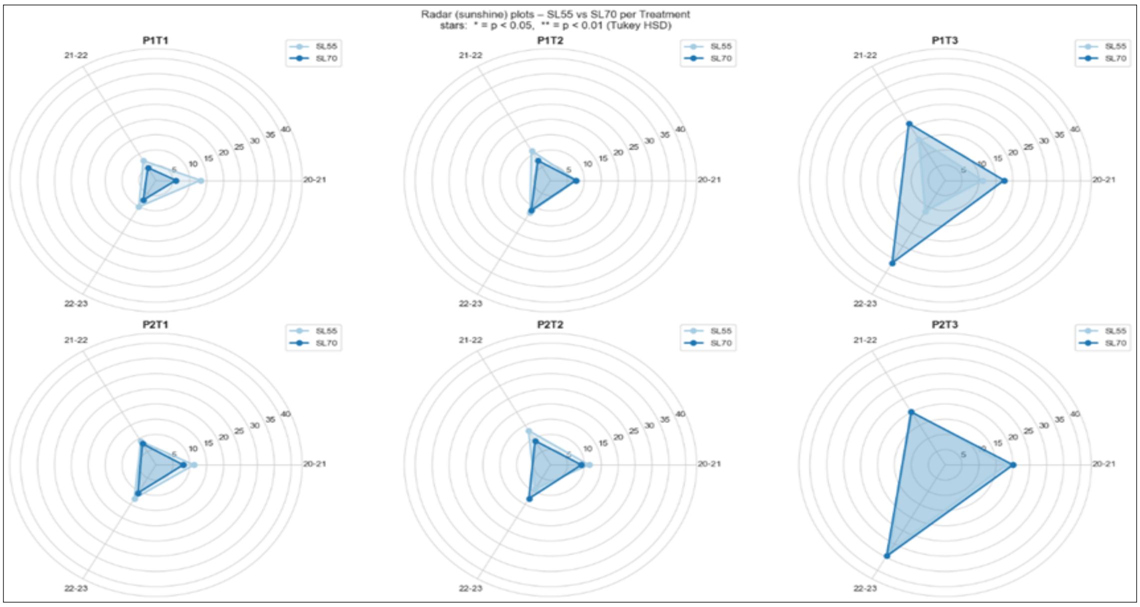

Fig.10. Indicates that SL55 outperformed SL70 under low and intermediate input conditions, particularly in earlier years, whereas SL70 surpassed SL55 under high-input conditions by the final year. This environment-specific performance was confirmed by a significant SL× year interaction ($F_{2,36} = 12.7$, $p < 0.001$). The radar plot visualizes these yield trends across the six treatment regimes, with two colored polygons representing SL55 and SL70 performance shaded by ± SEM and red stars highlighting years with statistically significant differences between the SL.

which included foliar sprays of Spiromesifen 240 SC (0.7 mL L^{-1} at 35 DAS) and λ-cyhalothrin 5 EC (0.6 mL/L^{-1}at 55 DAS), was the most effective treatment for managing all three pests compared to the biological control/botanical module (T2) and the untreated control (T3). Spiromesifen 240 SC is a lipid biosynthesis inhibitor targeting acetyl-CoA carboxylase in mites. This disrupts wax and lipid metabolism, reducing mite fecundity, egg viability and juvenile development. Such inhibition explains the consistently lower mite populations in T1 plots. λ-Cyhalothrin acts on voltage-gated sodium channels, causing rapid knockdown of semilooper and BHC larvae, which aligns with the reduced pest numbers observed. The biological control/botanical module T2, which involved spraying azadirachtin (10000 ppm) at 3 mL L^{-1} at both 35 and 55 DAS, also contributed to pest suppression and was statistically the same as the chemical treatment module T1 in managing mite infestations. Azadirachtin (10,000 ppm) interferes with insect feeding by blocking chemoreceptors and antifeedant pathways, reduces larval molting by disrupting ecdysone activity and inhibits ovarian development-particularly relevant for semilooper and BHC. This explains the noticeable but lower efficacy of T2 compared to T1. Results from Fig. 8–10 show that T1 consistently maintained lower pest populations than T2 and T3. Although T2 suppressed mite populations nearly as effectively as T1, it was less effective against semilooper and BHC due to the slower, growth-regulating nature of azadirachtin compared to the rapid neurotoxic action of λ-cyhalothrin. The plant population did not significantly affect pest incidence; however, P2 tended to show higher semilooper infestation, possibly because a denser canopy favored larval establishment. Overall, the combination of spiromesifen and λ-cyhalothrin in T1 provided rapid and sustained suppression of major pests. Similar findings were reported in an earlier study who demonstrated the superior efficacy of pyrethroids and lipid-biosynthesis inhibitors in jute pest management (19).

Effect of integrated management on fibre yield in jute

The impact of integrated pest and disease management on jute fibre yield was evident throughout the study. Fig. 11 presents the impact of various fungicide and insecticide combinations on jute fibre yield and B: C Ratio over three years. The results suggest that different treatments achieved varying levels of pest control and crop yield, with some performing better than others in terms of effectiveness and economic returns. However, the highest fibre yield (25.79 q ha^{-1}) was obtained from Treatment P1T1, which involved line sowing (P1) combined with seed treatment using Carbendazim 50WP (2 g kg^{1} seed), spraying of Spiromesifen 240 SC (0.7 mLL^{-1} at 35 DAS), spraying of Tebucanazole (0.15 % at 45 DAS) and spraying of λ-cyhalothrin 5 EC (0.6 mL L^{-1} at 55 DAS) (T1). This was followed by P2T1, where the seed was broadcast (P2) using the same chemical treatment (T1), yielding 23.74 q ha^{-1}. Fiber yields from the control treatments P1T3 and P2T3, where no fungicides or insecticides were applied, were significantly lower than those from the other treatments, underscoring the importance of integrated pest and disease management in enhancing fiber yield.

This study showed that combining pest and disease control methods significantly improved jute fibre production. The best results were obtained by planting seeds in rows and treating them with specific chemicals at different growth stages. This method produced the highest number of fibres. The second-best method used the same chemicals but scattered the seeds. When no pest or disease control was used, the fibre yield was much lower, highlighting the importance of these management techniques for better jute production. This indicates that the untreated plots (T3) not only resulted in significantly lower fibre yields but also had a less favourable cost-effectiveness compared to the chemical treatment module T_1. Integrated pest and disease management significantly influenced fibre yield. The highest yield (25.79 q ha^{-1}) was obtained from P1T1 (line sowing + chemical module), followed by P2T1 (23.74 q ha^{-1}). Control plots had substantially lower yields, highlighting the importance of pest suppression in maintaining fibre quality and productivity. The benefit–cost ratio was highest in T1 (1.87), while untreated plots had the lowest (1.43). This demonstrates that investing in effective IPM modules yields substantial economic benefits (20, 21). Furthermore, this study underscores the potential for farmers to improve profitability by implementing effective chemical treatment modules.

The superior performance of T1 can be due to carbendazim-mediated inhibition of M. phaseolina (disrupting fungal β-tubulin polymerization and arresting hyphal growth), reduced mite fecundity and population buildup due to spiromesifen (through inhibition of acetyl-CoA carboxylase affecting lipid biosynthesis) and rapid suppression of foliage-feeding larvae by λ-cyhalothrin (due to its neurotoxic action on sodium channels). These mechanisms directly prevent stem damage, leaf loss and physiological stress, enabling higher fibre accumulation. The superior performance of T1 compared to the untreated control (T3) in both fibre yield and benefit-cost ratio suggests that additional investment in pest and disease management can yield substantial economic benefits for jute cultivators. These findings emphasize the importance of adopting appropriate agronomic practices and pest control strategies to optimize jute cultivation outcomes, as suggested by various scientists (22). They also suggest that proper farming methods and insect management are crucial for growing jute successfully. By using the right techniques, farmers can improve the yield and quality of their jute crops. These practices help protect jute plants

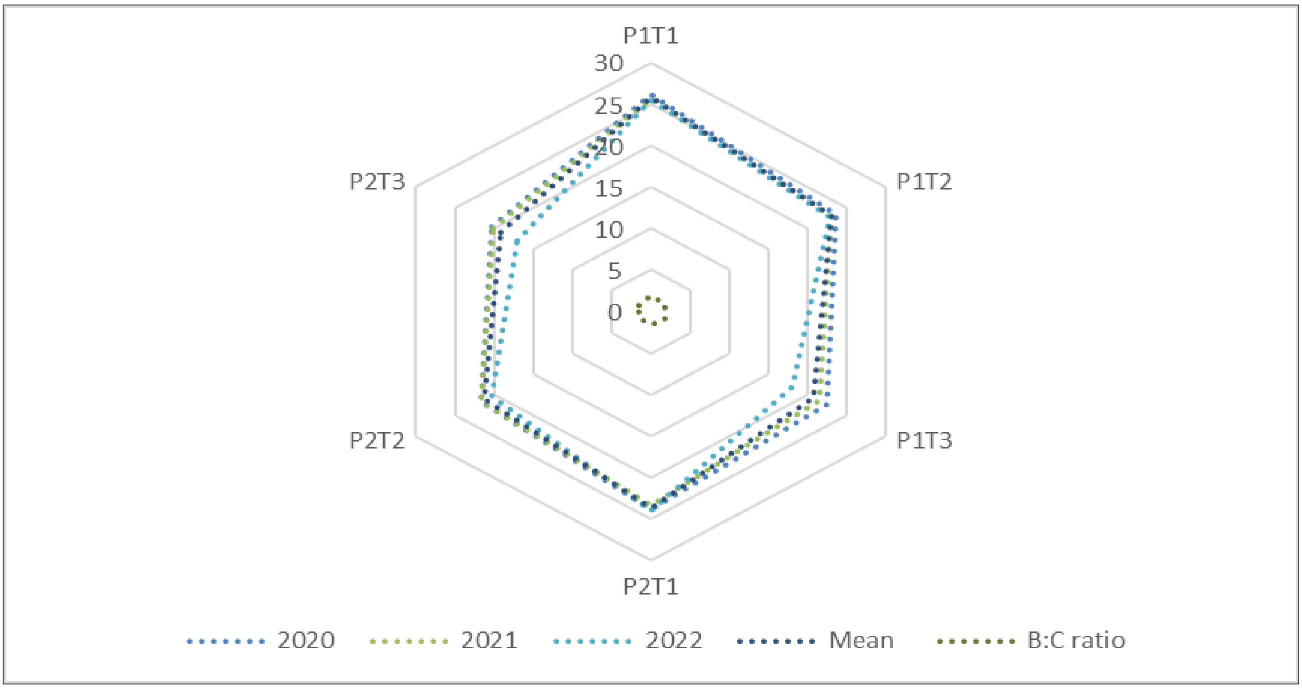

Fig. 11. Effect of fungicides and insecticides on fibre yield (q ha^{-1}) and B: C ratio in Jute from the year 2020-2021 (CD=2.14).

from pests and create better growing conditions.

Limitations

Despite the comprehensive evaluation of integrated pest and disease management strategies in jute, several limitations has been acknowledged to contextualize the findings. The study was conducted at a single location, limiting the generalizability of the results across jute-growing regions that differ in soil type, rainfall, pest pressure and microclimate; thus, multi-location validation is necessary. Although three years of data provide useful insights, this duration is relatively short for capturing long-term ecological and agronomic dynamics, as pest populations, pathogen virulence and soil microbial communities may fluctuate with climate and seasonal cycles. The study also did not assess natural enemies such as predatory mites, parasitoids and entomopathogenic fungi, whose interactions with pesticides like spiromesifen and λ-cyhalothrin are critical for designing ecologically balanced IPM programs. Moreover, the absence of pesticide residue analysis limits conclusions regarding environmental safety, potential soil or water contamination and fibre quality standards relevant for industry and export. Finally, the economic analysis did not consider long-term factors such as changes in soil fertility, yield stability, or shifting pest dynamics, which may influence farmer adoption and the long-term viability of the recommended practices.

Conclusion

Based on the findings of this study, it can be concluded that all the tested fungicides, insecticides, biological controls and botanicals were more effective than the control treatment in reducing pest and disease infestations (>74.11 % reduction) and improving fiber yield (>2.82 t ha-^{1}). Among the chemical and biological modules, the chemical module outperformed the biological module in managing *M. phaseolina*, a pathogen that causes stem and root rot. Specifically, seed treatment with carbendazim and foliar application of 0.15 % tebuconazole were the most effective in managing stem and root rot disease in jute. Regarding insect pests, foliar sprays of Spiromesifen 240 SC (0.7 mL L^{-1} at 35 DAS) and λ-cyhalothrin 5 EC (0.6 mL L^{-1} at 55 DAS) resulted in the maximum reduction in pest infestations and significantly increased fiber yield. While these chemical interventions demonstrated clear superiority under the present experimental conditions, their wider recommendation requires caution due to possible environmental risks, pesticide residue concerns and potential impacts on natural enemies, which were not assessed in this study. In conclusion, the chemical module, which incorporates both fungicides and insecticides, is the most effective integrated approach for managing diseases and pests in jute cultivation, but its large-scale adoption should be considered within an IPM framework that accounts for ecological sustainability, residue management and long-term implications.

Authors' contributions

KP designed the experiments, carried out the field experiment and drafted the manuscript. AG, JV and PK conceptualized the research and assisted with the research. VC, RS and PKY analyzed the data and contributed to its interpretation. RK prepared the final manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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