

Evaluation of Strobilurin and Triazole-Based Fungicides for Managing Foliar Blight in Large Cardamom in Taplejung, Nepal

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Abstract: Large cardamom (*Amomum subulatum* Roxb.) is an important spice crop in the Eastern Himalayas, including Nepal, but its productivity is severely affected by Colletotrichum Leaf Blight (CLB) caused by *Colletotrichum* spp. To manage this disease, a field experiment was conducted using a Randomized Complete Block Design (RCBD) with seven treatments and three replications. The treatments included three fungicides: Nativo (Tebuconazole 50% + Trifloxystrobin 25% WG), Syodia (Azoxystrobin 11% + Tebuconazole 18% SC), and Symister Top (Azoxystrobin 18.2% + Difenconazole 11.4% SC): each applied at two different concentrations (1 g/ml per liter and a lower dose), along with a control. Before treatment, 40 leaves were randomly selected to assess initial disease severity. Fungicides were applied using a high-volume knapsack sprayer at 4 liters per plot. A second spray was done 15 days after the first when disease severity reached about 5%. All treatments followed recommended agronomic practices. Among the treatments, Symister Top at 1 ml/L was the most effective, reducing disease severity by 68.4%, followed by Nativo (61.7%) and Syodia (57.9%). The highest yield increase (22.5%) was also recorded with Symister Top. The efficacy is due to the systemic and translaminar action of the fungicides, though the risk of resistance development remains a concern. The study suggests that appropriate fungicide use can effectively manage CLB in large cardamom. However, integrating chemical control with other sustainable practices is essential for long-term disease management and environmental safety.

Keywords: Large cardamom, Leaf Blight, Fungicide efficacy, Disease Severity Index, Area Under Disease Progress Curve

INTRODUCTION

Large cardamom (*Amomum subulatum* Roxb.), a member of the Zingiberaceae family and Scitaminae order, is predominantly grown in the Eastern Himalayan region, including Nepal, Sikkim and Darjeeling in India, and Bhutan (Basnet et al., 2021). It is locally known as Alaichi in Nepali, Badi Alaichi in Hindi, and is widely recognized internationally as Black cardamom, Black gold, or the Queen of Spices (Shrestha, 2018; Gurung & Pandey, 2021). The species was thoroughly described by Roxburgh in his botanical works *Flora Indica* and *Plants of the Coast of Coromandel* (Subedi et al., 2022). In Nepal, cultivation dates back more than a hundred years, with commercial production beginning in Ilam around 1865 AD (Pun, 2019). The expansion of cultivation was further supported by the establishment of the Cardamom Development Center in Ilam in 1915 (Paudel et al., 2018). Today, Nepal ranks as the second-largest producer of large cardamom globally, following Guatemala, and the crop remains a vital source of income for over 80% of rural households (Rijal, 2002; Gurung & Bag, 2023).

The primary cardamom-growing districts in Nepal include Taplejung, Ilam, Panchthar, Bhojpur, Dhankuta, Tehrathum, and Sankhuwasabha, contributing over 80% of the total national production (Gautam, 2014). Large cardamom thrives in marshy, humid, and shaded environments at altitudes

ranging from 900–2000 meters above sea level (m.a.s.l.), with an optimal temperature range of 10–30°C and an annual rainfall of 2000–3500 mm (Singh & Pothula, 2013). It is a perennial herbaceous plant that produces green leafy shoots from underground rhizomes (Sony & Upreti, 2017). The plant grows 1.5 to 3 meters in height, with long, tuberous rhizomes and broad leaves (30–60 cm long and 5–15 cm wide) (Zuntini et al., 2019). The inflorescence is a spike, usually bearing 30–40 flowers, which bloom during the spring season (Praveena et al., 2013). The fruit is a capsule containing 20–30 brown seeds, widely used as a spice and for medicinal purposes (Vijayan, 2018). Essential oils derived from large cardamom contain terpineol, myrcene, limonene, cineol, and sabinene, making it valuable for pharmaceutical, cosmetic, and food industries (Devadason et al., 2016; Mohiddin et al., 2021).

Despite its economic significance, large cardamom production is increasingly threatened by various biotic and abiotic stresses, with fungal diseases being a major limiting factor (Belbase et al., 2018). Among them, Colletotrichum Leaf Blight (CLB), caused by *Colletotrichum* spp., is a severe foliar disease responsible for significant yield losses (Ghazanfar et al., 2009). The disease manifests as small, circular, water-soaked lesions on leaves, which gradually enlarge into necrotic patches with concentric rings, leading to yellowing, drying, and premature leaf fall (Chaudhari & Gohel, 2016). In severe cases, it causes defoliation and weakens the plants, reducing their photosynthetic ability and overall productivity (Feksa et al., 2019). *Colletotrichum* spp. follow a polycyclic life cycle, with conidia and mycelium persisting on infected plant debris and spreading through rain splashes, wind, and contaminated tools (Scherin et al., 2009; Nasir et al., 2017). High humidity (>80%) and temperatures between 20–30°C favor rapid disease development, leading to 40–60% yield losses in unmanaged fields (Oo & Oh, 2016; Kumar, 2019). Currently, chemical fungicides such as mancozeb, carbendazim, and copper oxychloride are commonly used for controlling CLB (Gudade et al., 2013). In addition, systemic fungicides like Tebuconazole (a demethylation inhibitor targeting sterol biosynthesis), Trifloxystrobin and Azoxystrobin (both QoI fungicides disrupting mitochondrial respiration), and Difenoconazole (a triazole fungicide inhibiting ergosterol synthesis) have shown strong efficacy against *Colletotrichum* spp. due to their site-specific actions and curative properties (Gautam et al., 2020; Zubair et al., 2022). However, frequent and indiscriminate use of these fungicides may lead to resistance development, environmental contamination, and residual toxicity, thus highlighting the urgent need for alternative, eco-friendly strategies such as biocontrol agents and integrated disease management approaches (Singh & Jadon, 2021; Tiwari et al., 2023).

However, continuous fungicide application leads to pesticide resistance, environmental pollution, and negative impacts on non-target organisms (Gaurilcikiene & Ronis, 2006). Moreover, concerns about residue accumulation in the spice trade have led to stricter regulations, pushing researchers toward eco-friendly disease management strategies (Saju et al., 2013). One of the most promising alternatives is the use of biocontrol agents, including antagonistic fungi (e.g., *Trichoderma* spp.) and bacteria (e.g., *Bacillus* spp.), which suppress pathogen growth through competition, antibiosis, and induced systemic resistance (ISR) (Gautam et al., 2016; Shrestha et al., 2018).

This study aims to evaluate and compare the efficiency of different doses of mixed formulation Strobilurin + Triazole fungicides in controlling the foliar blight of large cardamom in Taplejung District, Nepal.

MATERIALS and METHODS

Experimental site selection

This field experiment was conducted at Phungling-5, Taplejung district, located in the eastern temperate region of Nepal (Figure 1), to evaluate the efficacy of different fungicides in managing foliar

blight of large cardamom (*Amomum subulatum*; variety: Ramsai). The research site featured a long-established large cardamom plantation, where plant stands ranged in age from 15 to 20 years, situated at an elevation of 1,690 m above sea level. Geographically, the location lies at 27°2'1"51 N latitude and 87°4'0"45 E longitude. During the experimental period, the maximum temperature ranged from 26.06°C to 31.26°C, while the minimum temperature varied between 12.78°C and 16.77°C. Relative humidity levels reached a peak of 67.31% before declining to a minimum of 32.16%. No rainfall was recorded at the beginning and end of the study, with a maximum rainfall of 6.82 mm occurring during the observation period. and 16.77°C. Relative humidity peaked at 67.31% before dropping to 32.16%. Rainfall was absent at the beginning and end of the study, reaching a maximum of 6.82 mm during the period.

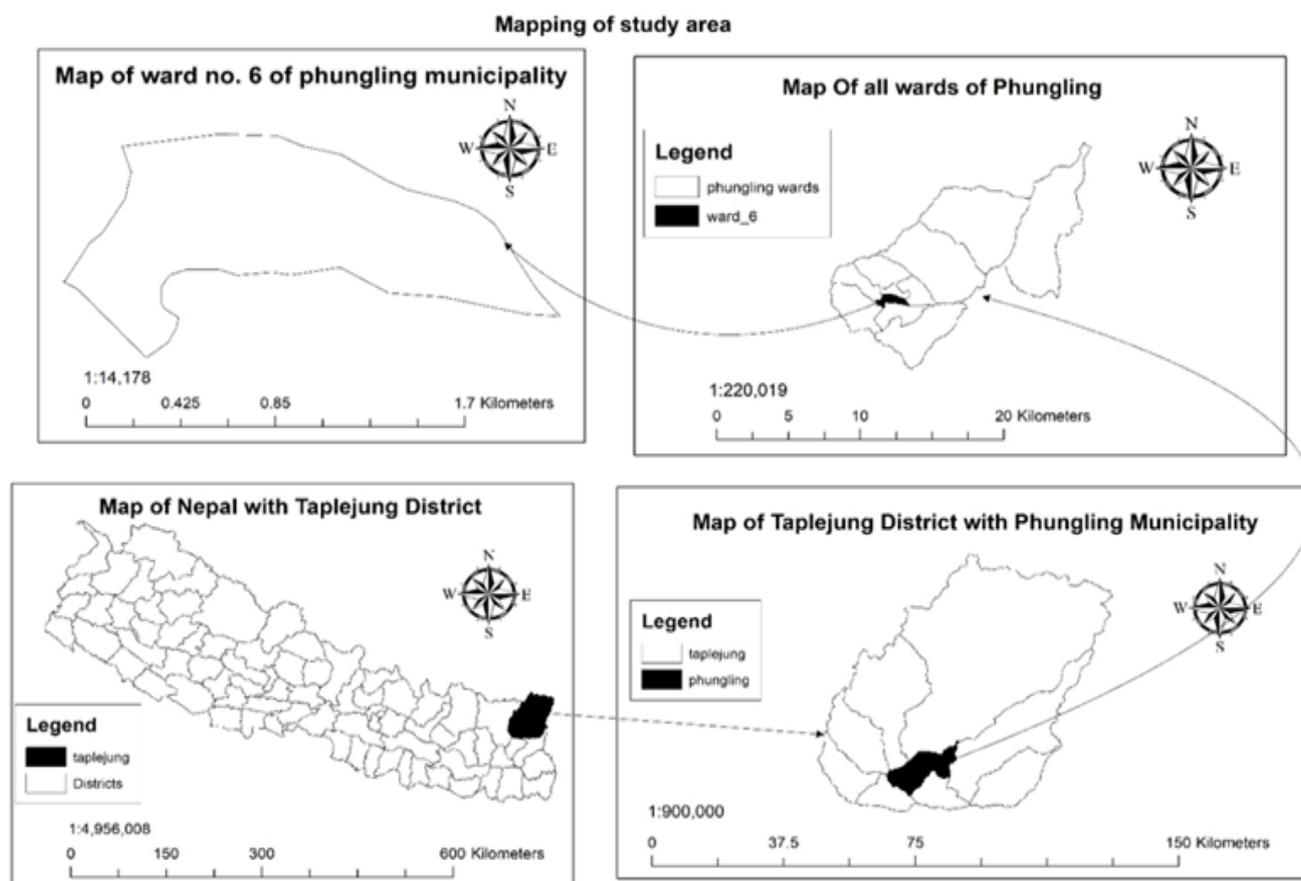


Figure 1. Mapping of a study area.

Experimental Design

The experimental site was laid out following the principles of a Randomized Complete Block Design (RCBD) to ensure the minimization of experimental error and uniform distribution of variability across treatments. The study comprised seven treatments, including various fungicidal formulations and an untreated control, each replicated three times, resulting in a total of 21 experimental units. Each plot measured 4 meters by 3 meters (12 m²) and was clearly demarcated to avoid interference between treatments. The layout and distribution of treatments across the blocks are illustrated in Figure 2. All plots received standard agronomic practices as recommended for large cardamom cultivation in the region, including appropriate irrigation, weeding, shade regulation, and nutrient management to ensure that the observed effects were primarily due to the fungicidal treatments rather than external variables. The experimental design enabled rigorous statistical analysis to.

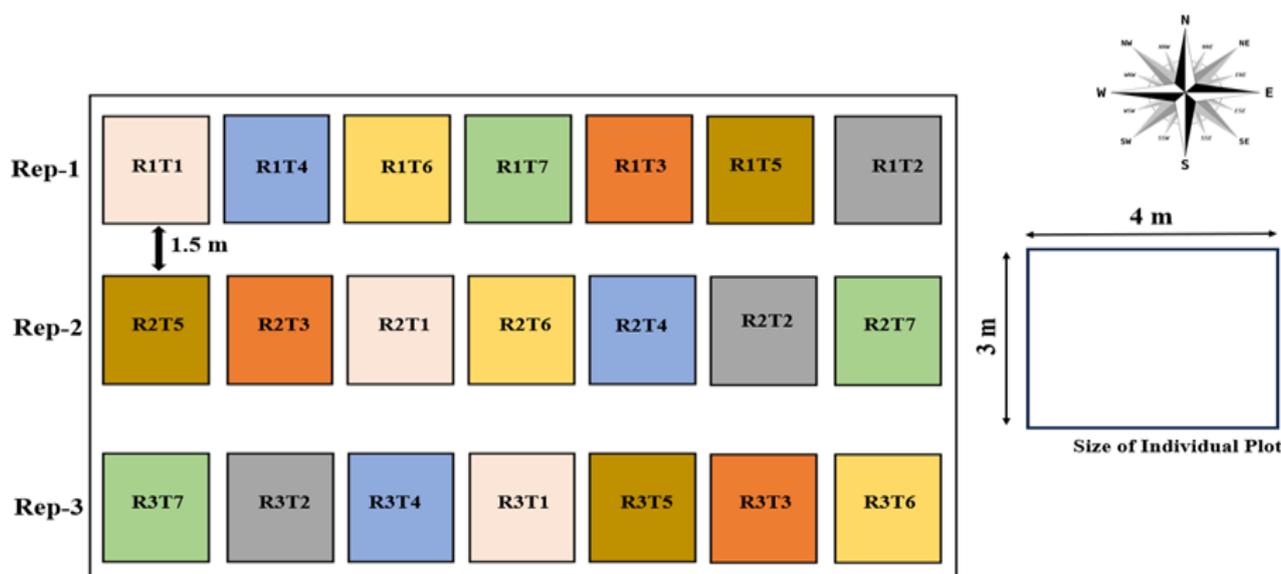


Figure 2. Layout of an experimental area.

Treatment details

A total of seven treatments were evaluated in the study. These included three commercial fungicide formulations: Symister Top, containing Azoxystrobin 18.2 percent and Difenoconazole 11.4 percent SC; Syodia, composed of Azoxystrobin 11 percent and Tebuconazole 18 percent SC; and Nativo, containing Tebuconazole 50 percent and Trifloxystrobin 25 percent WG. Each fungicide was tested at two dosage levels (low and high), in addition to one untreated control. The complete list of treatments, including trade names, active ingredients, and application rates, is presented in Table 1.

Table 1. List of the treatments used in research

Treatments	Trade name	Composition	Dose
T1	Symister Top	Azoxystrobin 18.2% + Difenoconazole 11.4% SC	0.5 ml ^{-L} water
T2	Symister Top	Azoxystrobin 18.2% + Difenoconazole 11.4% SC	1 ml ^{-L} water
T3	Syodia	Azoxystrobin 11% + Tebuconazole 18% SC	0.5 ml ^{-L} water
T4	Syodia	Azoxystrobin 11% + Tebuconazole 18% SC	1 ml ^{-L} water
T5	Nativo	Tebuconazole 50% + Trifloxystrobin 25% WG	0.5 gm ^{-L} water
T6	Nativo	Tebuconazole 50% + Trifloxystrobin 25% WG	1 gm ^{-L} water
T7	Control	-	-

Allocation and application of fungicides

This experiment aimed to evaluate the efficacy of three different fungicides, each applied at two concentrations, along with an untreated control, as detailed in the treatment section (Table 1). Treatment allocation to the 21 experimental plots was done using a lottery method to ensure randomization within each of the three replications. Prior to treatment application, leaves were randomly selected from across the experimental site to assess baseline disease severity caused by *Colletotrichum* spp. Fungicide application commenced when disease severity reached approximately 5%, ensuring a uniform infection threshold across all plots. A high-volume knapsack sprayer fitted with a hollow cone nozzle (brass nozzle) was used to apply the fungicides uniformly, delivering 4 liters of spray solution per plot. The spraying was carried out at an approximate pressure of 2.5 bar to ensure fine droplet formation and

uniform coverage across the leaf surface. Applications were performed in the early morning under favorable environmental conditions—ambient temperatures ranging from 18°C to 24°C, relative humidity between 70–85%, and minimal wind speed to reduce drift. A second spray was administered 15 days after the initial application to simulate realistic field-level disease management intervals and evaluate the continued efficacy of the fungicide treatments.

Observation and Data collection

Disease severity assessment

Ten leaves were selected randomly in four directions of plants from each experimental unit. The disease severity assessments were made regularly at three-day intervals based on visual observation. The assessment was carried out using a 0-9 Amended 10% Ordinal scale.

Disease scoring

As stated below in table 2, an Amended 10% Ordinal Scale was used to score the diseases (Chiang et al., 2014).

Table 2. Amended 10% Ordinal Scale

Score	Description	Midpoint
0	0% (No Infection)	0
1	0+ - 1%	0.5
2	1+ - 4%	2.5
3	4+ - 10%	7
4	10+ - 20%	15
5	20+ - 30%	25
6	30+ - 40%	35
7	40+ - 50%	45
8	50+ - 70%	60
9	70+ - 100% Disease	85

Disease Severity Index

The disease severity index (DSI) was calculated based on the midpoint of the severity range of each class rather than based on the severity score of each class to avoid overestimation (Chiang et al., 2017).

$$DSI (\%) = \Sigma \frac{\text{Frequency of each class} \times \text{Midpoint}}{\text{Total no. of observations} \times \text{Maximum midpoint of scale}} \times 100\%$$

AUDPC calculation

According to Simko and Piepho (2012), the formula below was used to determine the Total area Under Disease Progress Curve (AUDPC).

$$AUDPC = \sum_{i=1}^{n-1} \frac{y_i + y_{i+1}}{2} \times (t_{i+1} - t_i)$$

Where,

y_i = Percentage, proportion, and other metrics used to assess an illness during the time of observation,

t_i = Time (in hours or days) at the time of the i th observation.

n = Overall number of observations.

Statistical analysis

The experimental data were first entered into MS-Excel (2019) for further analysis. To ensure the homogeneity of variances of data, the Square Root Transformation (SQRT) of original data was done as suggested by (Gomez & Gomez 1984). Analysis of Variance (ANOVA) was then conducted using R-studio Statistical software (4.3.1). Duncan's Multiple Range Test (DMRT) was used to compare the means of the relevant variables at a significance level of $p \leq 0.05$. Microsoft Excel was used to construct the figures and tables.

RESULTS

Effect of different biocontrol agents against leaf blight severity

At a 1% level of significance, all treatments exhibited a statistically significant reduction in disease severity across all observation dates compared to the untreated control (Table 3). On the 7th day following the initial spray, the lowest disease severity was recorded in the plot treated with Azoxystrobin 18.2% + Difenconazole 11.4% SC at 1 ml/L of water (2.79 ± 0.45), closely followed by Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L of water (3.32 ± 0.18). The latter was statistically at par with Tebuconazole 50% + Trifloxystrobin 25% WG at 0.5 g/L of water (3.54 ± 0.06). In contrast, the highest disease severity was observed in the untreated control plot (6.54 ± 0.69). By the 14th day after the first spray, the lowest disease severity was recorded in plots treated with Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L of water (3.97 ± 0.15), whereas the control plot exhibited the highest severity (7.87 ± 0.51).

Table 3. Effect of different fungicides on disease severity

Treatments	DSI(7DAS)	DSI (14DAS)	DSI (21DAS)	DSI (28DAS)	Mean DSI
Azo+Difen (0.5ml/l)	$4.29^{bc} \pm 0.65$ (2.65)	$5.17^{bc} \pm 0.19$ (2.38)	$6.12^{cd} \pm 0.60$ (2.57)	$6.54^c \pm 0.52$ (2.65)	$5.53^c \pm 0.37$ (2.45)
Azo+Difen (1ml/l)	$2.79^d \pm 0.45$ (1.80)	$4.51^{bcd} \pm 0.34$ (2.24)	$4.26^d \pm 0.04$ (2.18)	$4.61^d \pm 0.39$ (2.26)	$4.04^d \pm 0.27$ (2.13)
Azo+Teb (0.5ml/l)	$5.26^{ab} \pm 0.07$ (2.40)	$7.52^a \pm 0.37$ (2.83)	$8.33^b \pm 0.09$ (2.97)	$9.07^b \pm 0.54$ (3.09)	$7.54^b \pm 0.16$ (2.84)
Azo+Teb (1 ml/l)	$3.32^{cd} \pm 0.18$ (1.95)	$3.97^{cd} \pm 0.51$ (2.11)	$4.83^{cd} \pm 0.85$ (2.30)	$5.64^{cd} \pm 0.76$ (2.47)	$4.44^d \pm 0.30$ (2.22)
Tebu+Tri (0.5gm/l)	$4.39^{bc} \pm 0.51$ (2.21)	$5.59^b \pm 0.55$ (2.46)	$6.38^{bc} \pm 0.74$ (2.62)	$6.47^c \pm 0.67$ (2.67)	$5.75^c \pm 0.23$ (2.50)
Tebu+Tri (1gm/l)	$3.54^{cd} \pm 0.06$ (2.01)	$3.65^d \pm 0.45$ (2.03)	$5.29^{cd} \pm 0.56$ (2.40)	$5.41^{cd} \pm 0.50$ (2.43)	$4.47^d \pm 0.34$ (2.22)
Control	$6.54^a \pm 0.69$ (2.65)	$7.87^a \pm 0.51$ (2.89)	$11.37^a \pm 0.67$ (3.44)	$15.56^a \pm 0.54$ (4.01)	$10.34^a \pm 0.04$ (3.29)
Mean	4.30	5.47	6.66	7.64	6.02
CV	17.80	13.42	16.11	13.34	7.31
F-test	**	**	**	**	**

The performance of the control was statistically comparable to that of Azoxystrobin 11% + Tebuconazole 18% SC at 0.5 ml/L of water (7.52 ± 0.37). Throughout the subsequent observation periods, the plot treated with Azoxystrobin 18.2% + Difenconazole 11.4% SC at 1 ml/L of water consistently

recorded the lowest disease severity, while the untreated control plot exhibited the highest. On an overall basis, all treatments demonstrated significant efficacy ($p \leq 0.01$) in suppressing disease severity. The lowest mean disease severity was recorded in plots treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L of water (4.04 ± 0.27), followed closely by Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L of water (4.44 ± 0.30) and Tebuconazole 50% + Trifloxystrobin 25% WG at 1 g/L of water (4.47 ± 0.34), both of which were statistically at par with the best-performing treatment. The plot treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 0.5 ml/L of water recorded a disease severity of (5.53 ± 0.37), which was statistically comparable to that of Tebuconazole 50% + Trifloxystrobin 25% WG at 0.5 g/L of water (5.75 ± 0.23). The untreated control plot exhibited the highest disease severity (10.34 ± 0.04), followed by Azoxystrobin 11% + Tebuconazole 18% SC at 0.5 ml/L of water (7.54 ± 0.16). These findings underscore the superior efficacy of Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L of water in mitigating disease severity, while all tested treatments provided substantial disease suppression compared to the untreated control.

Effect of different fungicides on Area Under Disease Progress Curve (AUDPC)

A highly significant difference was observed among all treatments concerning the Area Under Disease Progress Curve (AUDPC) (Table 4), indicating substantial variation in disease progression across treatments. Compared to the untreated control, all fungicidal treatments effectively suppressed disease progression, demonstrating their efficacy in managing the infection. Among the tested treatments, the lowest total AUDPC score was recorded in the plot treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L of water (87.30 ± 4.76), signifying its superior effectiveness in minimizing disease advancement. The performance of this treatment was statistically comparable to that of Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L of water (92.96 ± 8.21) and Tebuconazole 50% + Trifloxystrobin 25% WG at 1 g/L of water (93.84 ± 8.11), both of which also exhibited strong disease suppression. The plot treated with Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 0.5 ml/L of water recorded an AUDPC value of 116.92 ± 7.71 , which was statistically at par with Tebuconazole 50% + Trifloxystrobin 25% WG at 0.5 g/L of water (122.47 ± 4.38).

Table 4. Effect of different fungicides on Area Under Disease Progress Curve.

Treatments	Total AUDPC
Azo+Difen (0.5ml/l)	$116.92^c \pm 7.71$
Azo+Difen (1ml/l)	$87.30^d \pm 4.76$
Azo+Teb (0.5ml/l)	$161.14^b \pm 3.17$
Azo+Teb (1 ml/l)	$92.96^d \pm 8.21$
Tebu+Tri (0.5gm/l)	$122.47^c \pm 4.38$
Tebu+Tri (1gm/l)	$93.84^d \pm 8.11$
Control	$212.06^a \pm 3.93$
Mean	126.67
CV	8.18
F-test	**

Although these treatments effectively reduced disease progression, their performance was slightly less effective compared to the highest-performing treatments applied at higher dosages. Conversely, the untreated control plot exhibited the highest AUDPC score (212.06 ± 3.93), indicating the most severe and continuous disease development throughout the assessment period. The second-highest disease progression was observed in the plot treated with Azoxystrobin 11% + Tebuconazole 18% SC at 0.5 ml/L

of water (161.14 ± 3.17), which showed a significant reduction in disease compared to the control but remained less effective than higher-concentration treatments. Overall, these findings confirm that all treatments significantly mitigated disease progression, with Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L of water emerging as the most effective fungicide. However, Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L of water and Tebuconazole 50% + Trifloxystrobin 25% WG at 1 g/L of water also demonstrated comparable efficacy. Lower dosages provided moderate disease control, but their effectiveness was inferior to the higher concentrations.

DISCUSSION

Leaf blight caused by *Colletotrichum* spp. remains one of the major diseases affecting large cardamom in Nepal, leading to significant yield losses. The present study aimed to evaluate the efficacy of mixed formulations of Strobilurin and Triazole fungicides under field conditions. The findings indicate that Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L water was the most effective treatment, recording the lowest disease severity and AUDPC score. The superior efficacy of this combination can be attributed to its dual mode of action, where Azoxystrobin inhibits mitochondrial respiration by blocking electron transfer in cytochrome b and c, while Difenoconazole disrupts ergosterol biosynthesis, compromising fungal cell membrane integrity (Chaudhari & Gohel, 2016; Devadason et al., 2016; Kumar, 2019). The performance of Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 1 ml/L water was statistically at par with Azoxystrobin 11% + Tebuconazole 18% SC at 1 ml/L water and Tebuconazole 50% + Trifloxystrobin 25% WG at 1 g/L water, demonstrating their comparable efficacy in disease control. This observation aligns with findings by Kumar (2019), who reported that two foliar applications of Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 350 g/ha, applied at disease onset and repeated 14 days later, resulted in a 78.06% disease reduction. Similarly, Subedi et al. (2022) reported that Azoxystrobin 50% WDG significantly reduced Disease Incidence (DI%), PDI, and AUDPC in *Colletotrichum* blight management. A critical factor contributing to the superior performance of Azoxystrobin + Difenoconazole is its systemic and translaminar activity. Strobilurin fungicides like Azoxystrobin exhibit deep penetration and redistribution within the leaf tissue, providing long-lasting protection, whereas Triazoles such as Difenoconazole and Tebuconazole target sterol biosynthesis, hindering fungal cell membrane formation (Mohiddin et al., 2021). The results of this study are further supported by Devadason et al. (2016), who demonstrated that Azoxystrobin effectively suppressed anthracnose disease in mango. Moreover, Chaudhari & Gohel (2016) reported that Azoxystrobin 18.2% + Difenoconazole 11.4% SC and Tebuconazole 50% + Trifloxystrobin 25% WG are highly effective against *Colletotrichum* spp., consistent with our findings. The untreated control plots exhibited the highest disease severity and AUDPC, reinforcing the necessity of fungicidal intervention for effective disease management. Notably, Azoxystrobin 18.2% + Difenoconazole 11.4% SC at 0.5 ml/L water showed moderate efficacy, with an AUDPC score significantly lower than the control but higher than the higher-dose treatments. This suggests that a dose-dependent response is critical, as lower concentrations may not provide sufficient residual activity for prolonged disease suppression. Similar trends were observed by Mohiddin et al. (2021), where varying concentrations of Strobilurin and Triazole fungicides resulted in differential disease control efficacy against rice blast. Comparing our findings with previous studies, Kumar (2019) found that Trifloxystrobin 25% + Tebuconazole 50% at 350 g/ha reduced disease severity by 78.06%, closely resembling our results. Likewise, Nasir et al. (2017) reported that Nativo 75% WDG (Tebuconazole + Trifloxystrobin) provided a 92.03% reduction in anthracnose severity, emphasizing the effectiveness of Triazole-Strobilurin mixtures in controlling fungal diseases. Additionally, field experiments by Ghazanfar et al. (2009) and Scherm et al. (2009) demonstrated that Strobilurin and Triazole fungicides significantly suppressed fungal growth in multiple

pathosystems. Despite their efficacy, a major concern with Strobilurin and Triazole fungicides is their single-site mode of action, which makes them susceptible to resistance development (Gaurilcikiene & Ronis, 2006; Feksa et al., 2019; Zuntini et al., 2019). Repeated applications of these fungicides could lead to the selection of resistant *Colletotrichum* strains, diminishing long-term efficacy. Therefore, integrated disease management (IDM) strategies incorporating fungicide rotation with different modes of action and the use of biocontrol agents should be explored to mitigate resistance risks (Mohiddin et al., 2021).

CONCLUSION

The findings of this study revealed that Azoxystrobin 18.2% + Difenconazole 11.4% SC at 1 ml/L of water was the most effective fungicide in managing leaf blight in large cardamom, significantly reducing disease severity and the area under the disease progress curve (AUDPC). Treatments involving Azoxystrobin 11% + Tebuconazole 18% SC and Tebuconazole 50% + Trifloxystrobin 25% WG also showed comparable efficacy. Their strong performance is likely due to their systemic and translaminar modes of action, which offer prolonged protection against *Colletotrichum* spp. However, repeated use of single-site fungicides may accelerate the development of resistance. Thus, adopting an integrated disease management (IDM) approach is critical. This should include rotation of fungicides with different modes of action, strict field sanitation (e.g., removal of infected plant debris), and the use of certified disease-free planting material. Incorporating biological control agents such as *Trichoderma harzianum* or *Pseudomonas fluorescens* may help suppress the pathogen population in the rhizosphere. Additionally, promoting disease-resistant cultivars and optimizing cultural practices like proper plant spacing and drainage can reduce humidity and disease pressure. Future research should prioritize multi-season field trials to validate the durability of these strategies across varied agro-climatic zones. Molecular surveillance of pathogen populations is also necessary to detect early signs of fungicide resistance. Emphasizing eco-friendly fungicides and biopesticides will further enhance the sustainability and environmental safety of large cardamom disease management in Nepal.

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AUTHOR CONTRIBUTIONS:

Kiran Chaulagain & Nirmal Adhikari: Conceptualization, data curation, investigation, Data curation & Methodology; Dipesh Kumar MEHATA: Conceptualization, data curation, investigation, methodology, visualization, original draft writing, review and editing of writing, and validation. Ayush KHAREL, Pawan Kumar YADAV & Tulasha GAUTAM: Data curation & Methodology. Sova YADAV: Supervision & Validation.

CONFLICTS of INTEREST

The authors declare there is no conflict of interest.

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