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Antifungal Activity of Bintaro Leaf Extract (*Cerbera odollam* Gaertn.) Against Anthracnose caused by *Colletotrichum* sp. in Red Chili Papper (*Capcisum annuum* L.)

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Abstract: *Red chili (Capsicum annuum L.) is an important horticultural commodity in Indonesia whose productivity is often constrained by anthracnose disease caused by Colletotrichum sp. The disease can significantly reduce yield and quality of chili. Control measures generally rely on synthetic fungicides, but their continuous use may result in environmental contamination and pathogen resistance. Therefore, environmentally friendly alternatives are needed. Bintaro (Cerbera odollam Gaertn.) leaves contain secondary metabolites with antifungal properties and have potential as a botanical fungicide. This study aimed to evaluate the effectiveness of bintaro leaf extract in suppressing the development of Colletotrichum sp. and to determine the optimum concentration for disease control. The experiment was arranged in a Completely Randomized Design (CRD) consisting of seven concentrations of bintaro leaf extract (0%, 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%) with four replications. Parameters observed included incubation period, spore germination percentage, disease incidence, and disease severity. The results showed that bintaro leaf extract significantly affected all observed variables. The optimum concentration for suppressing anthracnose development in red chili was 0.5 and 1%, while concentrations above 1% did not increase the effectiveness of disease control.*

Keywords: *anthracnose, Cerbera odollam, Colletotrichum sp., red chili, botanical fungicide.*

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I. INTRODUCTION

Indonesia country in which the agricultural sector plays an important role in supporting economic development and community welfare (Tosi et al., 2024). Red chili (*Capsicum annuum* L.) is one of the major horticultural commodities with high economic value and extensive use in household consumption and the food industry. Although chili production has increased in recent years, domestic production remains insufficient to meet the continuously growing market demand (Nurmalita et al., 2025).

Anthracnose, caused by *Colletotrichum* sp., is one of the most destructive diseases affecting red chili production. The disease is characterized by small water-soaked lesions that develop into sunken necrotic spots on the fruit surface, leading to tissue deterioration and reduced fruit quality and yield. Anthracnose can infect chili fruits at both immature and mature stages and may cause substantial economic losses under favorable environmental conditions (Setiono, 2024).

Anthracnose is a phytosanitary problem caused by various species of *Colletotrichum* that are widely distributed in tropical and subtropical regions. Members of this genus exhibit necrotrophic, hemibiotrophic, latent, and endophytic lifestyles. The disease cycle begins when fungal spores are dispersed by wind, rain, or insects and deposited on the fruit surface. Under conditions of high humidity and warm temperatures, conidia germinate and penetrate host tissues through the cuticle or natural openings such as stomata. In the hemibiotrophic phase, which is the most common infection strategy, the pathogen initially colonizes living tissues before switching to a necrotrophic phase that causes cell death and disease development (Rodriguez et al., 2025).

The management of anthracnose in Indonesia primarily depends on synthetic fungicides. However, excessive and prolonged use of these chemicals may result in residue accumulation in agricultural products, soil, and water, thereby posing risks to human health and the environment. Furthermore, continuous fungicide application may contribute to the development of pathogen resistance, reducing the long-term effectiveness of disease control measures (Setiono, 2024). Consequently, environmentally friendly and sustainable alternatives are urgently needed.

Several studies have demonstrated the effectiveness of botanical extracts, including betel leaf, noni leaf, and billygoat weed leaf extracts, in suppressing the growth of anthracnose pathogens at concentrations ranging from 0 to 3%. The antifungal activity of these extracts is mainly associated with the presence of secondary metabolites such as alkaloids, flavonoids, saponins, and tannins (Herviana et al., 2022).

Bintaro (*Cerbera odollam* Gaertn.) is known to contain similar bioactive compounds, including alkaloids, flavonoids, saponins, tannins, steroids, and cardiac glycosides, which possess antimicrobial and antifungal activities (Nurbaeti, 2025). Rahmawati et al. (2024) reported that bintaro leaves contain glycosides, particularly cerberine, as well as flavonoids, saponins, and polyphenols capable of inhibiting the growth of pathogenic microorganisms. In addition, bintaro leaf extract has been reported to exhibit antioxidant, antifungal, antitumor, and anticancer activities. The presence of phenolic and nitrogen-containing compounds makes these bioactive substances relatively polar and more efficiently extracted using polar or semi-polar solvents.

Despite the considerable potential of bintaro leaf extract as a botanical fungicide, information regarding its effectiveness against *Colletotrichum* sp. causing anthracnose in red chili plants remains limited. Therefore, this study aimed to evaluate the effectiveness of bintaro leaf extract in suppressing the growth and development of *Colletotrichum* sp. and to determine the optimum concentration for controlling anthracnose disease in red chili plants.

II. EXPERIMENTAL PROCEDURE

2.1 Experimental Design

The experiment was arranged in a Completely Randomized Design (CRD). The treatments consisted of seven concentrations of bintaro leaf (*Cerbera odollam* Gaertn.) extract, namely A (0%) as the control, B (0.5%), C (1%), D (1.5%), E (2%), F (2.5%), and G (3%). Each treatment was replicated four times, resulting in a total of 28 experimental units. The treatments consisted of seven concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract prepared in 100 mL of solution as follows:

- A = 0% bintaro leaf extract + 100 mL distilled water
- B = 0.5% bintaro leaf extract + 99.5 mL distilled water
- C = 1.0% bintaro leaf extract + 99.0 mL distilled water
- D = 1.5% bintaro leaf extract + 98.5 mL distilled water
- E = 2.0% bintaro leaf extract + 98.0 mL distilled water
- F = 2.5% bintaro leaf extract + 97.5 mL distilled water
- G = 3.0% bintaro leaf extract + 97.0 mL distilled water

2.2 Preparation of Potato Dextrose Agar (PDA) Medium

Potato Dextrose Agar (PDA) medium was prepared by dissolving 39 g of PDA powder in 1 L of distilled water. The mixture was heated until completely dissolved and then sterilized in an autoclave at 121°C for 15 min. The sterilized medium was poured into sterile Petri dishes and supplemented with chloramphenicol to prevent bacterial contamination (Hairani and Pakadang, 2023).

2.3 Preparation of Bintaro Leaf Extract

Healthy leaves of bintaro (*Cerbera odollam* Gaertn.) were washed thoroughly with clean water to remove dirt and dust and air-dried for three days. The leaves were subsequently oven-dried at 50°C for three days and ground into fine powder. A total of 500 g of leaf powder was macerated in 96% ethanol at a ratio of 1:4 (w/v) in a 2000 mL beaker for three days with daily stirring. The filtrate was concentrated using a rotary evaporator to obtain a crude extract (Susanti, 2024).

2.4 Isolation of *Colletotrichum* sp.

Colletotrichum sp. was isolated from infected chili fruits showing anthracnose symptoms collected from Koga Market, Bandar Lampung, Indonesia. Fruit surfaces were wiped with 70% ethanol to reduce surface contaminants without affecting internal pathogens. Tissue segments (0.5 × 0.5 cm) containing both healthy and infected areas were excised and transferred onto sterile PDA medium. The cultures were incubated until fungal growth appeared, after which colonies were identified and purified to obtain pure cultures of *Colletotrichum* sp. (Yulianty et al., 2022).

2.5 **Rejuvenation of *Colletotrichum* sp. Isolates**

Five-day-old fungal cultures grown on PDA medium were subcultured by transferring a loopful of mycelium onto fresh PDA plates and incubated at 28–30°C for five days. Colony morphology, including colony color and growth characteristics, was subsequently observed (Khoirunisa, 2017).

2.6 **Preparation of Conidial Suspension**

Fourteen-day-old fungal cultures were suspended in 50 mL of sterile distilled water and homogenized thoroughly. A drop of the suspension was placed on a hemocytometer and examined under a microscope to adjust the conidial density to 10^6 conidia mL^{-1} (Yulianty et al., 2022).

2.7 **Seed Germination**

Seeds were soaked in 25 mL of distilled water for three minutes and dried using filter paper. Subsequently, the seeds were immersed in bintaro leaf extract at concentrations according to each treatment for 2,5 h at room temperature. Treated seeds were placed on moist filter paper in sterile Petri dishes for germination and later transferred into seedling trays for seven days after sowing (Fahmi et al., 2024).

2.8 **Preparation and Sterilization of Planting Medium**

The planting medium consisted of a mixture of sterilized soil and composted manure at a ratio of 2:1. The medium was placed into polybags measuring 25 cm in diameter and 30 cm in height, with approximately 3 kg of medium per polybag (Khoirunisa, 2017).

2.9 **Transplanting of Chili Seedlings**

Healthy and uniformly growing seedlings were selected and transplanted into polybags at 14 days after sowing when they had developed two true leaves. Each polybag contained three seedlings. Seedlings were irrigated daily with approximately 5 mL of water per plant every morning (Salsabila, 2024).

2.10 **Application of Bintaro Leaf Extract**

Bintaro leaf extract was applied to chili plants at 21 days after transplanting using a combination of seed soaking and foliar spraying methods following Suwirmen et al. (2013). Each plant received 5 mL of extract according to the assigned treatment concentration (Fahmi et al., 2024).

2.11 **Inoculation of *Colletotrichum* sp.**

Chili plants aged 28 days were inoculated with a 14-day-old conidial suspension of *Colletotrichum* sp. The suspension was sprayed evenly onto plant leaves at a volume of 5 mL per plant until runoff. Inoculated plants were covered with transparent plastic for three days to maintain high humidity. Polybags were placed on plastic trays containing approximately 2 cm of water to further enhance humidity conditions favorable for disease development (Fahmi et al., 2024).

2.12 **Observation Parameters**

The parameters observed in this study included incubation period, germination percentage, disease incidence, and disease severity.

a. Incubation Period

The incubation period was determined as the time interval between inoculation and the appearance of the first anthracnose symptoms on chili fruits (Yulianty et al., 2022).

b. Germination Percentage

Germination percentage was used to determine the proportion of seeds that germinated normally within the observation period. The germination percentage was calculated using the following equation (Sombalatau et al., 2017):

$$\% \textbf{ Germination} = \frac{\textbf{Number of normal sprouts produced}}{\textbf{Number of seeds tested}) } \times \mathbf{100}\%$$

c. Disease Incidence

Disease incidence was defined as the proportion of infected plants relative to the total number of plants observed. Disease incidence (DI) was calculated using the following formula (Fakhdian *et al,* 2018):

$$\mathbf{KP} = \frac{\boldsymbol{n}}{\boldsymbol{N}} \times \mathbf{100}\%$$

KP :Disease incidence (%)
n : Number of chili plants showing anthracnose symptoms
N :Total number of chili plants observed

d. Disease Severity

Disease severity was determined based on the number of fruits within each disease category and classified according to the host resistance criteria described by Yulianty et al. (2022). Disease severity (DS) was calculated using the following equation:

$$\mathbf{IS} = \frac{\sum(\mathbf{n} \times \mathbf{v})}{\mathbf{N} \times \mathbf{V}} \times \mathbf{100\%}$$

DS : disease severity (%)
n : number of chili fruits in each disease category
N : total number of fruits observed
v : numerical value assigned to each disease category
V : highest disease rating score

Disease severity was assessed using a rating scale based on the percentage of fruit surface area affected by anthracnose symptoms, as presented in Table 1.

Table 1. Disease severity rating scale used for anthracnose assessment on chili fruits.

Skor	Percentage of damaged leaf surface
0	No infection
1	Very mild infection (0–10% of fruit surface damaged)
2	Mild infection (11–30% of fruit surface damaged)
3	Moderate infection (31–50% of fruit surface damaged)

2.13 **Statistical Analysis**

Data on incubation period, germination percentage, disease incidence, and disease severity were subjected to statistical analysis. The obtained data were analyzed using one-way analysis of variance (ANOVA) to determine the effects of different concentrations of bintaro leaf extract on the observed parameters. When significant differences among treatments were detected, means were further compared using the Honestly Significant Difference (HSD) test at the 5% significance level ($\alpha = 0.05$) to identify the treatments that differed significantly from each other.

III. RESULTS AND DISCUSSIONS

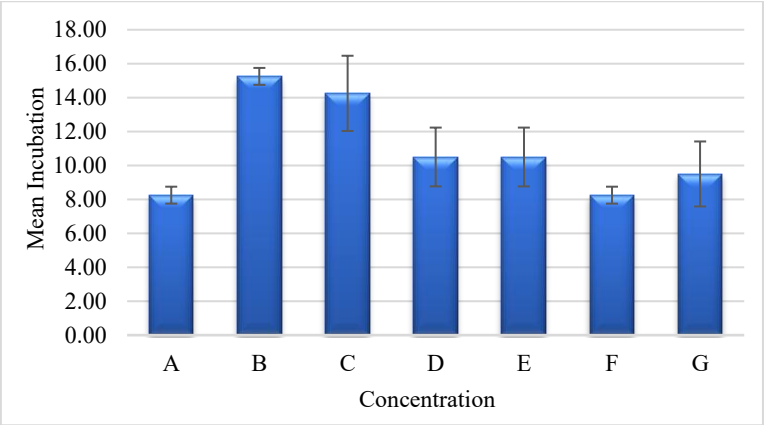
3.1. **Incubation Period**

The incubation period of anthracnose on red chili (*Capsicum annuum* L.) plants inoculated with *Colletotrichum* sp. ranged from 8 to 17 days after inoculation (DAI) across all treatments, including the control and bintaro leaf extract concentrations of 0.5%, 1%, 1.5%, 2%, 2.5%, and 3%. The mean incubation period observed for each treatment is presented in Table 2 and Figure 1.

Table 2. Mean incubation period of anthracnose on red chili plants treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.

Concentration	Incubation Period ± SD
A (0%)	$8{,}25 \pm 0{,}500^{b}$
B (0,5%)	$15{,}25 \pm 0{,}500^{a}$
C (1%)	$14{,}25 \pm 2{,}217^{a}$
D (1,5%)	$10{,}50 \pm 1{,}732^{b}$
E (2%)	$10{,}50 \pm 1{,}732^{b}$
F (2,5%)	$8{,}25 \pm 0{,}500^{b}$
G (3%)	$9{,}50 \pm 1{,}915^{b}$

Figure 1. Mean incubation period of anthracnose caused by *Colletotrichum* sp. on red chili (*Capsicum annuum* L.) treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.



The results showed that treatments B (0.5%) and C (1%) of bintaro (*Cerbera odollam* Gaertn.) leaf extract produced the longest incubation periods and differed significantly from the other treatments at the 5% significance level (Table 2). The extended incubation period observed in these treatments indicates that concentrations of 0.5% and 1% were more effective in suppressing pathogen infection and development within host tissues, thereby delaying symptom appearance. In contrast, the control treatment and treatment F (2.5%) exhibited the shortest incubation periods, suggesting that the pathogen was able to infect, colonize, and develop more rapidly in the absence of effective inhibition. Treatments D (1.5%), E (2%), and G (3%) showed intermediate responses but were less effective than treatments A and B in delaying disease development.

The prolonged incubation period observed in treatments A and B is likely associated with the antifungal activity of secondary metabolites present in bintaro leaf extract, including flavonoids, saponins, tannins, and alkaloids, which have been reported to inhibit the growth of *Colletotrichum* sp. (Sari et al., 2022). These compounds may interfere with several stages of pathogen development, including conidial germination, mycelial growth, and the formation of infection structures required for host penetration. Inhibition during these early stages of infection may slow pathogen colonization within host tissues and consequently delay symptom development (Marroquin et al., 2022).

The findings of this study are consistent with those reported by Purwantisari et al. (2016) and Nurmansyah (2015), who found that botanical extracts were capable of extending the incubation period of plant diseases by suppressing pathogen infection and colonization processes. A longer incubation period is generally considered an indicator of more effective disease suppression because it reflects reduced pathogen activity and slower disease progression in host tissues.

Variation in incubation period among treatments may also be influenced by pathogen virulence, host resistance, environmental conditions, and treatment effectiveness. High pathogen virulence and favorable environmental conditions can accelerate infection and disease development, resulting in earlier symptom expression. Conversely, plants with greater resistance or receiving effective treatments tend to exhibit longer incubation periods due to delayed pathogen colonization and slower disease progression (Leclerc et al., 2014).

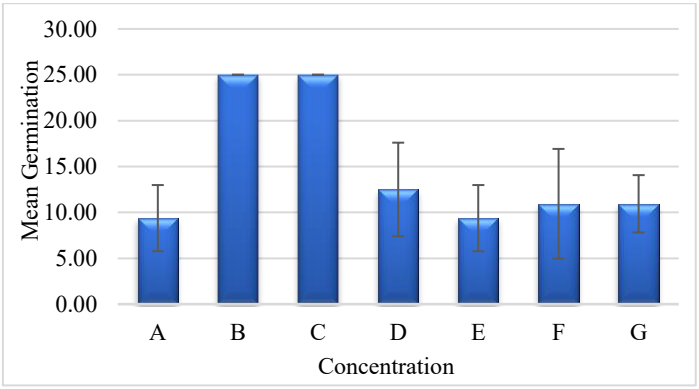
3.2 Germination Percentage

The results showed that the application of bintaro (*Cerbera odollam* Gaertn.) leaf extract at different concentrations significantly affected seed germination percentage. The mean germination percentages obtained from the HSD test at the 5% significance level.

Table 3. Mean germination percentage of anthracnose on red chili plants treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.

Concentration	Germination Rate (%) ± SD
A (0%)	9,38 ± 3,608^{b}
B (0,5%)	25,00 ± 0,000^{a}
C (1%)	25,00 ± 0,000^{a}
D (1,5%)	12,50 ± 5,103^{b}
E (2%)	9,38 ± 3,608^{b}
F (2,5%)	10,94 ± 5,984^{b}
G (3%)	10,94 ± 3,125^{b}

Figure 2. Mean germination percentage of anthracnose caused by *Colletotrichum* sp. on red chili (*Capsicum annuum* L.) treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.



The results showed that treatments B (0.5%) and C (1%) produced the highest germination percentages (25%) and differed significantly from the other treatments and the control, which recorded a germination percentage of only 9.38% (Figure 2). These findings indicate that low concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract were able to promote chili seed germination compared with untreated seeds. In contrast, increasing extract concentrations tended to reduce germination percentage.

The reduction in germination observed in treatments D (1.5%) to G (3%) suggests that higher concentrations of bintaro leaf extract may exert inhibitory effects on seed germination. This response is likely associated with the increased levels of secondary metabolites such as alkaloids, flavonoids, tannins, and saponins, which may induce allelopathic or phytotoxic effects and interfere with water uptake and early embryo development during germination. Therefore, bintaro leaf extract appears to possess an optimum concentration range for promoting seed germination, whereas excessive concentrations may inhibit this process.

These findings are consistent with those reported by Raden et al. (2008), who demonstrated that high concentrations of allelochemicals can suppress seed germination and early seedling growth. Similarly, Ali (2021) reported that increasing concentrations of botanical extracts do not necessarily improve treatment effectiveness and may inhibit plant growth beyond certain thresholds.

According to Ai and Ballo (2010), seed germination is influenced by interactions between internal and external factors. Internal factors include seed viability, physiological maturity, and nutrient reserves, whereas external factors include water availability, temperature, oxygen supply, light, and growing media conditions. Suboptimal conditions for any of these factors may restrict metabolic activity during germination and consequently reduce germination percentage.

The variation in germination responses among treatments indicates that chili seeds possess a specific tolerance threshold to the bioactive compounds present in bintaro leaf extract. Therefore, the selection of an appropriate extract concentration is essential to achieve optimal germination performance. Similar findings were reported by Purba et al. (2014), who observed that seed responses to botanical extracts are highly dependent on concentration and the sensitivity of the tested species.

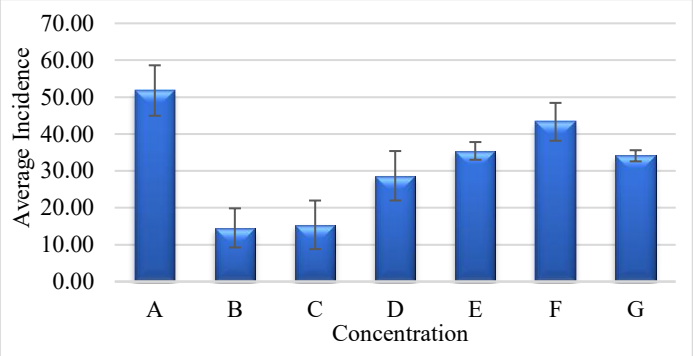
3.3 Disease Incidence Caused by *Colletotrichum* sp. on Red Chili (*Capsicum annuum* L.)

The results of the Honestly Significant Difference (HSD) test at the 5% significance level indicated that the application of bintaro (*Cerbera odollam* Gaertn.) leaf extract at different concentrations significantly affected the incidence of anthracnose caused by *Colletotrichum* sp. on red chili plants. The mean values of disease incidence for each treatment are presented in Table 4 and Figure 3.

Table 4. Mean Disease Incidence of anthracnose on red chili plants treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.

Concentration	Incidence of Disease (%) ± SD
A (0%)	$51{,}79 \pm 6{,}839^{a}$
B (0,5%)	$14{,}55 \pm 5{,}301^{d}$
C (1%)	$15{,}38 \pm 6{,}588^{d}$
D (1,5%)	$28{,}68 \pm 6{,}703^{c}$
E (2%)	$35{,}42 \pm 2{,}406^{bc}$
F (2,5%)	$43{,}30 \pm 5{,}129^{ab}$
G (3%)	$34{,}09 \pm 1{,}515^{bc}$

Figure 3. Average Incidence of anthracnose caused by *Colletotrichum* sp. on red chili (*Capsicum annuum* L.) treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.



The results demonstrated that the application of bintaro (*Cerbera odollam* Gaertn.) leaf extract significantly affected anthracnose incidence in red chili plants. The HSD test at the 5% significance level showed that treatments B (0.5%) and C (1%) resulted in the lowest disease incidence values, namely 14.55% and 15.38%, respectively, and differed significantly from the control treatment and several higher extract concentrations. In contrast, treatments D (1.5%), E (2%), F (2.5%), and G (3%) exhibited higher disease incidence values of 28.68%, 35.42%, 43.30%, and 34.09%, respectively. The control treatment showed the highest disease incidence (51.79%), indicating that the absence of bintaro leaf extract allowed more rapid pathogen infection and disease development. These findings suggest that increasing extract concentration beyond 1% did not improve disease suppression and was instead associated with higher disease incidence.

The superior performance of the 0.5% and 1% treatments may be attributed to the optimal activity of secondary metabolites present in bintaro leaves, including phenolic compounds, flavonoids, saponins, and alkaloids, which are known to possess antimicrobial properties (Sangkal et al., 2020). At appropriate concentrations, these compounds may inhibit pathogen growth and infection processes without causing adverse effects on plant physiology. Similar observations were reported by Asikin and Akhsan (2020), who stated that botanical pesticides exhibit optimum concentrations at which their biological activity is maximized, whereas higher concentrations do not necessarily increase their effectiveness.

The infection process of *Colletotrichum* sp. begins with conidial germination on plant surfaces under favorable environmental conditions, particularly high humidity and suitable temperatures. Germinated conidia produce germ tubes and appressoria that facilitate attachment and penetration of host tissues through mechanical pressure and the secretion of cell wall-degrading enzymes. Following penetration, the pathogen colonizes host tissues and utilizes nutrients from living cells during the early infection stage before inducing tissue necrosis and symptom development. This process results in the characteristic anthracnose symptoms, including sunken brown to black lesions that may progress to extensive tissue decay. Similar infection mechanisms have been described by Sari and Kasiamdari (2021) and Suryadi et al. (2021), who reported that successful colonization of host tissues is a major determinant of disease development in *Colletotrichum* infections.

Overall, the findings indicate that low concentrations of bintaro leaf extract, particularly 0.5% and 1%, were more effective in suppressing anthracnose incidence than higher concentrations. The reduced disease incidence observed in these treatments may be associated with the action of secondary metabolites that enhance plant defense responses and inhibit pathogen establishment during the early stages of infection. Phenolic compounds, in particular, are known to strengthen plant cell walls and interfere with pathogen development, thereby reducing disease incidence. These findings are consistent with those of Nabillah and Chatri (2024), who reported that secondary metabolites play an important role in enhancing plant resistance and suppressing disease development.

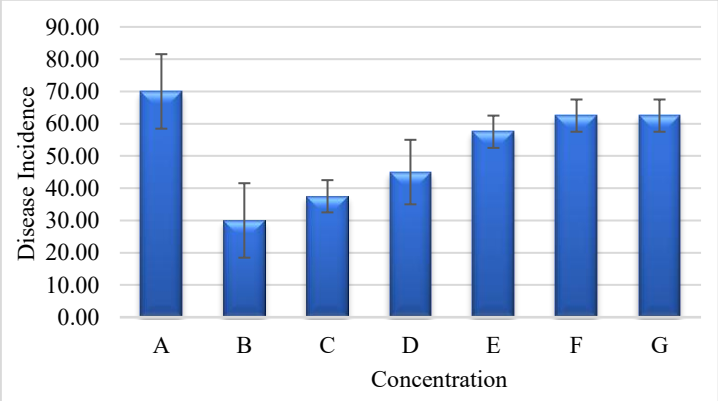
3.4 Disease Severity Caused by *Colletotrichum* sp. on Red Chili (*Capsicum annuum* L.)

The analysis of variance indicated that the application of bintaro (*Cerbera odollam* Gaertn.) leaf extract at different concentrations significantly affected the severity of anthracnose caused by *Colletotrichum* sp. on red chili plants. The mean disease severity values obtained from the Honestly Significant Difference (HSD) test at the 5% significance level are presented in Table 5 and Figure 4.

Table 5. Mean disease severity of anthracnose on red chili plants treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.

Concentration	Disease Severity (%) ± SD
A (0%)	70,00 ± 11,547[a]
B (0,5%)	30,00 ± 11,547[c]
C (1%)	37,50 ± 5,000[c]
D (1,5%)	45,00 ± 10,000[bc]
E (2%)	57,50 ± 5,000[ab]
F (2,5%)	62,50 ± 5,000[ab]
G (3%)	62,50 ± 5,000[ab]

Figure 4. Mean Disease Incidence of anthracnose caused by *Colletotrichum* sp. on red chili (*Capsicum annuum* L.) treated with different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract.



The results showed that different concentrations of bintaro (*Cerbera odollam* Gaertn.) leaf extract significantly affected anthracnose severity in red chili plants (Table 5). Treatment B (0.5%) resulted in the lowest disease severity (30.00%), followed by treatment B (1%) with a disease severity of 37.50%, whereas the control treatment exhibited the highest severity (70.00%). These findings indicate that low concentrations of bintaro leaf extract were more effective in suppressing disease development than higher concentrations. In contrast, treatments E (2%), F (2.5%), and G (3%) showed higher disease severity values of 57.50%, 62.50%, and 62.50%, respectively, although these values remained lower than those observed in the control treatment. Overall, the application of bintaro leaf extract at concentrations of 0.5% and 1% reduced disease severity by more than half compared with untreated plants.

According to Nurlita et al. (2024), the high disease severity observed in untreated plants is associated with the absence of bioactive compounds capable of inhibiting pathogen infection and colonization, allowing *Colletotrichum* sp. to penetrate and develop rapidly within host tissues. Conversely, plants treated with bintaro leaf extract benefited from the presence of secondary metabolites such as flavonoids, alkaloids, terpenoids, and tannins, which may contribute to enhanced plant defense responses and suppression of pathogen development during the early stages of infection. Although treatments with higher extract concentrations did not perform as effectively as the 0.5% and 1% treatments, the presence of these bioactive compounds still provided a certain degree of protection against disease progression compared with the untreated control (Hersila et al., 2023).

The superior performance of the lower extract concentrations may be related to the antifungal activity of secondary metabolites contained in bintaro leaves. Flavonoids, phenolic compounds, alkaloids, and saponins have been reported to inhibit fungal growth by disrupting cell membrane permeability, interfering with enzymatic activity, and suppressing mycelial development, thereby slowing disease progression. However, increasing extract concentration does not necessarily enhance antifungal activity because each bioactive compound has an optimum concentration range for maximum biological effectiveness. Similar findings were reported by Dalimunthe and Rachmawan (2017), who stated that the efficacy of botanical pesticides is strongly influenced by both the type and concentration of active compounds and that concentrations exceeding the optimum level may not improve disease control.

Overall, the findings of this study demonstrate that bintaro (*Cerbera odollam* Gaertn.) leaf extract has considerable potential as a botanical fungicide for the management of anthracnose disease in red chili plants. Concentrations of 0.5% and 1% were the most effective in suppressing disease severity, whereas increasing the concentration beyond 1% did not improve disease control efficacy. Similar observations were reported by

Masniati and Panggeso (2020), who concluded that the effectiveness of botanical extracts is determined by the optimum concentration of bioactive compounds rather than by increasing concentration alone.

IV. CONCLUSION

The results of this study demonstrated that the application of bintaro (*Cerbera odollam* Gaertn.) leaf extract significantly affected the incubation period, germination percentage, disease incidence, and disease severity of anthracnose caused by *Colletotrichum* sp. in red chili (*Capsicum annuum* L.). Among the tested treatments, bintaro leaf extract concentrations of 0.5% and 1% were found to be the most effective in suppressing the development of *Colletotrichum* sp., as indicated by prolonged incubation periods, higher germination percentages, and reduced disease incidence and severity. Increasing the extract concentration above 1% did not improve disease control efficacy, suggesting that the antifungal activity of bintaro leaf extract is dependent on an optimum concentration range rather than on increasing concentration alone.

Conflict of interest

There is no conflict to disclose.

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