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Bioactivity of teak (*Tectona grandis* L.f.) and cajeput (*Melaleuca cajuputi* Powell) leaf extracted on inhibition fruit fungal pathogens

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Abstract Results showed that cajeput oil at 10,000 ppm had the highest inhibitory effect on the mycelial growth of all tested fungi, with an inhibition rate of 92.5%. It was followed by cajeput crude extract at 20,000 ppm and teak crude extract at 25,000 ppm, with inhibition rates of 88.6% and 67.0%, respectively. Thus, cajeput oil and cajeput extract showed promising potential in controlling fruit fungal pathogens. Effective concentration (EC_{50} and EC_{90}) of each extract suggested that the lowest concentration to inhibit mycelial growth, spore germination and spore formation were in between 50-90%, which the concentration range between 100 to 30,000 ppm depending on the extracts and pathogen species. This finding could be useful in evaluating the appropriate concentration of each extract for controlling plant pathogenic fungi.

Keywords: Plant extracts, Bioactivity, *Tectona grandis* L.f., *Melaleuca cajuputi* Powell

Introduction

Thailand produces tropical fruits such as durian, mangosteen, rambutan, mango etc. which are both consumed domestically and exported. Agricultural products are the country's main source of income. Statistical data showed that in 2019s, tropical fruits production in Thailand was 39,811,512 tons with a fruit sales volume of around one hundred billion baht (FAOSTAT, 2020). The production of tropical fruit is still increasing but the grower has encountered plant disease problems in fruit production. These microorganisms, such as *Botryodiplodia* sp., *Colletotrichum* sp., *Fusarium* sp., *Lasiodiplodia* sp. and *Phytophthora* sp., can attack plants from the seedling stage to the post-harvest period (Prusky *et al*., 2010; Sangeetha *et al*., 2012; Kongtragoul *et al*., 2021; Tongsri *et al*., 2022). Many farmers have been applied chemical fungicides to protect plant diseases from destroying their crops but this method might be negative effects on the environment, farmers' health and consumers' health. Alternative methods have recently interest to apply plant extracts for disease

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control. The leaf extract of cajeput contain 1, 8-cineole, α-pinene, linalool, flavonoids, phenols, alkaloids, and glycosides, which actively against fungi and bacteria (Sutrisno *et al*., 2018; Isah *et al*., 2023). Its activity has been demonstrated against *Alternaria* sp., *Phytophthora palmivola*, *Staphylococcus aureus, S. pyogenes* and *Escherichia coli* (Somnuek *et al*., 2021, 2023; Abd Wahab *et al*., 2022). Additionally, teak has been studied for its antifungal activity. The leaf extract of this plant was evaluated to inhibit the growth of *Arthrinium phaeospermum* (wood decay on *Albizia falcataria*) (Astiti and Suprapta, 2012). In the work of Budianto *et al.* (2023) reported the secondary metabolites of this plant demonstrated numerous pharmacological activities. Therefore, this study aimed to evaluate the effective concentrations of teak extract, cajeput extract and cajeput oil to inhibit some fungal pathogens isolated from major fruit crops of Thailand.

Materials and methods

Preparation of crude extract

Teak and cajeput leaf samples were collected from King Monkut's Institute of Technology Ladkrabang, Chumphon campus. The leaves were cleaned and air dried, then dehydrate in a hot air oven at 45 ℃ until completely dried. The plant leaves were then rinsed in 75% ethanol and shaken in ultrasonic bath for 3 hours. The ethanolic extract was then evaporated using a rotary evaporator at 40 ℃ until it became crude extract and kept at 4 ℃ at the refrigerator before use.

Preparation of cajeput oil

Cajeput leaf was taken in the early morning, clean the fresh leaf. The essential oil was extracted from the fresh leaf using steam distillation. Cajeput oil was separated and stored at 4 ℃.

Isolation of fruit fungal pathogens

The pathogenic fungi were isolated from infected plant organs, namely, durian (stem rot, leaf blight, die-back and fruit rot), mango (crown rot), mangosteen (fruit rot), and rambutan (fruit rot). To isolate fungal pathogens from plant tissues, the tissue transplanting technique was used, which involves cutting infected plant tissues into small pieces and cleaning the surface by soaking the tissues in 10% sodium hypochlorite, 75% alcohol, and washing the pieces with distilled water before placing the sample in water agar (WA). After the hypha grew from the tissue sample, it was transferred to potato dextrose

agar (PDA). To isolate *Phytophthora* sp. from the infected durian, baiting technique (Dhingra and Sinclair, 1994) were used, and the obtained isolates were cultured on V8 juice medium for 7 days. The morphological identification of pathogenic fungi was compared with characterization features in the identification keys and species descriptions (Lim and Chan, 1986; Sangeetha *et al*., 2012; Lombard *et al*., 2014; Huang *et al*., 2020). Additional fungal isolates of *Phytophthora* sp. (ku-Dpttkl, ku-rwl, ku-Dptckkl), *Colletotrichum gloeosporioides* (ku-dc), *Fusarium* sp. (ku-bf), *Lasiodiplodia* sp. (ku-bl) and *Greeneria* sp. (ku-ngr) used in this experiment obtained from Dr. Veeranee Tongsri, (Department of Plant Pathology, Faculty of Agriculture, Kasetsart University, Bangkok Thailand) (Table 1).

The detached fruits and leaves were applied for pathogenicity test. The mycelial discs (5 mm) of the tested fungi causing fruit rot and crown rot disease were inoculated to the healthy host fruits. The mycelial discs (5 mm) of *Rhizoctonia* sp., *Phytophthora* sp. and *Fusarium* sp. isolated from durian were inoculated to the durian leaves (modified from the method of Vawdrey *et al*, 2005 and Lin *et al*., 2018). Each treatment was incubated in a plastic box at room temperature for 7 days and evaluated with disease severity as follows:

Disease severity = $(A \times 100)/B$ where A = size of the lesion on the tested plant organ and B = overall size of the tested plant organ.

Poisoned food technique

Teak extract, cajeput extract and cajeput oil were tested for their ability to inhibit fungal pathogen using a poisoned food technique. The experiment was designed in Completely Randomized Design (CRD) with 5 replications. To obtains the teak and cajeput extracts, Dimethyl sulfoxide (DMSO) and 2% Tween20 were used as a solvent, respectively. The dissolved crude extract was diluted to 5 different concentrations using sterilized distilled water as followed: teak crude extract was dissolved in 2% DMSO at 1,000, 5,000, 10,000, 15,000, 20,000 and 25,000 ppm. Cajeput crude extract was dissolved in 2%Tween20 at 500, 1,000, 5,000, 10,000, 15,000 and 20,000 ppm and cajeput essential oil at 100, 500, 1,000, 5,000, and 10,000 ppm. Five ml of each diluted plant extract was then mixed with PDA medium. The tested pathogens were cultured on each PDA medium at room temperature. The colony diameter was measured and calculated as percent inhibition of diameter growth (PI), as follows:

$PI= (A-B)/A \times 100$ % where A = colony diameter in control and B = colony diameter in treatment.

Spore germination test

The extracts of teak, cajeput, and cajeput oil at various concentrations as described above were mixed with pathogen spore suspension (1 x 10^6 spores/ml) with distilled water serving as a control. The experiment was conducted in CRD with 3 replications. The inhibition of spore germination was observed under a microscope for 12, 24, 48 and 96 hours. The percentage of spores germinated inhibition was calculated using the following formula:

(Gc-Gt)/Gc ×100 where Gc is number of the spores germinated in control and Gt is number of the spores germinated in treatment.

Sporulation test

The inhibitory effects of plant extracts on sporangium formation of *Phytophthora* sp. were tested using modified method from Mulugeta *et al*. (2019). The efficacy of teak crude extract, cajeput crude extract and cajeput oil was tested. The agar plug (2×2 mm) of *Phytophthora* sp. with the following isolates (KM-Dpt02, KM-Dpt4, KM-Dpt5, ku-Dptckkl, ku-Dpttkl, ku-rwl) was cultured on PDA medium for 5 days before being transferred to the extracts and the essential oil at various concentrations and incubated for 3 days at room temperature in the dark. The experimental design was conducted using CRD with 3 replications, each replication was randomly counted the number of sporangia in 3 areas under the microscope.

Statistical analysis

The experimental data were analyzed using One-way ANOVA, and mean values were compared using Duncan's Multiple Range test (DMRT) at 95% confidence level ($p< 0.05$). Effective concentrations were calculated using SPSS v.28.0.

Results

Isolation and pathogenicity test of the fruit fungal pathogens

Nineteen isolates of the pathogens were obtained from infected banana (crown rot and fruit rot), durian (stem rot, leaf blight, die-back, and fruit rot), mango (crown rot), mangosteen (fruit rot), and rambutan (fruit rot). They were morphological identified as *Phytophthora* spp. (6 isolates), *Lasiodiplodia* spp. (4 isolates), *Fusarium* spp. (3 isolates), *Colletotrichum* spp. (2 isolates), *Greeneria* sp. (1 isolate), *Gliocephalorichum* sp. (1 isolate), *Pestalotiopsis* sp (1 isolate) and *Rhizoctonia* sp. (1 isolate) (Table 1). Pathogenicity tests on detached fruit and leaf suggested that all isolates were the causal agent of fruit crop diseases (Figure 1).

Table 1. Sources of fruit fungal pathogens used in this study

Host plant/ location	Symptom	idenfication[1/]	isolates
Banana/Chanthaburi	crown rot	*Lasiodiplodia theobromae*	ku-bl
Banana/Chanthaburi	fruit rot	*Colletotrichum musae*	ku-bc
Banana/Chanthaburi	fruit rot	*Fusarium* sp.	ku-bf
Durian/Chumphon	leaf blight	*Rhizoctonia* sp.	KM-DRH
Durian/Chumphon	die-back	*Fusarium* sp.	KM-DFa
Durian/Chumphon	die-back	*Fusarium* sp.	KM-DFg
Durian/Chumphon	stem rot	*Phytophthora* sp.	KM-Dpt02
Durian/Chumphon	stem rot	*Phytophthora* sp.	KM-Dpt4
Durian/Chumphon	stem rot	*Phytophthora* sp.	KM-Dpt5
Durian/Chumphon	stem rot	*Phytophthora* sp.	ku-Dptckkl
Durian/Trat	stem rot	*Phytophthora* sp.	ku-Dpttkl
Durian/Rayong	stem rot	*Phytophthora* sp.	ku-rwl
Durian/Chanthaburi	fruit rot	*C. gloeosporioides*	ku-dc
Durian/Chumphon	fruit rot	*L. theobromae*	KM-dlt
Mango/Chanthaburi	crown rot	*L. theobromae*	KM-ml
Mangosteen/Chumphon	fruit rot	*Pestalotiopsis* sp.	KM-Mp
Mangosteen/Chumphon	fruit rot	*Lasiodiplodia* sp.	KM-gml
Rambutan/Chanthaburi	fruit rot	*Greeneria* sp.	ku-ngr
Rambutan/Chanthaburi	fruit rot	*Gliocephalorichum* sp.	KM-Ngc

[1/] Pathogen identification was based on morphological characteristic and host plant, except the obtained isolates.

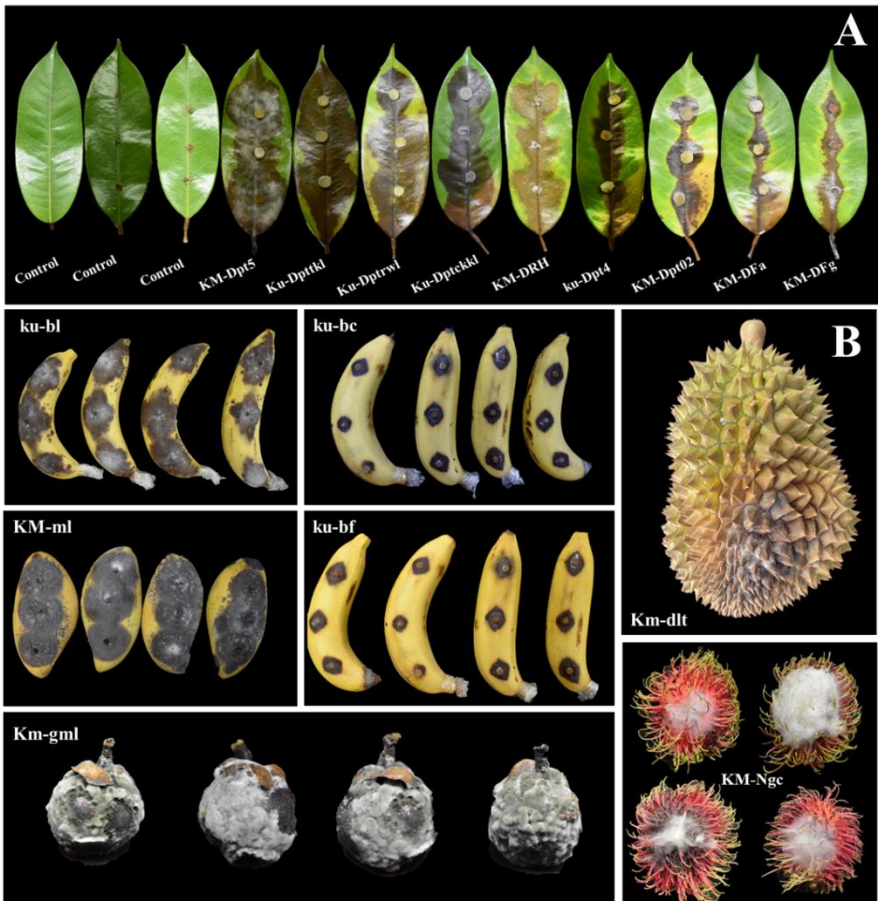

Figure 1. Pathogenicity test of the tested isolates A: Symptom on detached leaf, B: Symptom on detached fruit

Effect on mycelial growth

Teak extract

The efficacy of teak extract in inhibiting mycelial growth by poisoned food technique were evaluated. The result revealed that teak extract had significantly inhibitory effects compared to the control. The concentration at 25,000 ppm greatly reduced the mycelial growth of *Colletotrichum musae* (ku-bc), *Phytophthora* sp. (KM-Dpt02), *Greeneria* sp. (ku-ngr) and *Gliocephalotrichum* sp. (KM-Ngc) at 90-100% followed by *Colletotrichum gloeosporioides* (ku-dc) and *Lasiodiplodia theobromae* (KM-ml) at 80-85%. Meanwhile, the remaining treatments demonstrated to be moderate to high inhibition percentage (30-75%) (Table 2, Figure 2).

Table 2. Effect of crude ethanolic extract from *Tectona grandis* on mycelial growth

Tested isolates	Mycelial inhibition percentage[2/]							
	Control	2% DMSO	1,000 ppm	5,000 ppm	10,000 ppm	15,000 ppm	20,000 ppm	25,000 ppm
La (ku-bl)[3/]	0.0e[1/]	0.0e	19.8d	49.8c	62.8b	70.8a	70.8a	73.8a
Co (ku-bc)	0.0g	0.0g	9.4f	42.2e	55.6d	59.6c	66.6b	90.0a
Fu (ku-bf)	0.0e	0.0e	0.0e	26.6d	32.6cd	37.0c	47.4b	75.8a
Rh (KM-DRH)	0.0e	0.0e	26d	29.6cd	33.4c	64.4b	77.2a	79.0a
Fu (KM-DFa)	0.0d	0.0d	22.6c	25.2b	25.2b	25.4b	26.8b	29.8a
Fu (KM-DFg)	0.0d	0.0d	20.4c	33.2b	35.2ab	35.2ab	37.6ab	40.0a
Ph (KM-Dpt02)	0.0f	0.0f	0.0f	5.0e	14.4d	23.4c	33.4b	100a
Ph (KM-Dpt4)	0.0e	0.0e	0.0e	46.8d	60.4c	61.4c	75.0b	79.4a
Ph (KM-Dpt5)	0.0e	0.0e	0.0e	2.0e	18.0d	35.2c	51.4b	56.6a
Ph(ku-Dptckkl)	0.0e	0.0e	0.0e	6.2d	8.6d	24.8c	34.6b	49.6a
Ph (ku-Dpttkl)	0.0e	0.0e	0.0e	0.0e	9.6d	19.6c	27.2b	45.0a
Ph (ku-trwl)	0.0d	0.0d	0.0d	0.0d	11.2c	27.5b	29.8b	34.8a
Co (ku -dc)	0.0e	0.0e	0.0e	0.0e	42.8d	52.2c	58.6b	82.0a
La (KM-dlt)	0.0e	0.0e	0.0e	29.0b	31.8ab	32 ab	32.0ab	35.4a
La (KM-ml)	0.0g	0.0g	15.8f	33.0e	40.6d	46.0c	51.6b	85.6a
Pe (KM-Mp)	0.0d	0.0d	41.8c	44.6c	54.0b	56.6b	61.6a	62.6a
La (KM-gml)	0.0f	0.0f	0.0f	21.4e	50.2e	54.0c	58.4b	63.8a
Gr (ku-ngr)	0.0f	0.0f	0.0f	20.4e	31.6d	48.4c	57.4b	90.0a
Gl (KM-Ngc)	0.0f	0.0f	0.0f	20.8e	33.2d	47.4c	56.8b	100a

[1]/Values are followed by the same letter in each row are not significantly different as determined with (P>0.05), [2]/Percentage of growth inhibition = [(A-B)/A] × 100, [3/] *Co* = *Colletotrichum* sp., *Fu* = *Fusarium* sp., *Gl* = *Gliocephalorichum* sp., *Gr* = *Greeneria* sp., *La* = *Lasiodiplodia* sp., *Pe* = *Pestalotiopsis* sp., *Phy* = *Phytophthora* sp., *Rh* = *Rhizoctonia* sp.

Cajeput extract

Crude cajeput extract at 20,000 ppm was completely inhibited (100%) the mycelial growth of *Colletotrichum musae* (ku-bc), *Fusarium* sp. (KM-DFg), *Phytophthora* sp. (KM-Dpt02, KM-Dpt4, KM-Dpt5, ku-Dtpckkl), *Colletotrichum gloeosporiodes* (ku-dc), *Greeneria* sp. (ku-ngr) and *Gliocephalorichum* sp. (KM-Ngc). The concentration at 15,000 ppm was found to be completely inhibited the mycelial growth of *C. musae* (ku-bc), *Fusarium* sp. (KM-DFg), *Phytophthora* sp. (KM-Dpt02, KM-Dpt4), *C. gloeosporioides* (ku-dc) and *Greeneria* sp. (ku-ngr). The concentration at 10,000 ppm was completely inhibited *C. musae* (ku-bc), *Phytophthora* sp. (KM- Dpt4), *C. gloeosporioides* (ku-dc) and *Greeneria* sp. (ku-ngr) (Table 3, Figure 2).

Table 3. Effect of crude ethanolic extract from *Melaleuca cajuputi* on mycelial growth

Tested Isolates	Mycelial inhibition percentage[2/]							
	Control	2% Tween20	500 ppm	1,000 ppm	5,000 ppm	10,000 ppm	15,000 ppm	20,000 ppm
La (ku-bl) [3/]	0.0d[1/]	0.0d	0.0d	0.0d	0.0d	45.2c	69.4b	70.0b
Co (ku-bc)	0.0e	0.0e	20.4d	38.6c	82.0b	100a	100a	100a
Fu (ku-bf)	0.0e	0.0e	23.4d	28.4c	47.0b	58.8a	60.0a	60.0a
Rh (KM-DRH)	0.0d	0.0d	0.0d	0.0d	58.6c	79.4b	82.0a	82.6a
Fu (KM-DFa)	0.0f	0.0f	14.4e	17.8d	56.6c	64.0b	68.6a	71.2a
Fu (KM-DFg)	0.0f	0.0f	35.8e	43.2d	72.2c	79.0b	100a	100a
Ph (KM-Dpt02)	0.0f	0.0f	16.8e	64.8d	68.4c	83.8b	100a	100a
Ph (KM-Dpt4)	0.0d	0.0d	16.4c	21.2c	52.8b	100a	100a	100a
Ph (KM-Dpt5)	0.0f	0.0f	54.4e	58.0d	75.6c	79.0b	79.4b	100a
Ph (ku-Dpttkl)	0.0e	0.0e	52.6d	77.8c	82.0b	82.0b	82.8b	86.0a
Ph (ku-Dptckkl)	0.0e	0.0e	31.0d	77.6c	82.6b	82.6b	83.0b	100a
Ph (ku-trwl)	0.0f	0.0f	45.2e	58.8d	73.6c	78.8b	84.8a	85.4a
Co (ku -dc)	0.0e	0.0e	39.8d	44.8c	86.0b	100a	100a	100a
La (KM-dlt)	0.0e	0.0e	0.0e	0.0e	69.8d	76.0c	78.8b	87.0a
La (KM-ml)	0.0d	0.0d	0.0d	0.0d	52.8c	69.6b	72.8a	75.6a
Pe (KM-Mp)	0.0f	0.0f	16.2e	38.4d	77.6c	85.4b	87.0b	90.0a
La (KM-gml)	0.0d	0.0d	40.8c	40.8c	61.0b	62.4b	73.8a	76.4a
Gr (ku-ngr)	0.0c	0.0c	79.0b	100a	100a	100a	100a	100a
Gl (KM-Ngc)	0.0g	0.0g	28.6f	58e	73.2d	74.8c	83.6b	100a

[1]/Values are followed by the same letter in each row are not significantly different as determined with (P>0.05), [2]/Percentage of growth inhibition = [(A-B)/A] × 100, [3/] *Co = Colletotrichum* sp., *Fu = Fusarium* sp., *Gl = Gliocephalorichum* sp., *Gr = Greeneria* sp., *La = Lasiodiplodia* sp., *Pe = Pestalotiopsis* sp., *Phy = Phytophthora* sp., *Rh = Rhizoctonia* sp.

Cajeput oil

The effectiveness of cajeput oil in inhibiting mycelial growth using the poisoned food technique was evaluated. The results showed that using cajeput oil at concentrations of 5,000 and 10,000 ppm were shown to be effective for inhibiting mycelial growth of all isolates with an inhibition percentage greater than 50%. Cajeput oil at 5,000 ppm was completely inhibited the growth of *L. theobromae* (ku-bl), *C. musae* (ku-bc), *Phytophthora* sp. (KM-Dpt02, KM-Dpt4, ku-Dptckkl, ku-Dpttkl, ku-rwl), *C. gloeosporioides* (ku-dc) and *Greeneria* sp. (ku-ngr) (Table 4, Figure 2).

Effect on reproductive organ

Spore germination

Crude extract from teak was able to inhibit spore germination on the isolates of *Colletotrichum* sp., *Fusarium* sp., *Pestalotiopsis* sp., *Greeneria* sp., *Gliocephalorichum* sp. and *Lasiodiplodia* sp. at concentration of 1,000-25,000 ppm. Spore germinations of *C. musae* (ku-bc), *Fusarium* sp. (KM-DFg) and *Greeeria* sp. (ku.ngr) were completely inhibit since the concentration of 1,000 ppm. However, the other isolates were needed higher concentration to completely inhibition (Table 5**,** Figure 3).

Table 4. Effect of essential oil from *Melaleuca cajuputi* on mycelial growth

Tested Isolates	Mycelial inhibition percentage[2/]						
	Control	2% Tween20	100 ppm	500 ppm	1,000 ppm	5,000 ppm	10,000 ppm
La (ku-bl)[3/]	0.0b[1/]	0.0b	0.0b	0.0b	0.0b	100a	100a
Co (ku-bc)	0.0e	0.0e	23.0d	63.8c	74.0b	100a	100a
Fu (ku-bf)	0.0f	0.0f	16.8e	48d	61.2c	81.2b	100a
Rh (KM-DRH)	0.0f	0.0f	26.8e	33.6d	37.8c	62.4b	77.8a
Fu (KM-DFa)	0.0f	0.0f	11.8e	28.2d	38.8c	75.0b	82.0a
Fu (KM-DFg)	0.0f	0.0f	14.4e	39.0d	51.2c	76.8b	81.0a
Ph (KM-Dpt02)	0.0d	0.0d	2.6cd	7.4c	47.4b	100a	100a
Ph (KM-Dpt4)	0.0e	0.0e	8.0d	27.6c	57.6b	100a	100a
Ph (KM-Dpt5)	0.0e	0.0e	27.4d	31.4cd	35.4c	60.2b	68.8a
Ph (ku-Dptckkl)	0.0d	0.0d	0.0d	10.0c	55.0b	100a	100a
Ph (ku-Dpttkl)	0.0d	0.0d	0.0d	24.0c	58.4b	100a	100a
Ph (ku-rwl)	0.0e	0.0e	18.4d	50.8c	74.6b	100a	100a
Co (ku -dc)	0.0e	0.0e	33.0d	39.0c	58.4b	100a	100a
La (KM-dlt)	0.0c	0.0c	0.0c	0.0c	0.0c	79.8b	100a
La (KM-ml)	0.0e	0.0e	16.6d	19.0d	26.2c	80.6b	100a
Pe (KM-Mp)	0.0e	0.0e	39.6d	41.2d	60.8c	72.2b	81.6a
La (KM-gml)	0.0c	0.0c	0.0c	0.0c	0.0c	59.0b	100a
Gr (ku-ngr)	0.0e	0.0e	37.0d	44.4c	73.2b	100a	100a
Gl (KM-Ngc)	0.0e	0.0e	10.4d	10.4d	20.2c	51.2b	65.6a

[1]/Values are followed by the same letter in each row are not significantly different as determined with (P>0.05), [2]/Percentage of growth inhibition = [(A-B)/A] × 100, [3]/*Co* = *Colletotrichum* sp., *Fu* = *Fusarium* sp., *Gl* = *Gliocephalorichum* sp., *Gr* = *Greeneria* sp., *La* = *Lasiodiplodia* sp., *Pe* = *Pestalotiopsis* sp., *Phy* = *Phytophthora* sp., *Rh* = *Rhizoctonia* sp.

Crude extract from cajeput was tested for its ability to suppress spore germination of the pathogens at concentration range 500-20,000 ppm. The results showed completely inhibited the germination of *Fusarium* sp. (KM-DFg), *C. gloeosporioides* (ku-dc) and *Gliocephalorichum* sp. (KM-Ngc) at the concentration of 500 ppm and the concentration higher than 1,000 ppm which showed 50-100% inhibition on the other isolates such as *Lasiodiplodia theobromae* (ku-bl), *C. musae* (ku-bc), *Fusarium* sp. (KM-DFa) and *Greeneria* sp.(ku-ngr) (Table 5, Figure 3).

Essential oil of cajeput was tested to control spore germination at concentration of 100-10,000 ppm. The results showed that some isolates were sensitive to the substance at the concentration of 100 ppm. The concentration of cajeput oil which higher than 500 ppm gave 50-100% inhibition to many isolates such as *C. musae* (ku-bc), *Fusarium s*p. (ku-bf, KM-DFa, KM-DFg), *C. gloeosporioides* (ku-dc), *Pestalotiopsis* sp. (KM-Mp) and *Gliocephalorichum* sp. (KM-Ngc), including *L. theobromae* (KM-ml) but the crude extracts of teak and cajeput were not inhibited. (Table 5, Figure 3).

Table 5. Effect of plant extracts to inhibit spore germination at 96 hours

Plant extract	concentrations	% inhibition[2/]											
		La[3/] ku-bl	*Co* ku-bc	*Fu* ku-bf	*Fu* KM-DFa	*Fu* KM-DFg	*Co* ku-dc	*La* KM-dlt	*La* KM-ml	*Pe* KM-Mp	*La* KM-gml	*Gr* ku-ngr	*Gl* KM-Ngc
Crude extract *Tectona grandis*	Control	0.0	0.0b[1/]	0.0d	0.0e	0.0b	0.0d	0.0	0.0	0.0e	0.0c	0.0b	0.0d
	2% DMSO	0.0	0.0b	0.0d	0.0e	0.0b	0.0d	0.0	0.0	0.0e	0.0c	0.0b	0.0d
	1,000 ppm	0.0	100a	0.0d	54.5d	100a	71.3c	0.0	0.0	47.4d	0.0c	100a	83.8c
	5,000 ppm	0.0	100a	69.6c	66.7c	100a	84.1b	0.0	0.0	79.8c	0.0c	100a	88.1b
	10,000 ppm	0.0	100a	78.9b	88.1b	100a	100 a	0.0	0.0	84.8bc	0.0c	100a	97.0a
	15,000 ppm	0.0	100a	95.3a	98.3a	100a	100a	0.0	0.0	89.2ab	0.0c	100a	97.1a
	20,000 ppm	0.0	100a	97.5a	100a	100a	100a	0.0	0.0	93.1a	36.8b	100a	100a
	25,000 ppm	0.0	100a	100a	100a	100a	100a	0.0	0.0	94.6 a	62.0a	100a	100a
Crude extract *M. cajuputi*	Control	0.0c	0.0d	0.0	0.0d	0.0 b	0.0b	0.0	0.0	0.0d	0.0	0.0 c	0.0b
	2% Tween 20	0.0c	0.0d	0.0	0.0d	0.0 b	0.0b	0.0	0.0	0.0d	0.0	0.0 c	0.0b
	500 ppm	97.9 b	57.9c	0.0	0.0d	100a	100a	0.0	0.0	0.0d	0.0	0.0 c	100a
	1,000 ppm	98.1b	71.3b	0.0	41.6c	100 a	100a	0.0	0.0	33.6c	0.0	83.8b	100a
	5,000 ppm	100a	100a	0.0	58.9b	100a	100a	0.0	0.0	77.3b	0.0	100a	100a
	10,000 ppm	100a	100a	0.0	65.8b	100a	100a	0.0	0.0	100a	0.0	100a	100a
	15,000 ppm	100a	100a	0.0	100a	100a	100a	0.0	0.0	100a	0.0	100a	100a
	20,000 ppm	100a	100a	0.0	100a	100a	100a	0.0	0.0	100a	0.0	100a	100a
Essential oil *M. cajuputi*	Control	0.0b	0.0d	0.0b	0.0c	0.0e	0.0d	0.0	0.0b	0.0c	0.0c	0.0d	0.0c
	2% Tween 20	0.0b	0.0d	0.0b	0.0c	0.0e	0.0d	0.0	0.0b	0.0c	0.0c	0.0d	0.0c
	100 ppm	0.0b	0.0d	100a	63.2b	52.1d	0.0d	0.0	100a	75.0b	0.0c	0.0d	0.0c
	500 ppm	0.0b	58.6c	100a	66.4b	66.7c	58.6c	0.0	100a	94.5a	0.0c	0.0d	98.8a
	1,000 ppm	0.0b	75.3b	100a	69.6b	81.0b	75.3b	0.0	100a	100a	0.0c	45.3c	100a
	5,000 ppm	0.0b	100a	100a	70.4b	100a	100a	0.0	100a	100a	27.2b	82b	100a
	10,000 ppm	63.8a	100a	100a	100a	100a	100a	0.0	100a	100a	42.9a	100a	100a

[1/]Values are followed by the same letter in each row are not significantly different as determined with (P>0.05), [2/]The percentage of inhibited spore germination was calculated using the following formula: (Gc-Gt)/Gc ×100, The numbers in the formula represent the mean of the spore counts in each treatment (30 spores/replication), [3/]*Co* = *Colletotrichum* sp., *Fu* = *Fusarium* sp., *Gl* = *Gliocephalorichum* sp., *Gr* = *Greeneria* sp., *La* = *Lasiodiplodia* sp., *Pe* = *Pestalotiopsis* sp.,

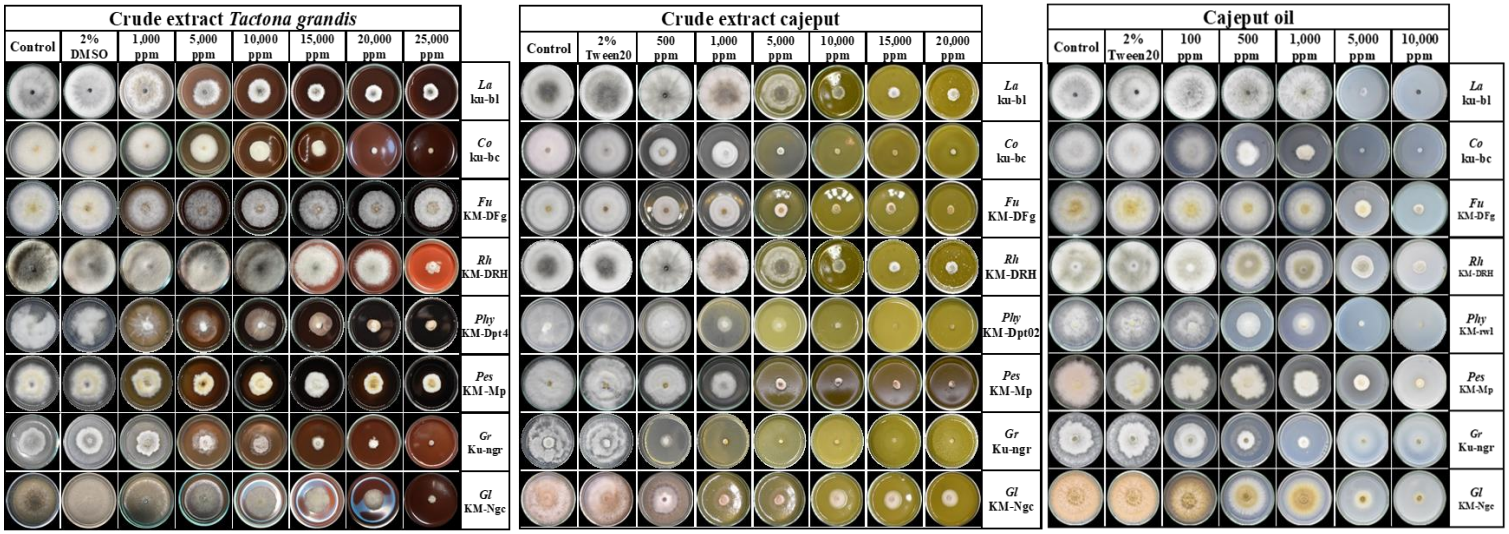

Figure 2. Effects of plant extracts on mycelial growth

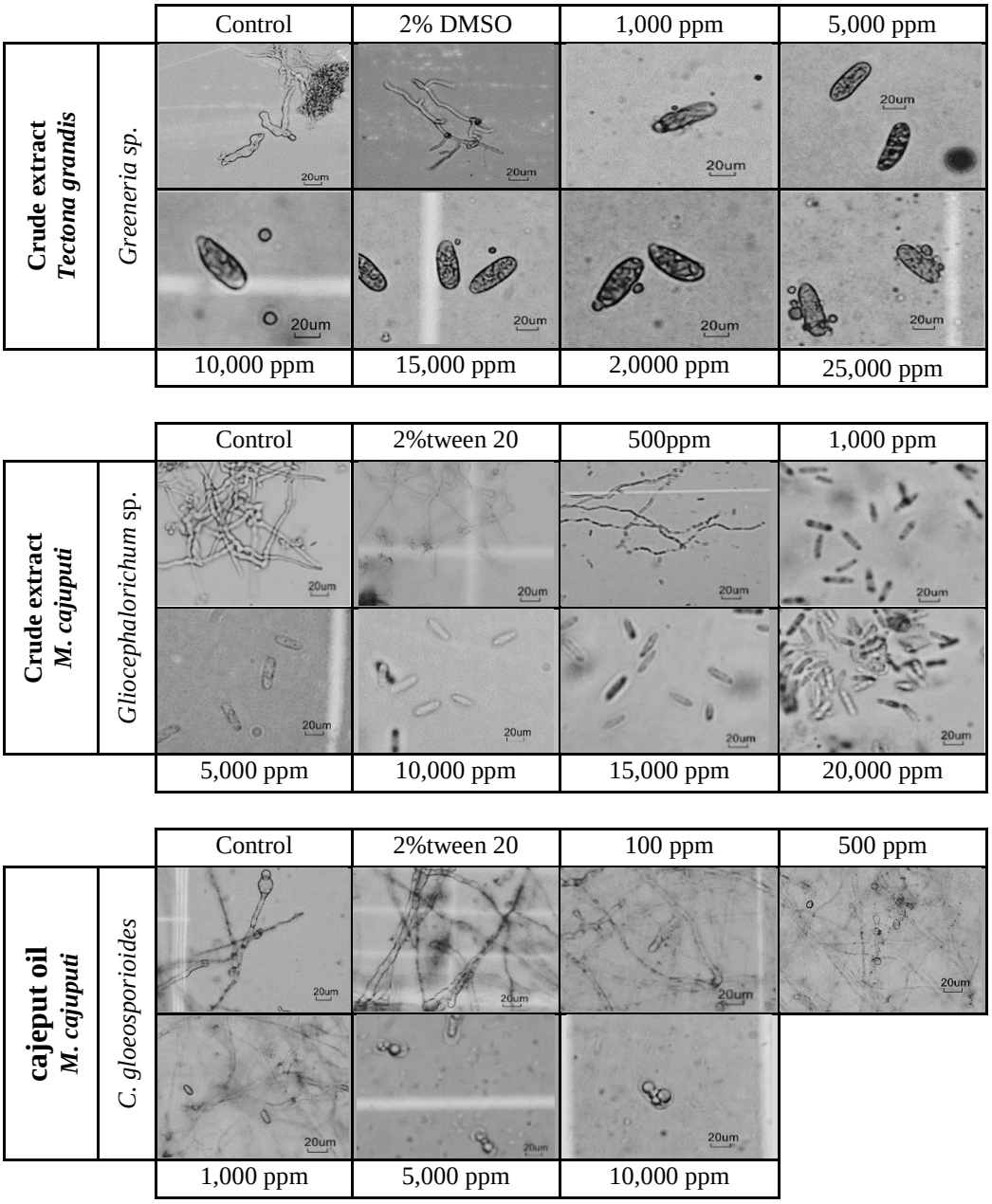

Figure 3. Effect of plant extracts for inhibiting spore germination at 96 hours

Sporulation

The efficacy of different concentrations of plant extracts in inhibiting sporangium formation of *Phytophthora* sp. revealed that all plant extracts could inhibit the sporulation of *Phytophthora* sp. Crude extract of teak could completely inhibit sporangium formation at 5,000-20,000 ppm. Crude cajeput was completely inhibited at concentrations ranging from 1,000 to 5,000 ppm, while cajeput essential oil could inhibit sporangium formation at 500-1,000 ppm (Table 6).

Table 6. Efficacy of plant extracts for inhibiting sporangium formation of *Phytophthora* sp.

Plant extract	% inhibition on sporangia formation						
	concentrations	KM-Dpt02	KM - Dpt4	KM - Dpt5	ku - Dpttkl	ku-rwl	ku-Dptckkl
Crude extract *Tectona grandis*	Control	0.0a[1/]	0.0a	0.0a	0.0a	0.0a	0.0a
	2% DMSO	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	1,000 ppm	0.0a	100b	0.0a	0.0a	100b	43.b
	5,000 ppm	100b	100b	100b	0.0a	100b	70.1c
	10000 ppm	100b	100b	100b	0.0a	100b	100d
	15,000 ppm	100b	100b	100b	0.0a	100b	100d
	20,000 ppm	100b	100b	100b	100b	100b	100d
	25,000 ppm	100b	100b	100b	100b	100b	100d
Crude extract *Melaleuca cajuputi*	Control	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	2% Tween 20	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	500 ppm	0.0a	100b	0.0a	0.0a	100b	39.1b
	1,000 ppm	100b	100b	100b	0.0a	100b	100c
	5,000 ppm	100b	100b	100b	100b	100b	100c
	10,000 ppm	100b	100b	100b	100b	100b	100c
	15,000 ppm	100b	100b	100b	100b	100b	100c
	20,000 ppm	100b	100b	100b	100b	100b	100c
cajeput oil *Melaleuca cajuputi*	Control	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	2% Tween 20	0.0a	0.0a	0.0a	0.0a	0.0a	0.0a
	100 ppm	0.0a	100b	100b	0.0a	100b	16.3b
	500 ppm	100b	100b	100b	0.0a	100b	45.8c
	1,000 ppm	100b	100b	100b	100b	100b	100b
	5,000 ppm	100b	100b	100b	100b	100b	100b
	10,000 ppm	100b	100b	100b	100b	100b	100b

[1/]Values are the mean of three replications. Values in the same column within each plant extract followed by the same letter are not significantly different as determined using Duncan's Multiple Range test (DMRT) at 95% confidence level ($p < 0.05$).

Effective concentrations (EC_{50} EC_{90})

The EC_{50} of teak extract for inhibiting colony growth were ranged from 7,000 to 40,000 ppm. *C. musae* (ku-bc), *Phytophthora* sp. (KM-Dpt4), *L. theobromae* (ku-bl), *Pestalotiopsis* sp. (KM-Mp), *L. theobromae* (KM-ml), *Rhizoctonia* sp. (KM-DRH) and *C. gloeosporioides* (ku-dc) were shown to be sensitive with the EC_{50} for colony inhibition was lower than 15,000 ppm. The extract was highly affected to the spore germination of *C. musae* (ku-bc) which the EC_{50} and EC_{90} were lower than 1,000 ppm (Table 7).

Table 7. Effective concentrations (EC_{50} and EC_{90}) of the ethanolic extract from *Tectona grandis* against plant pathogen

Pathogen	Isolate	Colony inhibition (ppm)		Reproductive organ inhibition[2/] (ppm)	
		EC_{50}[1/]	EC_{90}	EC_{50}	EC_{90}
Colletotrichum musae	ku-bc	7,177	25,040	<1,000[3/]	<1,000
Phytophthora sp.	KM-Dpt4	8,427	27,496	<1,000	<1,000
La. theobromae	ku-bl	8,567	32,777	>25,000	>25,000
Pestalotiopsis sp.	KM-Mp	8,826	45,601	2,505	16,268
Lasiodiplodia sp	KM-gml	9,870	39,736	22,943	28,635
Rhzoctonai sp.	KM-DRH	12,921	27,850	-	-
Co. gloeosporioides	ku-dc	12,259	26,600	562	5,268
Greeneria sp.	ku-ngr	15,637	25,000	>25,000	>25,000
Gliocephalorichum sp.	KM-Ngc	15,842	24,851	<1,000	7,148
La. theobromae	KM-ml	16,709	31,179	>25,000	>25,000
Phytophthora sp.	KM-Dpt5	17,965	33,002	3,101	3,928
Fusarium sp.	ku-bf	20,851	34,177	4,328	10,712
Phytophthora sp.	KM-Dpt02	21,994	22,235	3,101	3,928
Phytophthora sp.	ku-Dptckkl	26,461	42,991	1,235	7,079
Phytophthora sp.	ku-rwl	26,689	41,798	<1,000	<1,000
Fusarium sp.	KM-DFg	27,794	64,808	<1,000	<1,000
Phytophthora sp.	ku-Dpttkl	27,943	38,319	17,438	19,310
La. theobromae	KM-dlt	28,077	55,335	>25,000	>25,000
Fusarium sp.	KM-DFa	44,121	984,707	968	10,201

[1/]Effective concentrations were calculated using SPSS v.28.0, [2/]Spore germination or formation, [3/]The effective concentration was higher or lower than the range of this study

The EC_{50} of cajeput extract for inhibiting colony growth were ranged from 300 to 14,000 ppm. The highly sensitive isolates to the tested extract were *Greeneria* sp. (ku-ngr), *Phytophthora* sp. (KM-Dpt5, ku-Dptckkl, ku-rwl, ku-Dptckkl and KM-Dpt02), *Gliocephalorichum* sp. (KM-Ngc), which the value

was lower than 1,000 ppm. The tested extract was highly effective to inhibit colony growth and spore formation in many isolates of *Phytpohthora* sp. causing durian disease. It is actively demonstrated to suppress spore formation of isolate ku-Dptckkl, ku-rwl and KM-Dpt02 with the EC_{50} was lower than 500 ppm (Table 8).

Table 8. Effective concentrations (EC_{50} and EC_{90}) of the ethanolic extract from *Melaleuca cajuputi* against plant pathogen

Pathogen	Isolate	Colony inhibition (ppm)		Reproductive organ inhibition[2/] (ppm)	
		EC_{50}[1/]	EC_{90}	EC_{50}	EC_{90}
Greeneria sp.	ku-ngr	331	773	870	1,032
Phytophthora sp.	KM-Dpt5	472	19,200	710	898
Phytophthora sp.	ku-Dpttkl	496	23,124	<500[3/]	3,441
Phytophthora sp.	ku-rwl	628	24,246	<500	<500
Phytophthora sp.	ku-Dptckkl	639	18,271	539	721
Gliocephalorichum sp.	KM-Ngc	888	19,077	<500	<500
Phytophthora sp.	KM-Dpt02	876	13,307	<500	<500
C.gloeosporioides	ku-dc	1,397	5,471	<500	<500
Pestalotiopsis sp.	KM-Mp	1,860	20,000	3,098	6,041
C.musae	ku-bc	2,299	5,833	247	1,931
L.theobromae	KM-dlt	2,224	23,169	>20,000	>20,000
Rhzoctonai sp.	KM-DRH	2,938	52,750	-	-
Fusarium sp.	KM-DFg	2,698	10,870	<500	<500
Phytophthora sp.	KM-Dpt4	3,400	8,099	<500	<500
Lasiodiplodia sp.	KM-gml	3,623	29,097	>20,000	>20,000
L. theobromae	KM-ml	3,914	28,664	>20,000	>20,000
Fusarium sp.	KM-DFa	4,019	21,576	3,187	12,362
Fusarium sp.	ku-bf	6,439	30,845	>20,000	>20,000
L. theobromae	ku-bl	13,866	23,480	322	664

[1/]Effective concentrations were calculated using SPSS v.28.0, [2/]Spore germination or formation, [3/]The effective concentration was higher or lower than the range of this study

Cajeput oil was strongly affected to inhibit colony growth of all isolates. The EC_{50} for inhibiting colony growth were ranged from 300 to 5,000 ppm, and the highly sensitive isolates were *C. musae* (ku-bc), *Phytophthora* sp. (ku-rwl), *Fusarium* sp. (ku-bf), *Greeneria* sp. (ku-ngr), *Pestalotiopsis* sp. (KM-Mp), *C. gloeosporioides* (ku-dc) and *Phytophthora* sp. (KM-Dpt4, ku-Dpttkl and ku-Dptckkl) with the EC_{50} values were lower than 1,000 ppm. In addition, the EC_{50} for inhibiting sporulation was lower than 100 ppm on some of the sensitive isolates (Table 9).

Table 9. Effective concentrations (EC_{50} and EC_{90}) of the essential oil from *Melaleuca cajuputi* against plant pathogens

Pathogen	Isolate	Colony inhibition (ppm)		Reproductive organ inhibition[2/] (ppm)	
		EC_{50}[1/]	EC_{90}	EC_{50}	EC_{90}
Colletotrichum musae	ku -bc	311	1,797	302	1,337
Phytophthora sp.	ku-rwl	500	1,199	<100[3/]	<100
Fusarium sp.	ku-bf	579	5,928	<100	<100
Greeneria sp.	ku-ngr	597	1,346	2,914	5,316
Pestalotiopsis sp.	KM-Mp	742	12,518	92	242
C. gloeosporioides	ku -dc	776	1,724	249	1,308
Phytophthora sp.	KM-Dpt4	868	1,495	<100	<100
Phytophthora sp.	ku-Dpttkl	878	1,364	762	953
Phytophthora sp.	ku -Dptckkl	950	1,366	659	831
Fusarium sp.	KM-DFg	1,000	13,162	<100	1,622
Phytophthora sp.	KM-Dpt02	1,043	2,324	312	406
L. theobromae	KM-ml	2,687	5,999	45	57
L. theobromae	ku -bl	2,942	3,592	7,649	16,338
Fusarium sp.	KM-DFa	3,586	10,391	42	7,076
Rhzoctonai sp.	KM-DRH	3,680	13,151	-	-
L. theobromae	KM-dlt	4,281	5,398	>10,000	>10,000
Lasiodiplodia sp.	KM-gml	4,313	6,030	10,545	17,761
Phytophthora sp.	KM-Dpt5	4,561	14,272	<100	<100
Gliocephalorichum sp.	KM-Ngc	4,784	16,095	320	442

[1/]Effective concentrations were calculated using SPSS v.28.0, [2/]Spore germination or formation, [3/]The effective concentration was higher or lower than the range of this study

Discussion

All 19 pathogen isolates including *Colletotrichum musae* (ku-bc), *C. gloeosporioides* (ku-dc), *Fusarium* sp. (ku-bf, KM-DFg, KM-DFa), *Gliocephalorichum* sp. (KM-Ngc), *Greeneria* sp. (ku-ngr), *Lasiodiplodia theobromae* (ku-bl, KM-dlt, KM-ml, KM-gml) *Pestalotiopsis* sp. (KM-Mp), *Phytophthora* sp. (KM-Dpt02, KM-Dpt4, KM-Dpt5, ku-Dptckkl, ku-Dpttkl, ku-rwl) and *Rhizoctonia* sp. (KM-DRH) were morphologically identified, and the pathogenicity tests were confirmed by Koch's postulates.

The highest concentration of teak extract was 25,000 ppm which greatly reduced the mycelial growth of tested fungi including *C. musae*, *Phytophthora* sp., *Greeneria* sp. and *Gliocephalotrichum* sp. at 90-100%, and completely inhibit spore germination of *Fusarium* sp., *Colletotrichum* sp., *Greeneria* sp. and *Gliocephalotrichum* sp. The result revealed that tested extract was able to

inhibit the growth of fugal pathogen with varying levels of sensitivity. The EC_{50} of teak extract for inhibiting colony growth was found to be in the concentration ranged from 7,000 to 40,000 ppm. However, the sensitive isolates were affected at lower than 15,000 ppm, except for *C. musae* (ku-bc), whose spore germination was highly affected by the extract, with the EC_{50} and EC_{90} were lower than 1,000 ppm. The result supported the work of Montri *et al*. (2019) who stated that crude extract of teak could control *C. musae* causing fruit rot disease of banana. Similar results were reported by Astiti and Suprapta (2012), who discovered that teak extract could inhibit fungal growth and sporulation at a low concentration. Additionally, they found that the growth of *Arthrinium phaeospermum* was reduced by 81.4% at the minimum concentration of 0.4% (w/v). Consistent with the findings of Carcamo-Ibarra *et al*. (2022), extracts of teak exhibited antifungal activity against some fungal strains of *Trametes*, *Gloeophyllum*, *Aspergillus*, *Macrophomina*, and *Schizophyllum*, and showed the LC_{50} of 84.9 μg/mL with hexane extract. Sumthong *et al*. (2006) found that quinones derived from teak could rupture fungal cell walls. According to Krishna and Jayakumaran (2010) who stated that teak extract can reduce bacterial growth and cytotoxicity in *Staphylococcus aureus*. These results suggested that secondary metabolites such as alkaloids, flavonoids, tannins, anthraquinones, and napthaquinones expressed antitoxin, antibacterial, and antioxidant activities (Purushotham *et al*., 2010; Murukan and Murugan, 2017). There were some reports indicated that bioactive phenolic compound from teak such as flavonoid, tannin and chlorogenic acid could inhibit bacterial growth by disrupting cell wall and plasma membrane integrity (Dos Santos *et al*., 2018).

According to the study, the highest concentration of ethanolic extract from cajeput at concentration of 20,000 ppm that inhibited mycelial growth by 90-100% which the mycelial growth of 9 fungal isolates such as *C. musae* (ku-bc), *Fusarium* sp. (KM-DFg), *Phytophthora* sp. (KM-Dpt02, KM-Dpt4, KM-Dpt5, ku-Dtpckkl), *C. gloeosporiodes* (ku-dc), *Greeneria* sp. (ku-ngr), and *Gliocephalorichum* sp. (KM-Ngc) were inhibited. Moreover, some isolates were completely inhibited at the concentration of 10,000 and 15,000 ppm. The results also showed that cajeput extract displayed significant inhibitory effects against the growth and sporulation of *Phytophthora* spp. which is a major pathogen of durian rot. The EC_{50} values for inhibiting colony growth were ranged from 300 to 14,000 ppm for *Greeneria* sp., *Phytophthora* sp., and *Gliocephalorichum* sp. which showed the highest sensitivity to the extract. The tested extract suppressed the colony growth and sporulation of *Phytophthora* sp., particularly in isolates ku-Dptckkl, ku-rwl, and KM-Dpt02, where the EC_{50} was below 500 ppm. Similarly, in the study by Somnuek *et al*. (2023) stated

that out of the 20 isolates *P. palmivora* causing durian rot, 9 isolates were found to be sensitive to the cajeput extract. Tiwari *et al*. (2011) reported that the effective concentration was less than 1,000 ppm and observed that certain isolates of *Phytophthora* sp. were sensitive to low dosages. Montri *et al*. (2010) reported the efficacy of crude extract from cajeput against some plant pathogens (*Phytophthora parasitica*, *Pythium deliense*, *Fusarium* sp., and *Colletotrichum* sp.) at a concentration of 800 ppm, which could inhibit *P. parasitica* and *P. deliense* by 100%. Jacquin *et al*. (2022) and Zhu *et al*. (2023) reported that the compounds in plant extracts influence the cell anti-oomycete to activity membranes and walls, which could be related to membrane permeability or a loss of cell wall integrity. These results suggested that crude cajeput extract is shown the potential to act as an antifungal agent against *Phytophthora*. Al-Abd *et al*. (2015) identified flavonoids, terpenoids, phenolic and alkaloids as potential antimicrobial compounds in ethanolic extracts of cajeput using GC/MS analysis. These findings are consistent with the results of Stanković *et al*. (2012) that confirmed the antimicrobial activity of plant extracts, such as phenolic compounds, terpenoids, and alkaloids which attributed to the presence of numerous bioactive secondary metabolites, important components in antimicrobial activity.

Cajeput oil was strongly affected to inhibit colony growth of all isolates at concentration of 10,000 ppm, with an inhibition percentage greater than 50%. Specifically, it was completely inhibited the growth of *Lasiodiplodia* sp., *Colletotrichum* sp., *Phytophthora* sp. and *Greeneria* sp. at 5,000 ppm. The EC_{50} values for inhibiting colony growth were ranged between 300 to 5,000 ppm, with highly sensitive isolates showing values lower than 1,000 ppm. The susceptible isolates were *C. musae* (ku-bc), *Phytophthora* sp. (ku-rwl, KM-Dpt4, ku-Dpttkl and ku-Dptckkl), *Fusarium* sp. (ku-bf), *Greeneria* sp. (ku-ngr), *Pestalotiopsis* sp. (KM-Mp) and *C. gloeosporioides* (ku-dc). Moreover, the EC_{50} values for inhibiting reproductive structures were highly affected at concentration lower than 100 ppm in highly sensitive isolates. Corresponding with this study, the antimicrobial properties of cajeput both extract and essential oil were proved for inhibition the growth of plant pathogenic fungi. Wardana *et al*. (2021) reported that the cajuput extract could inhibit the growth of *Botrytis cinerea* at 0.75% concentration resulting in the lowest spore germination percentage, and consistent with research of Montri *et al.* (2010) who reported the efficacy of the cajeput extract against some plant pathogens. Many reports suggested that cajeput could produce various important phytochemicals: 1,8-cineole, α-terpineol, caryophyllene, α-pinene and γ-terpinene (Quoc, 2021; Abd Wahab *et al*., 2022; Chaudhari *et.al*, 2022; Isah *et al*., 2023) which could damage the cell integrity subject to oxidative stress and decrease the virulence

as well as growth of the fungi and obstruction to the respiration process in the mitochondrial membrane (Abdel-Aziz *et al*., 2019; Chaudhari *et al*., 2022).

The findings of this study suggested that extracts obtained from teak and cajeput possessed the potential antifungal properties due to their abilities to inhibit the growth and reproductive structures of various fruit fungal pathogens. The effectiveness of these extracts varied with depending on the pathogens. The ethanolic extract from teak demonstrated high efficacy against the tested isolate of *C. musae*, whereas cajeput extract displayed growth inhibition properties against several fungal isolates, particularly *Phytophthora* sp., which is the major pathogen of durian. Additionally, cajeput oil was highly effective against the fruit fungal pathogens at minimal concentrations. The essential oils of cajeput contain essential phytochemicals that can damage the cell integrity and decrease the virulence and growth of fungi. Therefore, the extracts of cajeput, either crude or oil gave the potential to be promising substance for controlling the major fruit pathogens. Further research is necessary to explore the potential of these natural extracts and develop to be an alternative source of antifungal agents for plant disease control.

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References

Abd Wahab, N. Z., Ja'afar, N. S. A. and Ismail, S. B. (2022). Evaluation of antibacterial activity of essential oils of *Melaleuca cajuputi* Powell. Journal of Pure and Applied Microbiology, 16:549-557.

Abdel-Aziz, M. M., Emam, T. M. and Elsherbiny, E. A. (2019). Effects of mandarin (Citrus reticulata) peel essential oil as a natural antibiofilm agent against *Aspergillus niger* in onion bulbs. Postharvest Biology and Technology, 156:110959.

Al-Abd, N. M., Mohamed Nor, Z., Mansor, M., Azhar, F., Hasan, M. S. and Kassim, M. (2015). Antioxidant, antibacterial activity, and phytochemical characterization of *Melaleuca cajuputi* extract. BMC complementary and alternative medicine, 15:1-13.

Astiti, N. P. A. and Suprapta, D. N. (2012). Antifungal activity of teak (*Tectona grandis* Lf.) leaf extract against *Arthrinium phaeospermum* (corda) MB Ellis, the cause of wood decay on *Albizia falcataria* (L.) FOSBERG. International Society for Southeast Asian Agricultural Sciences, 18:62-69.

Budianto, P., Suroto, S., Wasita, B. and Mirawati, D. K. (2023). *Tectona grandis* Leaves: Determination of Total Flavonoid Content, Phenolic Content, Characterization of the Leaves, and Compound Identification in GC-MS. Pharmacognosy Journal, 15:165-170.

Carcamo-Ibarra, E., Martínez-Pacheco, M. M., Munro-Rojas, A., Ambriz-Parra, J. E. and Velazquez-Becerra, C. (2022). Antifungal Activity of Crude Extracts of *Tectona grandis* L.f. against Wood Decay Fungi. Phyton, 91:1796-1808.

Chaudhari, A. K., Singh, V. K., Das, S., Kujur, A. and Dubey, N. K. (2022). Unveiling the cellular and molecular mode of action of *Melaleuca cajuputi* Powell. Essential oil against aflatoxigenic strains of *Aspergillus flavus* isolated from stored maize samples. Food Control, 138:109000.

Dhingra, O. D. and Sinclair, J. B. (1994). Basic Plant Pathology Methods, 2nd ed. CRC Press. Baton Rouge, FL, USA.

Dos Santos, J. F. S., Tintinob, S. R., de Freitasb, T. S., Fabia, Campinab, F., de Irwin, A. R. M., Jose, Siqueira-Juniord, P., Henrique, D., Coutinhob, M. and Francisco, A. B. C. (2018). *In vitro* e in silico evaluation of the inhibition of *Staphylococcus aureus* efflux pumps by caffeic and gallic acid. Comparative Immunology, Microbiology, and Infectious Diseases, 57:22-28.

FAOSTAT (2020). Agricultural Production Data. Retrieved from http://www.fao.org/.

Huang, R., Sun, W., Wang, L., Li, Q., Huang, S., Tang, L., Guo, T., Mo, J. and Hsiang, T. (2020). Identification and characterization of *Colletotrichum* species associated with anthracnose disease of banana. Plant Pathology, 70:1827-1837.

Isah, M., Rosdi, R. A., Abdullah, H., Sul'ain, M. D. and Ishak, W. R. W. (2023). Phytoconstituents and biological activities of *Melaleuca cajuputi* Powell: A scoping review. Journal of Applied Pharmaceutical Science, 13:010-023.

Jacquin, J., Moureu, S., Deweer, C., Hakem, A., Paguet, A. S., Bonneau, N. and Rivière, C. (2022). Hop (*Humulus lupulus* L.) specialized metabolites: extraction, purification, characterization in different plant parts and in vitro evaluation of anti-oomycete activities against *Phytophthora infestans*. Agronomy, 12:2826.

Kongtragoul, P., Ishikawa, K. and Ishii, H. (2021). Metalaxyl resistance of *Phytophthora palmivora* causing durian diseases in Thailand. Horticulturae, 7:375.

Krishna, M. S. and Jayakumaran, N. A. (2010). Antibacterial, cytotoxic and antioxidant potential of different extracts from leaf, bark and wood of *Tectona grandis*. International Journal of Pharmaceutical Sciences and Drug Research, 2:155-158.

Lim, T. K. and Chan, L. G. (1986). Fruit Rot of Durian Caused by *Phytophthora palmivora*. PERTANIKA, 9:269-276.

Lin, S., Taylor, N. J. and Hand, F. (2018). Identification and characterization of fungal pathogens causing fruit rot of deciduous holly. Plant Disease, 102:2430-2445.

Lombard, L., Serrato-Diaz, L. M., Cheewangkoon, R., French-Monar, R. D., Decock, C. and Crous, P. W. (2014). Phylogeny and taxonomy of the genus *Gliocephalotrichum*. Persoonia, 32:127-140.

Mulugeta, T., Abreha, K, Tekie, H., Mulatu, B., Yesuf, M., Andreasson, E., Liljeroth, E. and Alexandersson, E. (2019). Phosphite protects against potato and tomato late blight in

tropical climate sand has varying toxicity depending on the *Phytophthora infestans* isolate. Crop Protection, 121:139-146.

Murukan, G and Murugan, K. (2017). Composition of purified anthocyanin isolated from teak and it's *in vitro* antioxidant activity. International journal of pharmacy and pharmaceutical sciences, 9:258-266.

Montri, N., Suwanajan, J. and Pronprapa, K. (2010). Effect of Aqueous extract of *Melaleuca cajuputi* Powell on growth inhibition of some pathogenic fungi. The Journal of Agricultural Science, 41:89-92.

Montri, N., Tongsri, V., Bunya-atichart, K. and Youryon, P. (2019). The effects of aqueous extract from teak leaves (*Tectona grandis* L.f.) on anthracnose disease controlling in Gross Michel banana (Musa AAA group) "Kluai Hom thong"). Final Report. King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon Province.

Prusky, D. N., Alkan, I., Miyara, S., Barad, M., Davidzon, I., Kobiler, S., Brown-Horowitz, A., Lichter, A., Sherman and Fluhr, R. (2010). Mechanisms modulation postharvest pathogen colonization of decaying fruits. In: Prusky, D. and Gullino, M. L. Post-harvest Pathology. Springer Dordrecht Heidelberg London New York, pp. 43-56.

Purushotham, K. G., Arun, P., Jayarani, J. J., Vasnthakumari, R., Sankar, L. and Reddy, B. R. (2010). Synergistic *in vitro* antibacterial activity of *Tectona grandis* leaves with tetracycline. International Journal of Pharmatech Research, 2:519-523.

Quoc, L. P. T. (2021). Physicochemical properties, chemical components, and antibacterial activity of *Melaleuca cajuputi* Powell essential oil leaves from Quang tri province, Vietnam. Bulletin of the Chemical Society of Ethiopia, 35:677-683.

Sangeetha, G., Anandan, A. and Usha Rani, S. (2012). Morphological and molecular characterisation of *Lasiodiplodia theobromae* from various banana cultivars causing crown rot disease in fruits, Archives of Phytopathology and Plant Protection, 45:475-486.

Somnuek, S., Kongtragoul, P. and Jaenaksorn, T. (2023). Fungicide resistance of *Phytophthora palmivora* causing durian diseases in eastern and southern Thailand and the in vitro alternative control by cajeput leaf extracts. International Journal of Agricultural Technology, 19:703-720.

Somnuek, S., Thipmanee, K. and Jaenaksorn, T. (2021). In vitro effect of *Callistemon viminalis* and *Melaleuca cajuputi* ethanolic extracts as botanical fungicide and insecticide. International Journal of Agricultural Technology, 17:2363-2374.

Stanković, M. S., Stefanović, O., Čomić, L., Topuzović, M., Radojević, I. and Solujić, S. (2012). Antimicrobial activity, total phenolic content, and flavonoid concentrations of *Teucrium species*. Central European Journal of Biology, 7:664-671.

Sumthong, P., Damveld, R. A., Choi, Y. H., Arentshorst, M., Ram, A. F., Van Den Hondel, C. A. and Verpoorte, R. (2006). Activity of quinones from teak (*Tectona grandis*) on fungal cell wall stress. Planta Medica, 72:943-944.

Sutrisno, S., Retnosari, R. and Asmaningrum, H. P. (2018). Profile of The Indonesian essential oil from *Melaleuca cajuput*. Proceedings of the Seminar Nasional Kimia - National Seminar on Chemistry. Advances in Engineering Research, 171:14-18.

Tiwari, P., Kumar, B., Kaur, M., Kaur, G. and Kaur, H. (2011). Phytochemical screening and extraction: A review. Internationale Pharmaceutica Sciencia 1: 98-106.

Tongsri, V., Sanosomneng, K., Umrung, S. and Montri, N. (2022). Antagonistic activity of *Candida utilis* SCKU1 yeast against crown rot disease of 'Hom Thong' banana (*Musa acuminata*, AAA group). International Journal of Agricultural Technology, 18:1847-1868.

Vawdrey, L. L., Langdon, P. and Martin, T. (2005). Incidence and pathogenicity of *Phytophthora palmivora* and *Pythium vexans* associated with durian decline in far northern Queensland. Australasian Plant Pathology, 34:127-128.

Wardana, A. A., Tanaka, F. and Tanaka, F. (2021). Inhibition of *Botrytis cinerea* by alginate/cajuput essential oil and the composite's surface properties as potential antifungal coating. Materials Today: Proceedings, 45:5263-5268.

Zhu, Z., Xiong, Z., Zou, W., Shi, Z., Li, S., Zhang, X., Liu, S., Liu, Y., Luo, X., Ren, J., Zhu, Z. and Dong, P. (2023). Anti-oomycete ability of scopolamine against *Phytophthora infestans*, a terrible pathogen of potato late blight. Journal of the Science of Food and Agriculture, 12717.

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