

Application of Mangosteen Peel Fermented Solution, *Trichoderma harzianum*, and Sodium Bicarbonate Mixed with Potassium Permanganate for Fruit Rot Control of Durian cv. ‘Monthong’

Bancha Wiangsamut¹, Titi Thongkamngam^{2*}, Sukritta Anutrakunchai², Maria Evangeline Loyola Wiangsamut³, Natdanai Poonnaprom¹, Phumin Noiyeam¹, Phanuphong Chaaum¹, Lamlest Suksupkit¹ and Rattiya Kasang¹

¹Department of Agricultural Technology, and ²Department of Plant Production Technology and Landscape, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus; ³Department of English Language, Faculty of Social Technology, Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus

Received : Feb 9, 2023

Revised : Mar 18, 2023

Accepted : Apr 12, 2023

Abstract

The study aimed to control fruit rot disease in durian cv. ‘Monthong’ caused by *Lasiodiplodia* sp. The symptomatic parts of the fruit were collected and the fungal pathogen—*Lasiodiplodia* sp.—was isolated using the tissue transplanting technique to obtain a pure culture for further testing. The experimental plan was designed as a completely randomized design (CRD). There were 4 treatments in total: 1) Treatment 1 (T1) was dipping inoculated durian fruit in the 100% concentration of mangosteen peel fermented solution; 2) Treatment 2 (T2) was dipping inoculated durian fruit in *Trichoderma harzianum* in sterilized water, concentration 10⁸ spore/ml.; 3) Treatment 3 (T3) was washing inoculated durian fruit with a 0.3% concentration solution of sodium bicarbonate (NaHCO₃) mixed with potassium permanganate (KMnO₄); and 4) Treatment 4 (T4) was dipping inoculated durian fruit in sterilized water (inoculated control). The results showed that T3 was able to inhibit the growth of *Lasiodiplodia* sp. more than the other treatments. T3 showed 72% growth inhibition as fruit rot symptoms were observed on the 9th day after incubation. Consequently, primary infection after the first exposure to the pathogen was the slowest and durian had the least damage, accounting for 22% of the total fruit production. This level of damage is not considered to be an economic loss for ‘Monthong’ durian production. The damage value was also lower by 56% than that of the inoculated control. Through correlation analysis, high growth inhibition of *Lasiodiplodia* sp. was associated with less fruit damage (r=-1.00). Meanwhile, both T1 and T2 were able to inhibit the growth of *Lasiodiplodia* sp. only with 44% after inoculation, and with 44% fruit damage of the total production. Whereas T4 (control treatment) had the fastest primary infection duration that was detected on day 6 after inoculation and maximum fruit damage equaled to 78%. It can be concluded that by washing fresh fruit of durian cv. ‘Monthong’ after harvest in the 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution (T3) before packing and transporting to a

container pickup truck without air conditioning system could be a better method among others to control and delay fruit rot disease of durian caused by *Lasiodiplodia* sp. This fruit rot control method is also found to be economical and safe for producers, consumers, and the environment.

Keywords: fruit rot, *Lasiodiplodia* sp., ‘Monthong’ durian, potassium permanganate, sodium bicarbonate

*Corresponding author. E-mail : Titi_th@rmutto.ac.th; bancha_wi@rmutto.ac.th

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อควบคุมโรคผลเน่าของทุเรียนหมอนทองซึ่งมีสาเหตุจากเชื้อราลาลิโอดิฟโพเลีย โดยเก็บตัวอย่างโรคจากบริเวณส่วนของผลที่แสดงอาการผลเน่าและคัดแยกเชื้อราลาลิโอดิฟโพเลียด้วยวิธี tissue transplanting technique ให้ได้เชื้อราบริสุทธิ์เพื่อใช้ในการทดสอบต่อไป โดยกำหนดแผนการทดลองแบบ completely randomized design (CRD) จำนวน 4 กรรมวิธี คือ กรรมวิธีที่ 1 จุ่มผลทุเรียนที่ปลูกลงในสารละลายน้ำหมักเปลือกมังคุด 100 เปอร์เซ็นต์ กรรมวิธีที่ 2 จุ่มผลทุเรียนที่ปลูกลงด้วยเชื้อราไตรโคเดอร์มาชนิดน้ำ ความเข้มข้น 10^{10} สปอร์ต่อมิลลิลิตร กรรมวิธีที่ 3 ล้างผลทุเรียนที่ปลูกลงด้วยสารละลายโซเดียมไบคาร์บอเนต (NaHCO_3) ผสมต่างทับทิมโพแทสเซียมเปอร์แมงกาเนต (KMnO_4) ความเข้มข้น 0.3 เปอร์เซ็นต์ และกรรมวิธีที่ 4 (กรรมวิธีควบคุม) จุ่มผลทุเรียนที่ปลูกลงในน้ำสะอาด ผลการศึกษาพบว่า กรรมวิธีที่ 3 สามารถยับยั้งการเจริญเติบโตของเชื้อราลาลิโอดิฟโพเลียได้มากกว่ากรรมวิธีอื่น ๆ โดยมีเปอร์เซ็นต์การยับยั้ง 72 เปอร์เซ็นต์ โดยพบอาการของโรคผลเน่าในวันที่ 9 หลังการปลูกลง ส่งผลให้การติดเชื้อหลังจากการได้รับเชื้อก่อโรคเป็นครั้งแรกช้าที่สุด และผลทุเรียนถูกเข้าทำลายน้อยที่สุดคิดเป็น 22 เปอร์เซ็นต์ ของผลผลิตทั้งหมด ซึ่งความเสียหายในระดับนี้ไม่จัดว่าเป็นความสูญเสียทางเศรษฐกิจของการผลิตทุเรียนพันธุ์หมอนทอง และการเข้าทำลายนี้ยังต่ำกว่าค่าการเข้าทำลายในกรรมวิธีควบคุม 56 เปอร์เซ็นต์ จากการวิเคราะห์สหสัมพันธ์พบว่าหากสามารถยับยั้งการเจริญเติบโตของเชื้อราลาลิโอดิฟโพเลียได้มาก ความเสียหายของผลทุเรียนจะน้อย ($r=-1.00$) ในขณะที่กรรมวิธีที่ 1 และกรรมวิธีที่ 2 สามารถยับยั้งการเจริญเติบโตของเชื้อโรคได้เพียง 44 เปอร์เซ็นต์ เท่านั้น และพบอาการของโรคผลเน่าในวันที่ 8 หลังการปลูกลง ซึ่งค่าความเสียหายของผลทุเรียนนั้นคิดเป็น 44 เปอร์เซ็นต์ ของผลผลิตทั้งหมด ในขณะที่กรรมวิธีที่ 4 (กรรมวิธีควบคุม) พบอาการของโรคผลเน่าเร็วที่สุดในวันที่ 6 หลังการปลูกลง และมีค่าความเสียหายของผลผลิตสูงที่สุดเท่ากับ 78 เปอร์เซ็นต์ สรุปได้ว่ากรรมวิธีที่ 3 คือ การล้างผลทุเรียนสดพันธุ์หมอนทองหลังการเก็บเกี่ยวด้วยสารละลายโซเดียมไบคาร์บอเนตผสมต่างทับทิมความเข้มข้น 0.3 เปอร์เซ็นต์ ทั้งก่อนบรรจุและขนส่งผลทุเรียนในรถกระบะคอนเทนเนอร์ที่ไม่มีระบบปรับอากาศเป็นกรรมวิธีที่สามารถควบคุมและชะลอการเน่าเสียของผลทุเรียนที่เกิดจากเชื้อราลาลิโอดิฟโพเลียได้ดีกว่าวิธีอื่น ๆ ที่ใช้ในการทดสอบ และยังเป็นกรรมวิธีที่ประหยัด และมีความปลอดภัยต่อผู้ผลิต ผู้บริโภค และสิ่งแวดล้อม

คำสำคัญ : โรคผลเน่า; เชื้อราลาลิโอดิฟโพเลีย; ทุเรียนพันธุ์หมอนทอง; ต่างทับทิม; โซเดียมไบคาร์บอเนต

Introduction

Durian (*Durio zibethinus* Murr.) is commonly known as the ‘king of tropical fruits’. It is a large perennial fruit plant and can grow and yield well in humid tropical climates (OAED, 2020). ‘Monthong’ is the most popular durian cultivar in Thailand (Somsri, 2017) due to its ability to grow in every region of the country, and is a

cultivar that has a mild smell and sweetness, delicious taste, and has more antioxidants than other cultivars. Its flesh is fine, dry, and full-bodied creamy, light-yellow color. In addition, 'Monthong' has the taste that is not too sweet (Bangkok Post, 2021; DAT, 2011); has small and aborted seeds (Wiangsamut *et al.*, 2021); and has many bioactive compounds in its fruit flesh that are beneficial to human health (Ketsa *et al.*, 2020). In 2020, there was a total of 132,362 ha of planting area but only 126,586 ha yielded with 1,111,928 tons (8.78 t/ha) of fruits. The fresh fruit for domestic consumption was 435,505 tons while the export volume of fresh durian was 655,362 tons that valued at 1,366.75 million USD. The fruit demand from the international market is still ongoing—especially in China, being the main and largest importer (57.92%) of fresh durian market in Thailand (OAE, 2020). According to the NBACFS (2013), the qualification of 'Monthong' for export must be based on the following requirements: fresh fruit with attached peduncle; hard pulp, tip burn, and wet core must not exceed 5 %; its fruit quality has 3 classes— 1) Extra class: 4 fertile lobes/fruit, 2) Class I: at least 3 fertile lobes and 2 unfertile lobes/fruit, and 3) Class II: At least 2 fertile lobes and 2 unfertile lobes/fruit with good shape; fruit weight is between 1.5-6 kg/fruit; a minimum of 32% dry flesh weight at harvest. And the natural fruit ripening is between 6-9 days after harvest (Wiangsamut & Wiangsamut, 2023). However, exporters are confronted with inevitable problems on crop quality and diseases such as *Lasiodiplodia theobromae* which causes fruit rot on postharvest fruits (Ismail *et al.*, 2012) such as bananas, rambutans, mangosteens, and durians (Chirawut *et al.*, 2015; Sangchote & Pongpisuta, 1995). *Lasiodiplodia theobromae* is the most common fungal disease found in 87% of durians (Theerawongpinyo *et al.*, 2021). This disease infects on the pericarp of the durians; Sangchote *et al.* (1996) reported that surface disinfection could not reduce disease incidence. The symptoms of this disease are very similar to those caused by *P. palmivora*, which resulted to misunderstanding that the symptoms are caused by such infections (Sangchote, 1991). This disease can be found from the immature fruiting stage and during the month before harvest, or at the harvest period. According to the DOA (2020), fruit rot was found during the ripening of durian after it was harvested. Similarly, fruit rots happened during the transportation causing farmers to suffer enormous financial damage and lack of confidence from consumers and buyers especially from importing countries of durian; one main reason why most farmers opted for chemical use in killing said diseases. However, this consequently made the fungus resistant to chemicals (Ferrin & Wadsworth, 1992) preventing future mold removal from being effective. Chemicals also affect the activity of other microorganisms useful in the soil (Kitjaideaw *et al.*, 2000) and a cause of pollution to the environment (Disthaporn, 1997) increasing maintenance cost of durian trees. In addition, the export of fresh Thai durian had some major trading partners, such as China, introduced measures that farmers and exporters must comply to. Farmers are then conformed to the standard of good agricultural practices (GAP) in producing quality durian, that is free from any diseases. For this reason, the researchers aimed to study the methods in controlling fruit rot after harvest, by testing the inoculated durians in treatments with: a) mangosteen peel fermented solution, b) *Trichoderma harzianum* in sterilized water, and c) sodium bicarbonate mixed with potassium permanganate solution. The said products for control solution are locally available which not only makes it easily accessible

for farmers, but can also be self-made. This study could be a guideline to reduce chemical use, as well as promote safe and effective methods for managing the production of durian cv. ‘Monthong’ at postharvest period.

Materials and Methods

Experimental place and experimental design

The experiment was performed at The Royal Project Chanthaburi Fruit Development Center in the subdistrict of Tha Luang, Makhm District, Chanthaburi province, Thailand; in the months of July to August of 2021. The experiment was laid out in a completely randomized design (CRD). The treatments consisted of four control methods of fruit rot on durian cv. ‘Monthong’: dipping in the 100% concentration of mangosteen peel fermented solution (treatment 1 or T1); dipping in *Trichoderma harzianum* in sterilized water (treatment 2 or T2); washing in a 0.3% concentration of sodium bicarbonate (NaHCO₃) mixed with potassium permanganate (KMnO₄) solution (treatment 3 or T3); and dipping in sterilized water as inoculated control or control treatment (treatment 4 or T4). Each treatment had nine replications where there was one durian cv. ‘Monthong’ per replication, totaling of 36 fruits; all fruits were 121 days old after full bloom (anthesis) and fruit weights were between 2.33-2.50 kg/fruit. All of the tested durians cv. ‘Monthong’ were qualified for export according to the National Bureau of Agricultural Commodity and Food Standards in 2013.

Preparation of mangosteen peel fermented solution, Trichoderma harzianum, and sodium bicarbonate mixed with potassium permanganate

A 100% concentration of mangosteen peel fermented solution was prepared by mixing the 10 L of mangosteen peel fermented solution with the 10 ml of surfactant (Apsa-80). *Trichoderma harzianum* in sterilized water was prepared by mixing the 10 L of sterilized water with the 200 g of live culture of *T. harzianum*, (10⁸ spore/ml). This was done by rubbing the spores from the culture medium in sterilized water. When the spores had been completely isolated, they were filtered with a thin white cloth. Then, all the isolated *T. harzianum* in sterilized water was mixed with 10 ml of the surfactant (Apsa-80). Note that *Trichoderma harzianum* was provided by the Department of Agriculture to be used in the study. The 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution was prepared by mixing the 20 g of sodium bicarbonate with 10 g of potassium permanganate and then dissolved in 10 L of sterilized water that mixed with 10 ml of the surfactant (Apsa-80).

Isolation of durian fruit rot pathogen (Lasiodiplodia sp.)

Fruit rot sample of durian was collected—the symptomatic parts infected with *Lasiodiplodia* sp. of the fruit—by observing the wound symptoms as water-soaked lesions on the exocarp which had brown to black color. In addition, gray mycelium of the fungus was found in the wound area and were isolated by tissue

transplanting technique on water agar (WA). The fungi were purified and maintained on potato dextrose agar (PDA) and stored at 4°C on slant PDA. The isolated *Lasiodiplodia* sp. was identified based on microscopic (40x) structures of the fungus.

Durian fruit incubation and treatment test

The conidial suspension at 10^6 spore/ml of the pathogen was prepared. Afterwards, all 36 uninfected durians (except their peduncles) were inoculated by dipping shortly (5 seconds/durian) in the prepared conidial suspension to obtain all the inoculated durians. These were then placed on clean plastic pallets for 14 hours. The inoculated durians were equally divided into 4 groups (9 inoculated durians per group, or per treatment) as follows:

1) First group, nine inoculated durians with their peduncles were dipped shortly in the 100% concentration of mangosteen peel fermented solution (T1) for 10 seconds. Afterwards, they were placed on clean plastic pallets to drain off the solution and then blew them with a fan until the outer pericarp surface of the fruits dried (Figure 1);



Figure 1 Tested durians were placed on clean plastic pallets to drain off the solution then blew with a fan until the outer pericarp surface parts dried before packing

2) Second group, nine inoculated durians with their peduncles were dipped for 10 seconds in the prepared *T. harzianum* in sterilized water (T2). Subsequently, they were placed on clean plastic pallets to drain off the solution until the outer pericarp surface part dried naturally, without blowing. After which, all durians were packed in boxes with dimensions of 25 cm wide × 35 cm long × 20 cm high with holes on the sides for ventilation; 1 durian per tightly-closed box (Figure 2);



Figure 2 Packaging of durians: (a) durians being packed in fruit boxes; (b) packaged durians ready to be transported

3) Third group, nine inoculated durians were washed in the 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution (T3) then gently brush over the solution on the entire durian. After that, they were washed with clean water, placed on clean plastic pallets, blew with a fan until the outer pericarp surface part dried, and then packed in boxes;

4) Fourth group, nine inoculated durians were dipped for 10 seconds in the prepared sterilized water as the control treatment (T4). All 36 tested durians were stored in a closed dark room with a temperature of 26-32°C, similar to a freight (cargo) truck or a container pickup truck without air conditioning (Figure 2a), and then data were gathered.

Data collection

Data such as growth inhibition, fruit damage, fruit ripening duration, and primary infection were gathered every day for 10 days after harvest (or inoculation). Growth inhibition was computed from the fruit damage of inoculated control minus the fruit damage of treatment, multiplied by a hundred, and then divided by the fruit damage of inoculated control and recorded in a unit of percentage. Primary infection duration was counted from the day of fruits inoculated with *Lasiodiplodia* sp. until the day of fruit rot onset (by the appearance of bruise with black spots on the outer pericarp of the fruit); recorded in a unit of days. Fruit damage was computed from a number of infected fruits, multiplied by a hundred, and then divided by the total number of fruits; recorded in a unit of percentage. Fruit ripening duration was determined by counting the number of days from the day of fruit harvest at maturity stage until its ripening stage, when durian started to emit smell on the first day of the ripening; recorded in a unit of days. All gathered data were statistically analyzed using Statistix 8.0 program; Duncan's multiple range test (DMRT) at 0.05 probability levels. The relationship among growth inhibition, primary infection, fruit damage, and fruit ripening duration was done through correlation analysis.

Results

Morphological identification of pathogen on durian fruit rot

After isolating the fungi that cause fruit rot in durian, it was found that in the early stages, the mycelium grew rapidly covering the durian peel in white and then it changed to a grayish-black color (Figures 3a-b). After being classified by morphology, the cause was found to be *Lasiodiplodia* sp. After cultivating the fungi at 7 days on PDA medium (Figures 3c), it was found to produce immature non-septate conidia with no separating walls and no color (blue in conidia is the dyed color) (Figure 3d). Later, they changed into mature conidia, brown-black in color with one septum and rough, irregular edges along the length (Figures 3d).

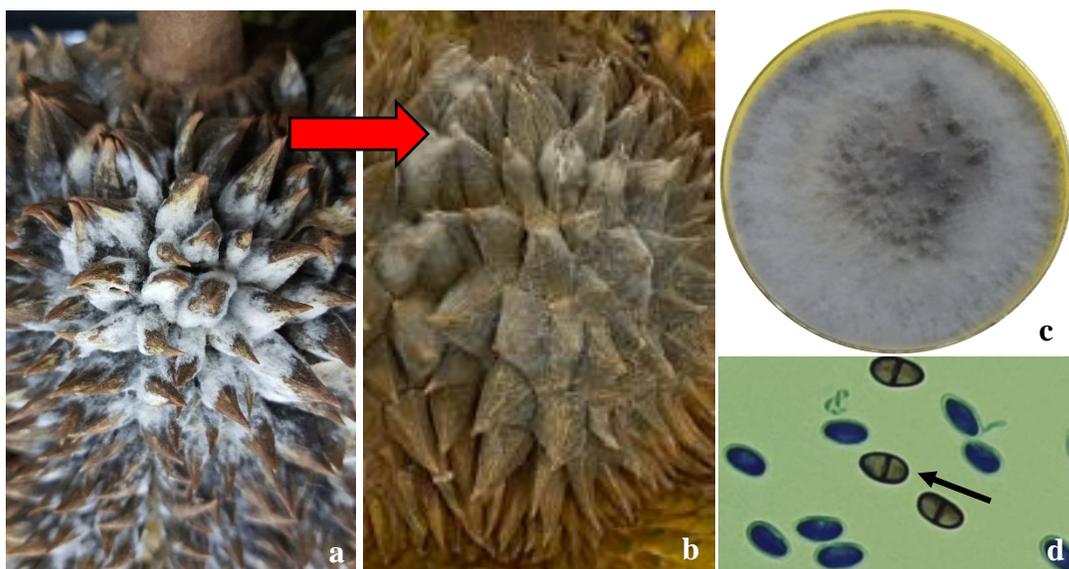


Figure 3 Morphological characteristics of *Lasiodiplodia* sp. recovered from durian fruit rot: (a-b) Mycelium growth covering the surface of the durian peel with a white color and changed dark grey into black color; (c) Colony on PDA at 7 days and; (d) Immature and mature conidia

Growth inhibition, primary infection duration, fruit damage, and fruit ripening duration

The best growth inhibition (72%) was found under T3 (washing in a 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution), as compared with the other treatments—T1 (100% concentration of mangosteen peel fermented solution) (44%), T2 (*T. harzianum* in sterilized water) (44%), and T4 (control treatment) (0%) (Table 1).

The primary infection duration caused by *Lasiodiplodia* sp. was significantly different among the four treatments. The inoculated fruits that were washed in a 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution had the slowest primary infection duration (9 days), followed by the solution of dipping in a 100% mangosteen peel fermented (8 days), dipping in *Trichoderma harzianum* in sterilized

water (8 days), while the inoculated control had significantly the fastest primary infection duration (6 days) (Table 1).

Table 1 Growth inhibition, primary infection duration, fruit damage, and fruit ripening duration

Control method for fruit rot	Growth inhibition (%)	Primary infection duration (days)	Fruit damage (%)	Fruit ripening duration (days)
100% concentration of mangosteen peel fermented solution (T1)	44	8b	44	7
<i>Trichoderma harzianum</i> in sterilized water (T2)	44	8b	44	6
0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution (T3)	72	9a	22	7
Sterilized water or control treatment (T4)	0	6c	78	6
F-test	ns	*	ns	ns

* In the column of treatment means with the different letter is significantly different at 0.05 probability level (DMRT); ns: In the column of treatment means is not significantly different at 0.05 probability level (DMRT)

Meanwhile, the slow primary infection duration was associated with less fruit damage ($r = -0.86$). Fruit damage was found to be the highest at 78% with only the inoculated fruits (control treatment) were washed in a 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution; hence, the lowest fruit damage at 22% (Table 1). The initial symptoms of a durian infected with *Lasiodiplodia* sp. were the appearance of small brown-black lesions on the outer pericarp surface of the fruits. These lesions continuously expanded until hyphae was found on the outer pericarp of the fruit. The hyphae (white in color) turned into black color within 7 days. When halving the fruit, its axis was found to be juicy, watery, foul-smelling, and sour. The lesion later spread progressively as the fruit ripened, and consequently added fruit damage observed at 1, 3, 5, and 7 days after inoculation (Figures 4 and 5). Through correlation analysis, high growth inhibition of *Lasiodiplodia* sp. was associated with less fruit damage ($r = -1.00$). By dipping in the 100% concentration of mangosteen peel fermented solution and in *T. harzianum* in sterilized water, fruits were found to have damages at 44% equally. Fruit ripening duration did not change significantly among the four treatments for fruit rot, ranged from 6-7 days.

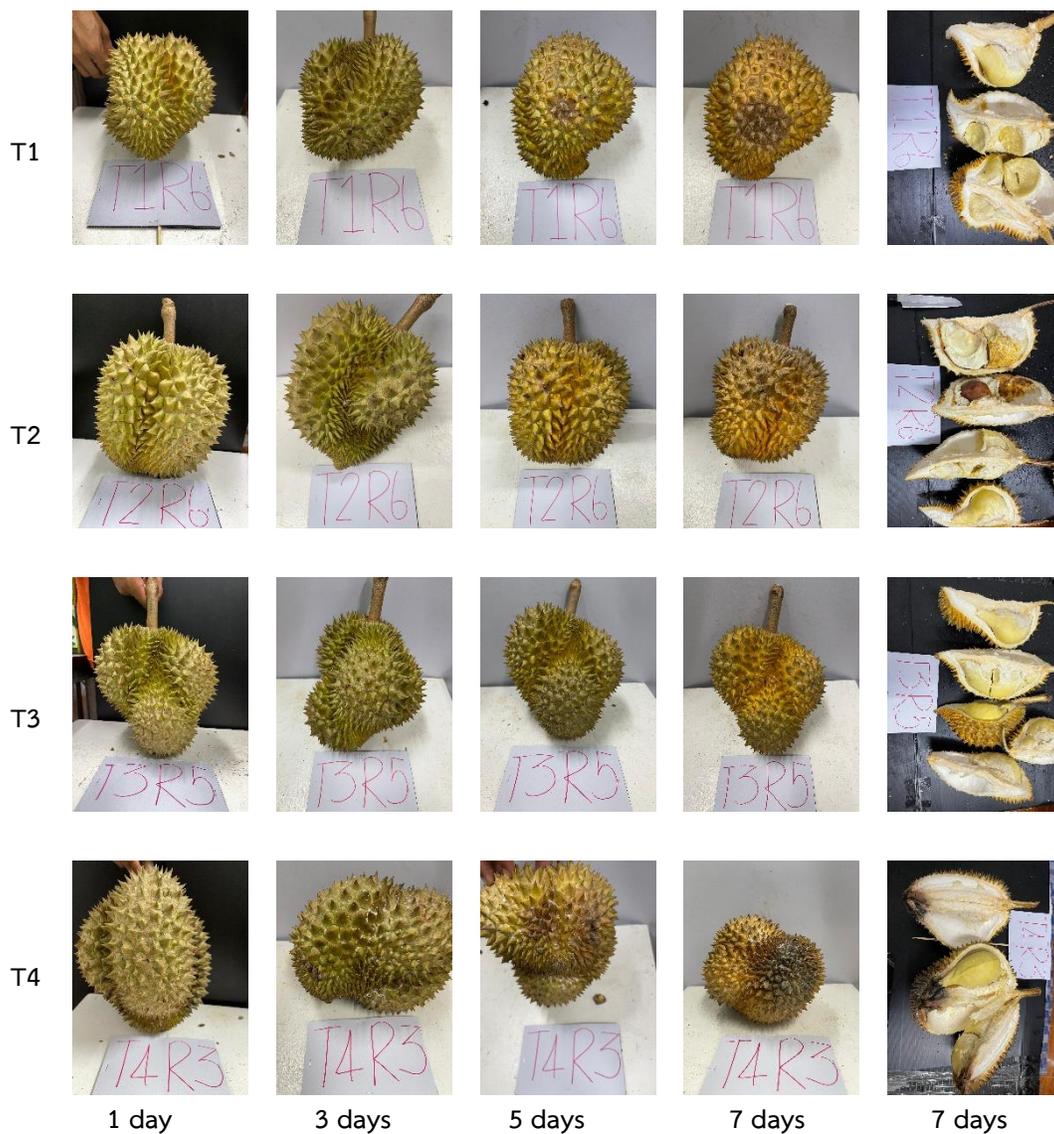


Figure 4 Characteristics of the durian after dipping and washing in each treatment: [T1) dipping in 100% concentration of mangosteen peel fermented solution; T2) dipping in *Trichoderma harzianum* in sterilized water; T3) washing in the 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution, and; T4) control treatment]

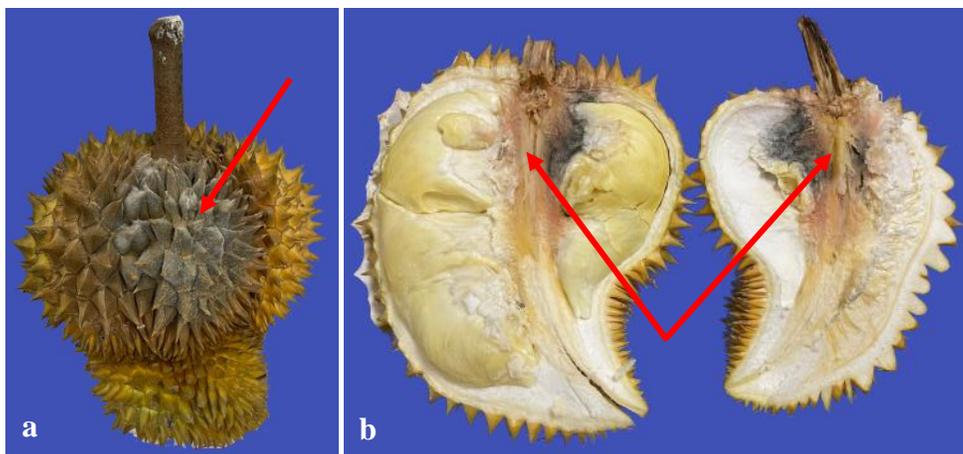


Figure 5 A durian infected with *Lasiodiplodia* sp. at 7 days after inoculation: a) the white and brown bloom in the middle of the lesion is hyphae that have formed on the surface of the lesion, and; b) halved durian, pinkish-white hyphae were found in the middle of the fruit axis

Discussions

By washing the inoculated fruits in a 0.3% sodium bicarbonate mixed with potassium permanganate solution, the maximum growth inhibition of *Lasiodiplodia* sp. for controlling fruit rot on durian cv. 'Monthong' was obtained, as compared with the other treatments (dipping in a 100% concentration of mangosteen peel fermented solution, *Trichoderma harzianum* in sterilized water, and the control treatment). Due to the 0.3% concentration of sodium bicarbonate mixed with the potassium permanganate solution having alkaline property with pH 8.28 that inhibited growth of *Lasiodiplodia* sp., which slowed down the primary infection duration ($r=0.86$). As a result, the inoculated durians had the slowest primary infection duration and the lowest fruit damage compared with the control treatment. Similar to Saha *et al.*, (2008), fungus grow at pH 3.0-8.0 and optimum growth was observed at pH 6.0. Tea root extract supplemented potato dextrose agar medium with pH 6.0 was the most suitable for production of conidia of *L. theobromae* at 28°C. Under complete dark conditions, sporulation was poor and was delayed until 20 days. Mycelial growth had a little variation under different light conditions, but light induced sporulation. Alam *et al.* (2001) likewise suggested that light was not necessary for growth of *L. theobromae* but it enhanced sporulation—*L. theobromae* grew and sporulated at 10-40°C; the optimum being 25-30°C. These temperature ranges were similar to the closed dark room in a container pickup truck without air conditioning, a common practice for domestic transportation of durian in Thailand. Eng *et al.* (2003) correspondingly cited that the growth density of *Botryodiplodia theobromae* was affected at temperatures above 40°C.

Growth inhibition of *Lasiodiplodia* sp. was poor in an acidic solution with pH 4.1 of a 100% concentration of mangosteen peel fermented solution compared with alkaline solution with pH 8.28 of a 0.3% concentration

of sodium bicarbonate mixed with potassium permanganate solution. This result was similar to Jumpeeruang *et al.* (2012) who reported that a 3% concentration of ammonium bicarbonate solution and sodium bicarbonate were alkaline that could inhibit the spore germination of *L. theobromae* by more than 90% in papaya. A 2% concentration of sodium bicarbonate could control well for fruit rot of apple caused by *Botrytis cinerea*. Moreover, Halee & Supavititpatana (2012) recorded that the 0.1% concentration of potassium permanganate solution had 68.69% efficiency for reducing methomyl residue in Chinese kale vegetable.

Trichoderma harzianum in sterilized water enabled the 44% growth inhibition for controlling fruit rot of durian cv. 'Monthong' caused by *Lasiodiplodia* sp. compared with the inoculated control. Rusin *et al.* (2021) also discussed that the use of *T. harzianum* decreased the re-isolation of *L. theobromae* in the grapevines. Kwangtid & Sangchote (2002) also recounted that the application of *T. harzianum* in the form of powder at 2.5 kg/tree together with, and without, rice straw cover on the ground under the durian tree; there was only 25% infected fruit rot found under a tree with powder together with rice straw cover, while it was 75% infection for trees with the powder without rice straw cover. This therefore suggested that *T. harzianum* could control fruit rot well caused by *Phytophthora palmivora*. However, when the inoculated fruits were cured by dipping in *T. harzianum* in sterilized water and in 100% concentration of mangosteen peel fermented solution, there were more fruit damages (44%) and faster primary infection duration (8 days) compared with washing in 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution.

Fruit ripening duration of mature durian cv. 'Monthong' when stored at room temperature (26-32°C) ripened within 4-8 days. OAED (2020) further reported that under room temperature conditions (28-30°C), mature durians ripened within 4-7 days. As the durian ripened, the respiration rate and ethylene (C₂H₄) production increased to peak and then declined. As a result, chemical composition changed, the total soluble solids and the sugar content increased, which made the durian flesh taste sweeter and had a specific smell (Jansanthea *et al.*, 2019). After which, pericarp turned yellow, fruit cracked open, and flesh was soft and soggy that it was impossible to eat; fruits are then more susceptible to fungal invasion and begin to degrade by cell death (Alexander & Grierson, 2002; OAED, 2020).

Through simple cost and return analysis, the production costs/fruit for T1, T2, T3, and T4 and wash cost/fruit for T3 were 4.11, 0.69, 0.97 and 0.62 baht/fruit, respectively. Note that 1 USD is equivalent to 34.09 baht on April 9, 2023. Assuming that there were a hundred durians used to compute for their production costs for each treatment. With these, the production cost of mangosteen peel fermented solution, *Trichoderma harzianum*, sterilized water, NaHCO₃, KMnO₄ and Apsa-80 derived from T1, T2, T3, and T4 were 411, 69, 97, and 62 baht/100 fruits, respectively. Based on the data in Table 1, fruit damages under T1, T2, T3, and T4 were 44, 44, 22, and 78%, respectively. On the other hand, the undamaged fruits under T1, T2, T3, and T4 were 56, 56, 78, and 22%, in that order. These undamaged fruits were qualified for sale to obtain the good selling price in both domestic and international markets The tested durian fruit weights between 2.33-2.50 kg/fruit which was in accordance with the NBACFS (2013). Assuming that the selling price of durian cv. 'Monthong' for both

domestic and international markets was the same at 100 Baht/kg. The returns of production derived from undamaged durians under T1, T2, T3, and T4 were 13,048-14,000 baht/56 fruits, 13,048-14,000 baht/56 fruits, 18,174-19,500 baht/78 fruits, and 5,126-5,500 baht/22 fruits, respectively. The return of production under T3 was higher than both T1 and T2 by about 28.2% and also higher than T4 by about 43.6-71.8%. Based on the cost and return of production abovementioned, T3 had the most possibility in controlling fruit rot disease among durians to be adapted by the durian producers due to its low production cost yet obtained the highest return.

Conclusions

Based on the results, washing the inoculated fruits in a 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution (T3) could contribute to having the 72% maximum growth inhibition that led to the slowest primary infection duration at 9 days for controlling fruit rot on durian cv. 'Monthong' caused by *Lasiodiplodia* sp. Consequently, there was less fruit damage (22%) accounted for 56% lower than the control treatment (inoculated fruits only), which was not characterized as economic loss for 'Monthong' durian production; 35% and above fruit damage was characterized as economic loss. Through correlation analysis, high growth inhibition of *Lasiodiplodia* sp. was associated with less fruit damage ($r=-1.00$). While the inoculated fruits dipped in the 100% concentration of mangosteen peel fermented solution (T1) and in *T. harzianum* in sterilized water (T2), the fungal growth inhibition was 44% with primary infection duration at 8 days and fruit damage of 44%. Whereas the control treatment (T4 or inoculated fruits only) had the fastest primary infection duration (6 days) and maximum fruit damage (78%). Therefore, by washing fresh fruit of durian cv. 'Monthong' after harvest in the 0.3% concentration of sodium bicarbonate mixed with potassium permanganate solution (T3) before packing and transporting to a container pickup truck without air conditioning system could be a better method of controlling and delaying fruit rot caused by *Lasiodiplodia* sp. This fruit rot control method is found to be economical and safe for producers, consumers, and the environment.

Dipping the durians shortly for 10 seconds in the 100% concentration of mangosteen peel fermented solution (T1) or in *Trichoderma harzianum* in sterilized water (T2) or in sterilized water (T4) is better than dipping for a long time. In the case of long-time dipping, there may be an infection around the epicarp (the outermost layer of a pericarp) that may destroy the durian due to the accumulation of moisture on its epicarp causing *Lasiodiplodia* sp. which may then spread quickly. In this study, if durian was dipped for too long in the unsterilized mangosteen peel fermented solution (T1), the other diseases present from the solution may accumulate and infect all dipped durians. Thus, it is necessary to shorten the dipping time of durian to just 10 seconds.

Acknowledgement

The authors would like to thank The Royal Project Chanthaburi Fruit Development Center for allowing the use of experiment station.

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