

Journal of Biotechnology and Tropical Environment
Vol 01 No 01 June 2026
ISSN: XXXX-XXXX (Print) ISSN: XXXX-XXXX (Electronic)
Open Access: https://jbte.uho.ac.id/jbt/index

The Role of Anthocyanins, Alkaloids, and Tannins on Cocoa Plant (*Theobroma cacao* L.) Resistance to *Phytophthora palmivora*

Muzuni[3*], Ernita[1], Sri Ambardini[2], Indrawati[2], Nurhayu Malik[2], Muhsin[2]
[1]Undergraduate Student, Biology Study Program, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kendari, Indonesia
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kendari, Indonesia
[2]Department of Biotechnology, Faculty of Mathematics and Natural Sciences, Halu Oleo University, Kendari, Indonesia
email: muzuni_fmipa@uho.ac.id

Article Info :
Received:
29-01-2026
Revised:
11-03-2026
Accepted:
01-06-2026

ABSTRACT

This study aimed to investigate the role of anthocyanins, alkaloids, and tannins in the resistance of cocoa plants (Theobroma cacao L.) to Phytophthora palmivora. The experiment employed a completely randomized factorial design with two factors: cocoa variety (susceptible PA7 and tolerant UIT1) and treatment type (non-inoculated and inoculated with P. palmivora), with three replications, resulting in twelve treatment combinations. The contents of anthocyanins, alkaloids, and tannins were analyzed using spectrophotometric methods. The results showed that cocoa leaves inoculated with P. palmivora developed necrotic lesions at 7 days after inoculation, with faster lesion development observed in susceptible leaves compared to tolerant leaves. Anthocyanin contents in both susceptible and tolerant cocoa leaves, whether infected or not, did not show significant differences. In contrast, alkaloid contents in both cocoa varieties increased significantly following P. palmivora infection. Tannin content showed no significant difference between infected and non-infected treatments in susceptible cocoa leaves, whereas a significant increase was observed in tolerant cocoa leaves after infection. These findings indicate that alkaloids contribute to the defense response of both susceptible and tolerant cocoa plants, while tannins play a specific and important role in the resistance mechanism of tolerant cocoa plants. Therefore, tannins may serve as a potential biochemical indicator of cocoa plant resistance to P. palmivora infection.

Keywords : Anthocyanins, Alkaloids; Tannins; Cocoa plant; Phytophthora palmivora

©2022 Authors.. This work is licensed under a Creative Commons Attribution-Non Commercial 4.0 International License.
(https://creativecommons.org/licenses/by-nc/4.0/)

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is one of the plantation commodities that plays an important role in the economy and national foreign exchange earnings. Approximately 60% of Indonesia's cocoa plantations are located in Sulawesi, contributing up to 500 million tons to national production. However, despite having a larger cocoa plantation area than South Sulawesi (257.7 thousand hectares compared to 245.8 thousand hectares), cocoa production in Southeast Sulawesi remains relatively low (Badan Pusat Statistik, 2017).

One of the main factors contributing to low cocoa productivity is disease incidence. *Phytophthora palmivora* is a major pathogenic fungus causing several important diseases in cocoa plants, including black pod rot, stem cancer, and leaf blight in cocoa nurseries in Indonesia (Azis et al., 2013). This disease can reduce cocoa yield by up to 44%, with higher incidence in regions with humid climates and during the rainy season (Rubiyo and Amaria, 2013).

Various efforts have been made to reduce losses caused by *P. palmivora*; however, pesticide application remains the most commonly used control method due to its ease of application. Nevertheless, excessive pesticide use may lead to environmental pollution, high production costs, and ecological imbalance (Aminullah et al., 2017).

Therefore, greater attention should be directed toward environmentally friendly disease control strategies. Minimol et al. (2024) stated that the most effective control approach is the use of cocoa genotypes that are tolerant to disease, as this method is environmentally sustainable and provides better adaptability to pathogen pressure.

The resistance mechanisms of tolerant cocoa varieties differ from those of susceptible varieties. According to Kaur et al. (2022), plants possess defense mechanisms against disease that can be classified into structural and biochemical mechanisms. Biochemical defense mechanisms are closely associated with the production of antimicrobial compounds derived from secondary metabolic pathways within plant cells.

Secondary metabolites found in cocoa plants include anthocyanins (Sari et al., 2016), alkaloids (Hasanah et al., 2017), and tannins (Rekhan et al., 2024). These metabolites are suspected to be involved in plant defense responses against pathogen infection. This assumption is supported by the study of Masroatun et al. (2017), which reported that cocoa leaf extracts significantly inhibited the growth of *P. palmivora*, indicating the presence of antifungal compounds. However, the contents of these secondary metabolites in susceptible and tolerant cocoa plants, as well as their changes following *P. palmivora* infection, remain unclear.

Therefore, this study aimed to investigate the role of anthocyanins, alkaloids, and tannins in the resistance of cocoa plants (*Theobroma cacao* L.) to *Phytophthora palmivora*. This research was conducted by observing leaf morphology and determining the content of anthocyanins, alkaloids, and tannins in susceptible and tolerant cocoa plants (*Theobroma cacao* L.), both infected and non-infected with *Phytophthora palmivora*. Understanding the differences in secondary metabolite profiles between the two cocoa varieties is expected to identify metabolites involved in the defense mechanisms of cocoa plants against *P. palmivora* infection.

RESEARCH METHODS

Research Materials

The materials used in this study included three-month-old cocoa seedlings (*Theobroma cacao* L.), *Phytophthora palmivora* isolates, Potato Dextrose Agar medium (Himedia, GM096), distilled water, 25% acetic acid, 10% acetic acid, 70% ethanol, ammonium hydroxide, Folin–Denis reagent, tannic acid, Whatman No. 41 filter paper, aluminum foil, label paper, moist cotton, and transparent adhesive tape.

Experimental Design

The experiment was arranged in a completely randomized design (CRD) with a factorial pattern consisting of two factors. The first factor was cocoa seedling variety, namely susceptible (R) and tolerant (T) varieties. The second factor was treatment type, consisting of non-inoculated (Ti) and inoculated (I) plants. Each treatment was replicated three times, resulting in a total of twelve experimental units (2 × 2 × 3 replications).

Research Procedures

Preparation of Cocoa Seedlings

Cocoa seedlings were obtained from East Kolaka Regency, Southeast Sulawesi, Indonesia. The seedlings used in this study were three-month-old cocoa plants of a susceptible variety (PA7) and a tolerant variety (UIT1) to *P. palmivora*. Prior to inoculation, the seedlings were acclimatized for 14 days in a greenhouse and watered twice daily, in the morning and afternoon.

Selection of Cocoa Leaves

Leaves selected for *P. palmivora* inoculation were the three leaves located below the apical (youngest) leaf. These young leaves were also used as samples for secondary metabolite analysis, including anthocyanins, alkaloids, and tannins.

Preparation of *Phytophthora palmivora* Isolates

Preparation of PDA Medium

A total of 1.95 g of Potato Dextrose Agar (PDA) powder was weighed and dissolved in 50 mL of distilled water by heating and homogenized using a magnetic stirrer (Muzuni et al., 2020). Sterilization PDA media is carried out using an autoclave at a temperature of 121°C with a pressure of 1 atm for 15-20 minutes.

Rejuvenation of *Phytophthora palmivora* Isolates

Approximately one inoculation loop of *P. palmivora* mycelium was aseptically transferred onto PDA medium in a Petri dish and incubated in a dark place at room temperature for seven days.

Inoculation of *Phytophthora palmivora* on Cocoa Leaves

Inoculation was performed by cutting PDA medium containing actively growing mycelium (at the colony margin) into discs with a diameter of 0.6 cm. Prior to inoculation, the leaf surface was wounded by gently scratching the three selected young leaves using a sterile needle. The PDA disc containing *P. palmivora* mycelium was then placed onto the wounded leaf surface, covered with moist cotton, and secured with transparent adhesive tape. The leaves were subsequently wrapped with transparent plastic, with the ends tied using rubber bands (Rubiyo & Amaria, 2013).

The inoculated leaves were incubated at room temperature for seven days, and disease symptoms were observed daily. Infected leaves exhibited yellowing around the inoculation site.

Determination of Secondary Metabolite Contents

Anthocyanin content was determined using a spectrophotometric method at a wavelength of 510 nm and calculated according to the formula described by Suzery et al. (2010). Alkaloid content was determined using the Harborne method (Tochukwu et al., 2023). Tannin content was determined using the Folin–Denis reagent and saturated Na_2CO_3 solution, followed by spectrophotometric analysis at a wavelength of 725 nm (Septiana et al., 2014).

RESULTS AND DISCUSSION

Morphology of Susceptible and Tolerant Cocoa Leaves Infected with *Phytophthora palmivora*

Cocoa seedling leaves inoculated with *P. palmivora* showed disease symptoms beginning at the inoculation site and first appearing at four days after inoculation (DAI). The symptoms observed were the formation of yellowish-brown necrotic lesions surrounding the infected area (Figure 1b–c). Sriwati dan Muarif (2012) reported that *P. palmivora* infection on cocoa seedling leaves resulted in blight symptoms that became visible at seven days after inoculation. The morphology of susceptible and tolerant cocoa leaves infected with *P. palmivora* is shown in Figure 1.

The size of lesions caused by *P. palmivora* infection reflects the degree of tolerance of the cocoa varieties tested. The susceptible variety PA7 exhibited larger lesion areas compared to the tolerant variety UIT1. Although infection of *P. palmivora* on UIT1 leaves also caused yellowish-brown necrotic lesions (Figure 1e), the necrotic spread was relatively slower than that observed in PA7 leaves (Figure 1b). Rubiyo and Amaria (2013) reported that *P. palmivora* is capable of penetrating both susceptible and tolerant cocoa fruits; however, pathogen spread within host tissues differs between the two. In susceptible tissues, necrotic symptoms develop rapidly and pathogen movement between cells occurs quickly, whereas in tolerant tissues, symptom development and pathogen spread are slower. Similar observations were reported by Rubiyo & Amaria (2013), who found that susceptible cocoa variety GC7 exhibited larger lesion diameters than the tolerant variety Sca12 following *P. palmivora* inoculation. These findings suggest that differences in lesion development also occur in cocoa leaves, indicating variation in tolerance between susceptible and tolerant varieties.

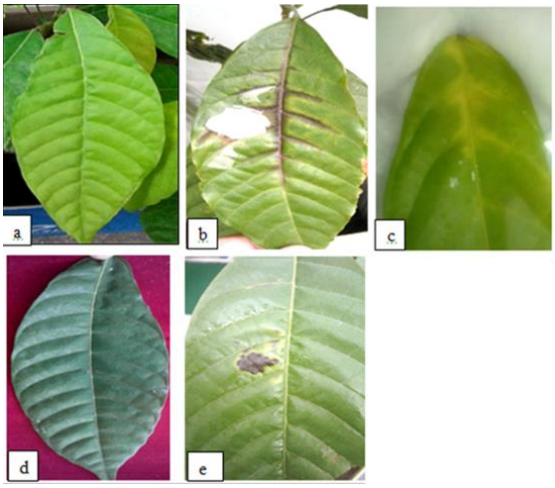

Figure 1. Morphology of Susceptible and Tolerant Cocoa Leaves Infected with *Phytophthora palmivora*.
(a) Morphology of non-inoculated susceptible cocoa leaves (PA7);
(b) Morphology of susceptible cocoa leaves inoculated with *P. palmivora* at 7 days after inoculation (Day After Infection, DAI);
(c) Morphology of cocoa leaves infected with *P. palmivora* at 7 DAI (Sriwati and Muarif, 2012);
(d) Morphology of non-inoculated tolerant cocoa leaves (UIT1);
(e) Morphology of tolerant cocoa leaves inoculated with *P. palmivora* at 7 DAI.

Anthocyanin Content in Susceptible and Tolerant Cocoa Leaves

Based on the data presented in Table 1, the average anthocyanin content of susceptible (PA7) cocoa leaves was higher than that of tolerant (UIT1) leaves, both in non-inoculated and inoculated treatments. However, paired t-test analysis at a 95% confidence level showed no significant difference in anthocyanin content between non-inoculated and inoculated susceptible cocoa leaves (sig. = 0.884 > 0.05). Similarly, anthocyanin content in tolerant cocoa leaves did not differ significantly between non-inoculated and inoculated treatments (sig. = 0.681 > 0.05).

Table 1. **Anthocyanin content of susceptible and tolerant cocoa leaves under non-inoculated and inoculated conditions with *Phytophthora palmivora*.**

Treatment	Mean Anthocyanin Content (%)
Susceptible, non-inoculated (Ti)	0.0253 ± 0.0117
Susceptible, inoculated (I)	0.0242 ± 0.0081
Tolerant, non-inoculated (Ti)	0.0214 ± 0.0042
Tolerant, inoculated (I)	0.0237 ± 0.0051

Statistical significance (t-test, α = 0.05):
– Susceptible (Ti vs I): sig. = 0.884 (not significant)
– Tolerant (Ti vs I): sig. = 0.681 (not significant)
– Non-inoculated (Susceptible vs Tolerant): sig. = 0.403 (not significant)
– Inoculated (Susceptible vs Tolerant): sig. = 0.919 (not significant)

Comparison between varieties also showed no significant difference in anthocyanin content between susceptible and tolerant cocoa leaves, either in non-inoculated (sig. = 0.403 > 0.05) or inoculated treatments (sig. = 0.919 > 0.05). These results indicate that *P. palmivora* infection does not affect anthocyanin biosynthesis in cocoa leaves and suggest that anthocyanins are not involved in the defense mechanisms of either susceptible or tolerant cocoa plants against *P. palmivora* infection.

The lack of significant changes in anthocyanin content may be related to the physiological role of anthocyanins, which are primarily responsible for red, purple, blue, or black pigmentation. Cocoa leaves are predominantly green, indicating low anthocyanin accumulation (Zhao et al. 2025).

Alkaloid Content in Susceptible and Tolerant Cocoa Leaves

As shown in Table 2, the average alkaloid content of cocoa leaves inoculated with *P. palmivora* was higher than that of non-inoculated leaves in both susceptible and tolerant varieties. Paired t-test analysis demonstrated significant differences in alkaloid content between non-inoculated and inoculated treatments for susceptible cocoa leaves (sig. = 0.040 < 0.05) as well as for tolerant cocoa leaves (sig. = 0.028 < 0.05). These results indicate that *P. palmivora* infection stimulates alkaloid biosynthesis in cocoa leaves.

Table 2. Alkaloid Content of Susceptible and Tolerant Cocoa Leaves Under Non-Inoculated and Inoculated Conditions with *Phytophthora palmivora*.

Treatment	Mean Alkaloid Content (g)
Susceptible, non-inoculated (Ti)	0.027 ± 0.004
Susceptible, inoculated (I)	0.039 ± 0.003
Tolerant, non-inoculated (Ti)	0.026 ± 0.001
Tolerant, inoculated (I)	0.035 ± 0.002

Statistical significance (t-test, α = 0.05):
– Susceptible (Ti vs I): sig. = 0.040 (significant)
– Tolerant (Ti vs I): sig. = 0.028 (significant)
– Non-inoculated (Susceptible vs Tolerant): sig. = 0.561 (not significant)
– Inoculated (Susceptible vs Tolerant): sig. = 0.180 (not significant)

Although the average alkaloid content of susceptible cocoa leaves was slightly higher than that of tolerant leaves in both treatments, independent t-test analysis showed no significant difference between varieties, either in non-inoculated (sig. = 0.561 > 0.05) or inoculated leaves (sig. = 0.180 > 0.05). This suggests that both cocoa varieties respond to *P. palmivora* infection by increasing alkaloid production as a general defense response.

Alkaloids are nitrogen-containing organic compounds widely distributed in higher plants and are commonly associated with bitter taste. Edo et al. (2023) reported that bitterness in cocoa leaves is attributed to catechins and alkaloids. Alkaloids have been reported to possess antifungal activity by intercalating into fungal cell walls or DNA, thereby inhibiting DNA replication and fungal growth (Saket et al., 2025). Thus, increased alkaloid biosynthesis may enhance cocoa plant resistance to *P. palmivora* infection.

Tannin Content in Susceptible and Tolerant Cocoa Leaves

Based on Table 3, tannin content in both susceptible and tolerant cocoa leaves increased following *P. palmivora* infection. However, paired t-test analysis revealed no significant difference in tannin content between non-inoculated and inoculated susceptible cocoa leaves (sig. = 0.253 > 0.05). In contrast, tannin content in tolerant cocoa leaves showed a significant increase after infection (sig. = 0.005 < 0.05).

Table 3. Tannin Content of Susceptible and Tolerant Cocoa Leaves Under Non-Inoculated and Inoculated Conditions with *Phytophthora palmivora*.

Treatment	Mean Tannin Content (mg/mL)
Susceptible, non-inoculated (Ti)	2.068 ± 0.101
Susceptible, inoculated (I)	2.161 ± 0.034
Tolerant, non-inoculated (Ti)	2.056 ± 0.033
Tolerant, inoculated (I)	2.349 ± 0.062

Statistical significance (t-test, α = 0.05):
– Susceptible (Ti vs I): sig. = 0.253 (not significant)
– Tolerant (Ti vs I): sig. = 0.005 (significant)
– Non-inoculated (Susceptible vs Tolerant): sig. = 0.722 (not significant)
– Inoculated (Susceptible vs Tolerant): sig. = 0.038 (significant)

Comparison between varieties indicated no significant difference in tannin content between susceptible and tolerant cocoa leaves under non-inoculated conditions (sig. = 0.722 > 0.05). However, a significant difference was observed between varieties following *P. palmivora* infection (sig. = 0.038 < 0.05), with higher tannin content detected in tolerant cocoa leaves. These findings suggest that tolerant cocoa plants respond to *P. palmivora* infection through enhanced tannin biosynthesis, whereas susceptible plants do not exhibit a similar response.

Increased tannin biosynthesis in tolerant cocoa plants indicates that tannins function as chemical inhibitors involved in defense against *P. palmivora*. Iqbal & Poór (2025) reported that tannins are produced by healthy cells and accumulated in tissues surrounding damaged or necrotic cells to restrict pathogen development. Tannins can inactivate adhesins, bind to polysaccharides, inhibit extracellular enzymes and proteins, and directly disrupt fungal cell membranes (Zhu et al., 2019; Kursa et al., 2022; Huang et al., 2024). Damage to fungal cell membranes interferes with enzymatic processes essential for fungal growth, ultimately leading to pathogen death.

The significant increase in tannin content observed exclusively in tolerant cocoa plants suggests that tannins play a key role as secondary metabolites associated with resistance to *P. palmivora* infection. This supports the statement by Mohapatra et al. (2025) that plant defense responses are effective when phytoalexins reach sufficient concentrations to inhibit pathogen development. Urdukhe & Mogle (2025) also reported that phenolic extracts, including tannins, from resistant plants exhibited stronger inhibitory effects on fungal growth compared to extracts from susceptible plants.

CONCLUSION

1. The lesion development in tolerant cocoa leaves progressed more slowly than in susceptible leaves, indicating differences in disease response between the two varieties.
2. Anthocyanin does not play a role in the defense mechanisms of cocoa plants against *P. palmivora* infection.
3. Alkaloids contribute to the defense response of cocoa plants regardless of varietal tolerance.
4. Tannins play an important role in the defense mechanism of tolerant cocoa plants and may serve as a biochemical indicator of cocoa plant resistance to *P. palmivora* infection.

REFERENCES

Aminullah, M. F. S., Panggeso, J., & Rosmini. (2017). Resistance Test of Several Cocoa Clones (*Theobromae cacao* L.) to Fruit Rot Disease (*Phytophthora palmivora* Butl.), *Jurnal Agrotekbis*, **5(4)**: 458-456.

Azis, A.I., Rosmana, A. & Dewi, S.V. (2013). Controlling Phytophthora Leaf Blight Disease in Cocoa Seedlings with *Trichoderma asperellum*, *Jurnal Fitopatologi*,**9(1)**: 15-20

Badan Pusat Statistik (2017) *Indonesian Cocoa Statistics 2017*, Jakarta.

Edo, G.I., Samuel, P.O., Oloni, G.O., Ezekiel, G.O., Onoharigho, F.O., Oghenegueke, O., Nwachukwu, S.C., Rapheal, O.A., Ajokpaoghene, M.O., Okolie, M.C., Ajakaye, R.S., Ndudi, W. & Igbodo, P.C. (2023). Review on the Biological and Bioactive components of Cocoa (Theobroma Cacao). Insight on Food, Health and Nutrition. Natural Resources for Human Health, **3(4)**: 426–448. https://doi.org/10.53365/nrfhh/174302

Hasanah, M., Amaliani, S. & Rikmasari, Y. (2017). Antioxidant Analysis of Various Fractions of Cocoa Leaves (*Theobroma cacao* L.), *Jurnal Ilmiah Bakti Farmasi*, **2(1)**: 33-40

Huang, J., Zaynab, M., Sharif, Y., Khan, J., Al-Yahyai, R., Sadder, M., Ali, M., Alarab, S.R., & Li, S. (2024). Tannins as antimicrobial agents: Understanding toxic effects on pathogens. *Toxicon.* **247**: 107812. https://doi.org/10.1016/j.toxicon.2024.107812.

Iqbal, N., Poór, P. (2025). Plant Protection by Tannins Depends on Defence-Related Phytohormones. *J Plant Growth Regul.* **44**:22–39. https://doi.org/10.1007/s00344-024-11291-1

Kaur, S., Samota, M. K., Choudhary, M., Choudhary, M., Pandey, A. K., Sharma, A., & Thakur, J. (2022). How do plants defend themselves against pathogens-Biochemical mechanisms and genetic interventions. *Physiology and molecular biology of plants : an international journal of functional plant biology*, *28*(2), 485–504. https://doi.org/10.1007/s12298-022-01146-y

Kursa, W., Jamiołkowska, A., Wyrostek, J., & Kowalski, R. (2022). Antifungal Effect of Plant Extracts on the Growth of the Cereal Pathogen *Fusarium* spp.—An In Vitro Study. *Agronomy*, *12*(12), 3204. https://doi.org/10.3390/agronomy12123204

Masro'atun, Sari, D.N.R., & Hasanah, H.U. (2017). Effectiveness of Cocoa Leaf Extract Against *Phytophthora palmivora*, *Jurnal Biologi dan Pembelajaran Biologi*, **2(1)**: 50-57

Muzuni, Haidin, & Yanti, N. A. (2020). Morphological characterization of *Phytophthora* sp. from the cocoa fruit of Olo-oloho Village, Konawe Regency, Southeast Sulawesi. *BioWallacea: J Biolo Res* 7(1):1064-1069. http://dx.doi.org/10.33772/biowallacea.v7i1.11812

Rubiyo & Amaria, W. (2013). Resistance of Cocoa Plants to Pod Rot Diseases (*Phytophthora palmivora* Butl.), *Perspektif*, **12(1)**: 23-36

Septiana, A., Indrawati, & Rustin. (2014). Analysis of Alkaloid and Tannin Content of *Pluchea indica* Less. on Saline Land in Tinaggea District and Non-Saline Land in Lambodijaya Village, Lalembuu District, Southeast Sulawesi, *Jurnal Biowallacea*, **1(2)**: 82-89

Sriwati, R., & Muarif, R. (2012). Characteristic Symptoms of *Phytophthora palmivora* on Cocoa Leaves, *Jurnal Natural*, **12(2)**: 30-35

Manalu, R. (2018). Processing of Smallholder Plantations Cocoa Production to Increase Farmers Income, Pusat Penelitian Perkembangan Ilmu IPTEK (PAPPIPTEK)-LIPI, Jakarta

Minimol, J.S., Suma, B., Mary, A., Shija, T.K., Jose, S., & Plappalli, S.K. (2024). Evaluating black pod resistance in cocoa (Theobroma cacao L.) and its relationship with phenotypical and biochemical characteristics. *Beverage Plant Research* 4: e038 doi: 10.48130/bpr-0024-0028

Mohapatra, S., Rithesh, L., Tiwari, R.K., Behera, L., Lal, M.K., & Kumar, R. (2025). Plant Defense Mechanisms: Innate and Induced Immunity in Plants. CABI Biotechnology Series. doi:10.1079/9781800627659.0015, 221–234p.

Rekhan, M.R., Maryam, S., & Aminah. (2024). Comparıson of Tannın-Compound Levels from Cacao Leaf Ethanol Extract (Theobroma cacao L.) by Place of Growıng. *Pharm Rep*. **3(2)**: 62-67

Saket, A., Choudhary, H., Singh, S., Shukla, A.K., & Srinivasan, T. (2025). Prospective on Alkaloids-based sustainable methods to treat fungal pathogens: a comprehensive review. *Arch Microbiol* **207**: 183. https://doi.org/10.1007/s00203-025-04381-5

Sari, I.A., Sobir, Faizal, I., Susilo, A.W., Adhiwibawa, M.A.S., & Nugroho, R.A.P. (2016). Anthocyanin and Chlorophyll Content in Flush as Selection Markers on Fine Flavor Cocoa (Theobroma cacao L.) *Pelita Perkebunan*, **32(3)**: 171—180

Suzery, M., Lestari, S., & Bambang, C. (2010). Determination of Total Anthocyanin from Roselle Flower Petals (*Hibiscus sabdariffa* L.) Using Maceration and Soxhletation Methods, *Jurnal Sains dan Matematika*, **18(1)**: 1-6

Tochukwu, E.H., Usman, W.A., & Shehu, S. (2023). Determination of Quantitative Phytochemical Composition and Antioxidants Activities of Methanolic Leaf Extract of *Parinari curatellefolia*. IJNRD. **8(11)**: d544-d553.

Urdukhe, Y., & Mogle, U. (2025). Quantitative analysis of phenolic, tannin and flavonoid content and in vitro antifungal activity of wild plant extracts against soil-borne phytopathogenic fungi affecting broccoli. *Current Botany*, **16:** 254–265. https://doi.org/10.25081/cb.2025.v16.9180

Zhao, P., Yang, Z., Tan, Z., Yang, Y., Tian, Z., & Yang, X. (2025). Leaf color as an indicator of the accumulation pattern of pharmaco-nutritional compounds in *Lithocarpus litseifolius* spring foliage. *Front Plant Sci*. **16:1726934**. doi: 10.3389/fpls.2025.1726934.

Zhu, C., Lei, M., Andargie, M., Zeng, J., & Li, J. (2019). Antifungal activity and mechanism of action of tannic acid against Penicillium digitatum. *Physiol. Mol. Plant Pathol.* **107**: 46-50. https://doi.org/10.1016/j.pmpp.2019.04.009.