

Distribution and Phenology of Lampung Black Pepper as Teaching Materials for Plant Growth and Development

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ABSTRACT

Black pepper is historically and culturally important in Lampung, yet information on its introduction route, annual development, and educational use remains fragmented. This study reconstructed the historical diffusion of black pepper in Lampung, described the annual phenology of Natar 1 and Natar 2 vines in relation to climate, and identified its potential as contextual biology teaching material on plant growth and development. Historical information was collected through purposive expert interviews and literature study. Field observations were conducted from July 2011 to August 2012 at Kebun Percobaan Cahaya Negeri, North Lampung, and Kebun Percobaan Negara Ratu Natar, South Lampung. Ten plants of each cultivar were observed at each location, with ten inflorescences marked per plant and checked twice weekly. The synthesis indicates that pepper was introduced from Banten to the Belantung coastal area before spreading northward through Lampung. Productive vines completed a recurring sequence of fruit ripening and drop, leaf fall, vegetative growth, flowering, fruit formation, and berry filling. Flowering began earlier at Kebun Percobaan Cahaya Negeri than at Kebun Percobaan Negara Ratu Natar; the flower-to-fruit interval was consistently 27 days, and Natar 1 reached red-fruit maturity five days earlier than Natar 2. The monthly sequence, climate data, and cultivar comparison can be transformed into teaching material that helps students distinguish vegetative growth indicators from reproductive development and analyze environmental influences on plant phenology. The study provides an integrated historical, biological, and educational resource, although instructional validity and effectiveness require expert review and classroom testing.

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INTRODUCTION

Black pepper (*Piper nigrum* L.) is a perennial climbing vine cultivated for its berries and valued as a food spice, trade commodity, and source of biologically active compounds. Its fruit

development, ripening, piperine formation, and cultivar diversity are increasingly understood through physiological and molecular studies, but field production still depends strongly on the interaction between plant genotype, local climate, soil condition, and crop management (Ashokkumar et al., 2021; Khew et al., 2020a, 2020b; Nair, 2020). Indonesian plantation statistics continue to place pepper among nationally important estate crops, and Lampung remains historically associated with black pepper production and the commercial identity of "Lampung Black Pepper" (Directorate General of Estate Crops, 2026).

Biogeographic and historical accounts associate cultivated black pepper with the Western Ghats of India and with long-distance spice trade across the Indian Ocean. Molecular evidence supports a deep evolutionary history of *Piper* in South and Southeast Asia, while historical sources describe pepper as one of the earliest commodities connecting Asian producers with Middle Eastern and European markets (Nair, 2020; Purseglove, 1968; Sen et al., 2019). The supplied historical records indicate that pepper was probably brought from the Banten region into southern Lampung, initially through the coastal area of Belantung, and then spread toward Kota Agung and northern production zones such as Kotabumi, Bukit Kemuning, and Sukadana. This reconstruction is important because pepper in Lampung is not only an agricultural commodity but also a cultural plant represented in provincial and district symbols and maintained through intergenerational farming practices.

The persistence of pepper cultivation does not eliminate production constraints. The source data describe declining plantation area under the combined pressures of disease, unstable prices, environmental change, and the continued use of production practices that may no longer match present land and climate conditions. Previous work in Lampung has similarly shown that rainfall, light intensity, air humidity, soil properties, and cropping-system structure are associated with pepper growth and productivity (Sanjaya & Pangestika, 2024; Yudiyanto et al., 2014). Local experiments have also sought to improve vegetative growth, flowering, and yield through planting media, beneficial microorganisms, foliar nutrition, and growth regulators, indicating the practical need for better-timed management of the crop cycle (Almahdi et al., 2022; Gusta et al., 2021; Syatrawati et al., 2022).

An ideal management schedule requires knowledge of when mature vines shift from vegetative growth to flowering, fruit set, berry filling, and ripening under a specific local climate. Black pepper needs substantial moisture, but the effects of rainfall are stage-dependent: water availability can stimulate shoot emergence and reproductive transition, whereas prolonged dry

conditions and high temperature may reduce growth and yield (Kandiannan et al., 2011; Krishnamurthy et al., 2011; Negi et al., 2021; Sivaraman et al., 1999). Studies outside Lampung also show that differences in rainfall regime, temperature, and microclimate can alter flowering, fruit development, and yield components among locations and pepper types (Shango et al., 2021). Therefore, a calendar derived from local observations is more useful than a generalized tropical crop calendar.

A research gap remains between studies that emphasize production correlations and the practical description of a complete recurring annual sequence in productive vines. Historical diffusion, cultural persistence, and field phenology are also commonly discussed separately. In this study, the term annual life-history calendar refers operationally to the recurring vegetative and generative stages of mature productive pepper vines within one observation year; it does not refer to the entire ontogeny from germination to plant death. Integrating this calendar with the reconstructed introduction route provides a combined ethnobiological and applied-biological account of black pepper in Lampung. The same dataset also has educational relevance because it presents locally observable evidence of vegetative growth, reproductive development, and environmental influences on plant phenology, but it has not previously been organized explicitly as biology teaching material.

For biology education, an ideal treatment of plant growth and development should connect conceptual distinctions with observable biological evidence. The emergence of new shoots and leaves and the filling of berries can be used as indicators of growth, whereas flowering, fruit formation, ripening, and seasonal transition represent developmental stages. Relating these events to rainfall, humidity, and temperature enables students to analyze how environmental factors accompany changes in plant development. Therefore, the phenological calendar and climate records in this study have the potential to become contextual teaching material rooted in Lampung biodiversity and agricultural culture. This pedagogical use is consistent with calls to strengthen the integration of local potential so that science concepts are understood through real and factual contexts (Carolina et al., 2024).

Accordingly, this study aimed to (1) reconstruct the probable historical introduction and spread of black pepper in Lampung from expert testimony and documentary sources; (2) describe the monthly annual phenology of productive Natar 1 and Natar 2 vines at Kebun Percobaan Cahaya Negeri and Kebun Percobaan Negara Ratu Natar; (3) interpret differences in flowering and fruit development in relation to recorded rainfall, humidity, and temperature; and (4) identify

the potential use of the findings as contextual biology teaching material on plant growth and development. The resulting calendar is expected to support locally timed field management, future multi-year phenological monitoring, and learning activities based on authentic local biological data.

RESEARCH METHODS

This research used a descriptive mixed-source design combining historical reconstruction and field phenological observation. The historical component was conducted in Lampung Province. Information about the introduction and spread of black pepper was collected through purposive interviews with experts selected according to the information required. Informants represented pepper researchers, agricultural technology and spice-crop institutions, the Lampung Provincial Plantation Service, and community leaders. Documentary study was conducted using collections from the Lampung Provincial Agriculture Service library, Lampung Museum, the Lampung Agricultural Technology Assessment institution, and a spice and medicinal plant research institution in Bogor.

The field component was conducted at Kebun Percobaan Cahaya Negeri in Abung Barat District, North Lampung Regency, and at Kebun Percobaan Negara Ratu Natar in Natar District, South Lampung Regency. Observations extended for approximately one annual cycle, from July 2011 to August 2012. At each location, two plots were selected, one planted with Natar 1 and one with Natar 2. Ten productive vines were selected from each cultivar. On every vine, ten inflorescences were marked to record the beginning of flower emergence, initial fruit formation, and yellowing or ripening of the berries. Vegetative development was also recorded. Flower and fruit observations were conducted twice each week.

Monthly rainfall, relative humidity, and air temperature were obtained from climatological stations associated with the experimental locations. Historical interview and documentary data were organized into a chronological narrative of introduction and regional spread. Field observations were aligned by month to produce an annual phenological calendar, and flowering and fruit-development dates were compared descriptively between locations and cultivars. Climate data were summarized in tables and a monthly rainfall graph. For the educational interpretation, the phenological sequence, climate records, and cultivar comparison were mapped descriptively to the concepts of vegetative growth, reproductive development, and environmental factors affecting plant development, together with possible data-interpretation activities. This mapping identifies teaching potential only and does not constitute the development, expert validation, or classroom effectiveness testing of a teaching product.

RESEARCH RESULT

Historical origin and diffusion in Lampung

Historical sources describe black pepper and long pepper as spices used in the ancient Mediterranean world and later as high-value commodities in medieval trade. Botanical accounts place the origin of cultivated black pepper in the Western Ghats-Malabar region of India, with wild relatives also reported from adjacent parts of South and Southeast Asia. The historical reconstruction in the source document proposes that traders introduced pepper to Java between approximately 100 BCE and 600 CE, although the precise first cultivation site in the Indonesian archipelago cannot be confirmed from the available evidence.

Within Indonesia, Banten was identified as an early centre of pepper cultivation. The reconstructed route into Lampung begins in the southern coastal area, especially Belantung near Lampung Bay and the Sunda Strait, at a time when Lampung was politically connected to the Banten Sultanate. From Belantung, cultivation reportedly expanded to neighbouring coastal areas and Kota Agung, then moved northward toward Kotabumi, Bukit Kemuning, Sukadana, and other districts. Local cultivar names containing Belantung or Bulok Belantung were interpreted by informants as traces of this diffusion history.

The spread of pepper eventually produced a broad cultivation footprint across Lampung. Black pepper became closely associated with household economy, local identity, and regional symbols. Nevertheless, informants and documentary sources also described contraction of the crop due to disease, environmental change, uncertain prices, declining soil fertility, and the limited adaptation of inherited cultivation practices to changing farm size and climate conditions.

Annual phenological sequence of productive vines

The observed annual cycle began with harvest-ready yellow berries in July. Unharvested berries became red, dried, blackened, and dropped in August. Leaf fall occurred in September, followed by a predominantly vegetative phase in October and November. New leaves emerged near the end of November, and flower spikes appeared after the onset of the rainy period. Fruit formation began in late December or January, and berry filling continued from February through June before the next yellow-fruit stage in July (Table 1).

Table 1. Annual phenological calendar of productive black pepper vines in Lampung

Month	Dominant phenological event
July 2011	Yellow berries; harvest-ready fruit
August	Berries turn red, dry, blacken, and may drop

Month	Dominant phenological event
September	Older leaves fall; transition to vegetative phase
October	Vegetative shoot and leaf growth
November	Vegetative growth; new leaves and flower spikes begin near month end
December	New leaves and flowering; initial fruit formation begins near month end
January 2012	Fruit formation
February	Berry filling
March	Berry filling
April	Berry filling
May	Berry filling
June	Berry filling
July	Berries yellow and become ready for harvest

Source: Field observations, July 2011–August 2012.

Monthly climate pattern and phenological transition

The climate records show a pronounced rainfall increase at Kebun Percobaan Cahaya Negeri in November 2011, followed by high rainfall in December and January. At Kebun Percobaan Negara Ratu Natar, recorded rainfall remained low in September–October and increased from December through March. Several monthly values were not recorded, particularly at Kebun Percobaan Negara Ratu Natar, so comparisons are descriptive. Air temperature varied within a relatively narrow range, whereas humidity and rainfall showed stronger monthly fluctuation (Table 2).

Table 2. Monthly rainfall, humidity, and temperature at Kebun Percobaan Cahaya Negeri and Kebun Percobaan Negara Ratu Natar

Month	Rainfall (mm)		Humidity (%)		Temperature (°C)	
	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar
Jul 2011	61.6	46.4	NA	87.4	27.6	25.4
Aug	26.3	NA	66.4	NA	27.2	NA
Sep	54.3	2.8	67.7	75.6	28.0	26.4
Oct	24.4	11.6	76.5	76.3	28.1	26.3
Nov	333.5	NA	76.1	NA	27.2	NA
Dec	255.2	77.2	78.6	85.7	26.9	26.2
Jan 2012	305.8	109.2	78.9	89.6	28.0	26.7
Feb	205.7	168.6	75.6	77.0	28.1	27.7
Mar	241.3	192.9	78.8	74.9	27.8	27.9

Month	Rainfall (mm)		Humidity (%)		Temperature (°C)	
	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar	Kebun Percobaan Cahaya Negeri	Kebun Percobaan Negara Ratu Natar
Apr	187.2	174.1	76.7	73.6	27.3	27.6
May	177.0	113.0	NA	84.6	28.8	27.3
Jun	131.0	92.0	85.7	86.9	27.5	26.8
Jul	60.0	NA	84.7	82.0	27.5	26.3

Source: Climatological station records associated with the experimental gardens. NA = not available.

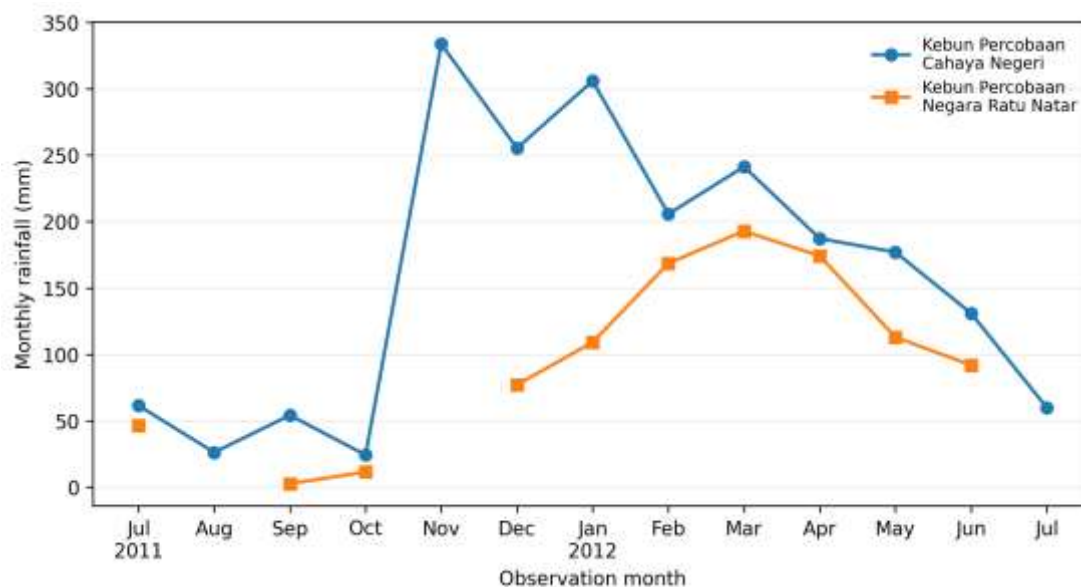


Figure 1. Monthly rainfall at Kebun Percobaan Cahaya Negeri and Kebun Percobaan Negara Ratu Natar

Source: Field climatological records; line gaps indicate months with no recorded value.

At Kebun Percobaan Cahaya Negeri, the sharp rise in rainfall preceded the recorded emergence of flower spikes in late December. At Kebun Percobaan Negara Ratu Natar, flowering was observed in late February, after rainfall had increased during December-February. The temporal difference between sites therefore corresponded with a difference in the timing and magnitude of recorded rainfall, although the observational design does not establish rainfall as the only causal factor.

Flowering, fruit formation, and cultivar differences

Flowering and fruit formation occurred earlier at Kebun Percobaan Cahaya Negeri than at Kebun Percobaan Negara Ratu Natar for both cultivars. Natar 1 flowered one day earlier than Natar 2 at each location. The interval between recorded flowering and fruit formation was 27 days in all four site-cultivar combinations. The time to red-fruit maturity was shorter in Natar 1 than in Natar 2: 140 versus 145 days at Kebun Percobaan Cahaya Negeri and 135 versus 140 days at Kebun Percobaan Negara Ratu Natar (Table 3).

Table 3. Flowering and fruit development of Natar 1 and Natar 2

Location	Cultivar	Flowering date	Fruit formation	Flower-fruit interval (days)	Red fruit (days)
Kebun Percobaan Cahaya Negeri	Natar 1	26 Dec 2011	26 Jan 2012	27	140
Kebun Percobaan Cahaya Negeri	Natar 2	27 Dec 2011	27 Jan 2012	27	145
Kebun Percobaan Negara Ratu Natar	Natar 1	22 Feb 2012	22 Mar 2012	27	135
Kebun Percobaan Negara Ratu Natar	Natar 2	23 Feb 2012	23 Mar 2012	27	140

Source: Field observations.

DISCUSSION

The historical reconstruction places the Lampung pepper tradition within a wider Indian Ocean history of plant movement and spice commerce. The Western Ghats origin described in classical agronomic literature is broadly consistent with modern phylogeographic evidence for the evolutionary diversification of *Piper* across South and Southeast Asia (Nair, 2020; Sen et al., 2019). However, the specific Banten-Belantung-northern Lampung route is based on expert testimony, local cultivar names, and documentary interpretation rather than direct archaeological evidence. It should therefore be treated as a probable regional diffusion pathway, not as a precisely dated introduction event. Its value lies in connecting biological cultivation history with the cultural geography of Lampung.

The annual calendar shows a clear alternation between a relatively short vegetative transition and a longer generative period. Leaf fall in September was followed by shoot and leaf growth in October-November. Flowering appeared after the rainy period began, and fruit filling occupied most of the first half of the following year. This sequence is biologically plausible for a perennial vine in which water availability supports renewed shoot growth, nutrient transport, floral development, and subsequent berry expansion. Classical black pepper agronomy emphasizes the importance of abundant rainfall and warm humid conditions, while later studies demonstrate that rainfall, temperature, humidity, and radiation interact in determining pepper productivity (Kandiannan et al., 2011; Krishnamurthy et al., 2011; Sivaraman et al., 1999; Yudiyanto et al., 2014).

The approximately two-month difference in flowering onset between Kebun Percobaan Cahaya Negeri and Kebun Percobaan Negara Ratu Natar indicates that location was more influential than the small difference between Natar 1 and Natar 2. Kebun Percobaan Cahaya Negeri experienced a strong rainfall pulse in November, whereas the observed increase at Kebun Percobaan Negara Ratu Natar occurred later. Previous studies in Lampung similarly report that microclimate differs among pepper-growing systems and that rainfall and humidity are associated

with plant performance (Sanjaya & Pangestika, 2024; Yudiyanto et al., 2014). The present result extends that observation by converting monthly events into a usable phenological sequence. Nevertheless, unrecorded values and the absence of soil-moisture measurements mean that rainfall onset should be interpreted as a seasonal indicator that co-varied with flowering, not as a single verified trigger.

Cultivar differences were comparatively modest. Natar 1 flowered one day earlier and reached red-fruit maturity five days earlier than Natar 2 at both locations, while the flower-to-fruit interval remained identical. Such consistency suggests a cultivar-related difference in the duration of later fruit development rather than in initial fruit set. Black pepper fruit development is regulated by coordinated hormonal and transcriptional changes, and cultivar-specific developmental profiles have been documented in other germplasm (Khew et al., 2020a, 2020b). The field difference observed here is small but agronomically relevant because a five-day shift may affect harvest coordination, labour planning, and exposure of mature berries to rainfall or fruit drop.

The calendar has practical implications for crop management. Vegetative-support practices, such as nutrient application, soil moisture conservation, and management of beneficial microorganisms, could be scheduled before or during the October-November vegetative phase, whereas monitoring of flower spikes and reproductive stress should intensify after the first sustained rains. Local studies show that growth regulators, foliar fertilizer, planting media, and microbial inoculants can influence vegetative growth, flower number, fruit number, or berry weight under specific experimental conditions (Almahdi et al., 2022; Gusta et al., 2021; Syatrawati et al., 2022). The present study did not test these interventions, so the calendar should guide the timing of future trials rather than be interpreted as direct evidence for a particular treatment.

Beyond its agronomic use, the phenological calendar has direct potential as contextual biology teaching material for the topic of plant growth and development. The sequence of leaf fall, emergence of new leaves, flowering, fruit formation, berry filling, ripening, and fruit drop provides a continuous example from a perennial plant rather than an isolated textbook illustration. Students can use the sequence to distinguish observable growth indicators, such as the emergence of vegetative organs and berry enlargement, from developmental transitions, such as the shift from vegetative to reproductive phases, flowering, fruit set, and maturation. Because the observations were made on a crop closely associated with Lampung, the material can also connect biological concepts with local biodiversity, agriculture, history, and culture. Using black pepper as a local case

therefore responds to the need to integrate local potential more explicitly into science learning (Carolina et al., 2024).

The data presentation in this article offers several components that can be adapted for learning. Table 1 can be converted into a phenological timeline or sequencing task; Table 2 and Figure 1 can support graph-reading and evidence-based discussion of relationships between rainfall and the timing of flowering; and Table 3 can be used to compare the effects of location and cultivar on reproductive development. Teachers may develop these components into a handout, student worksheet, digital module, inquiry activity, or field-observation project. Guiding questions may ask students to identify vegetative and generative stages, explain why flowering occurred at different times between locations, distinguish correlation from causation, and propose observations needed to test the role of rainfall more rigorously.

The educational implication should nevertheless be stated cautiously. This research generated biological and climatic data, not a validated instructional product, and it did not measure student learning outcomes. Before formal classroom use, the material should be aligned with the relevant learning outcomes and learner level, reviewed by plant-biology and biology-education experts, adapted for readability and visual clarity, and tested through limited and broader classroom trials. Thus, the present findings provide scientifically grounded source material and a framework for teaching-material development, while claims about practicality and effectiveness require subsequent educational research.

The findings are also relevant under increasing rainfall irregularity. Black pepper exhibits physiological and molecular responses to drought, and prolonged water limitation can alter growth, reproductive development, and yield (Negi et al., 2021). A fixed calendar based on one observation year may therefore become unreliable when the onset of rain shifts. Annual monitoring of rainfall, soil moisture, new-leaf emergence, and flower-spike appearance would allow farmers and extension services to update management timing dynamically. Multi-year observations across additional elevations and soil types are needed to distinguish stable cultivar traits from plastic responses to local weather.

In the Islamic environmental perspective represented in the source document, the dependence of plant growth on rainfall resonates with Qur'anic descriptions of rain as a means through which diverse plants and fruits grow (Qur'an 16:10-11; 20:53; 50:9). Read alongside the biological observations, this perspective can strengthen an ethic of water stewardship, soil care, and reflective use of natural resources. The theological interpretation complements but does not

replace the ecological explanation based on water availability, microclimate, and plant physiology (Ministry of Religious Affairs of the Republic of Indonesia, 2019).

This study has five main limitations. First, historical conclusions depend on purposively selected informants and available documents. Second, phenology was observed for only one annual cycle at two locations. Third, several climate values were missing and no continuous soil-moisture or light-intensity series was available. Fourth, the descriptive design cannot separate rainfall effects from correlated changes in humidity, temperature, soil condition, plant age, or management. Fifth, the proposed educational use was derived through conceptual mapping and has not been subjected to expert validation, readability assessment, or classroom testing. Despite these limitations, the integration of historical diffusion, a month-by-month field calendar, and an explicit educational interpretation provides a coherent baseline for further ethnobiological, phenological, and biology-education research in Lampung.

CONCLUSION

Black pepper in Lampung was reconstructed as an introduced crop that probably entered through the Banten-Belantung coastal connection and subsequently spread toward central and northern Lampung, where it became embedded in regional agriculture and culture. Productive Natar 1 and Natar 2 vines followed a recurring annual sequence consisting of yellow-fruit harvest in July, red-to-black fruit and fruit drop in August, leaf fall in September, vegetative growth in October-November, flowering after the onset of rain in late November-December or later depending on location, fruit formation about 27 days after flowering, and berry filling from February to June. Flowering occurred earlier at Kebun Percobaan Cahaya Negeri than at Kebun Percobaan Negara Ratu Natar, while Natar 1 reached red-fruit maturity five days earlier than Natar 2. The main contribution of this study is an integrated historical and location-specific phenological calendar that can support adaptive pepper management and serve as contextual biology teaching material on plant growth and development. The monthly stages, climate records, graph, and cultivar comparison can help students examine vegetative growth, reproductive development, and environmental influences using authentic local data. Before formal classroom implementation, however, the material should be adapted to learning outcomes, validated by relevant experts, and tested for readability, practicality, and learning effectiveness.

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CONFLICTS OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this paper.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Credit: Yudiyanto: Conceptualization, methodology, formal analysis, investigation, data curation, visualization, supervision, project administration, writing - original draft, and writing - review & editing.

DECLARATION OF THE USE OF AI

During the preparation of this manuscript, the author used OpenAI's ChatGPT (GPT-5, accessed August 2025) to assist with manuscript structuring, language alignment, and reduction of typographical errors. The author reviewed, verified, and edited the output and takes full responsibility for the scientific content and final publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, Yudiyanto, upon reasonable request.

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