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Research Article

Stomatal Density of Jackfruit (*Artocarpus heterophyllus Lamk*.) Leaves as a Bioindicator of Urban Air Quality in Bandar Lampung

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Abstract

Urban air pollution is a growing environmental concern, particularly in rapidly developing cities where vehicular emissions contribute significantly to deteriorating air quality. This study investigates the correlation between stomatal density in jackfruit (Artocarpus heterophyllus Lamk.) leaves and air quality in Bandar Lampung, focusing on two high-traffic urban locations: Sultan Agung Street and Pangeran Emir M Noer Street. Using a quantitative approach, leaf samples were collected through purposive sampling and analyzed for stomatal density using light microscopy (400× magnification). Concurrently, air quality was measured by assessing carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter (PM10 and PM2.5) concentrations, which were compared against National Ambient Air Quality Standards (PP No. 41 of 1999). The results indicate a positive correlation between traffic intensity and stomatal density, suggesting that jackfruit trees increase stomatal density as an adaptive response to vehicular pollution. However, while enhanced stomatal density may improve CO_2 uptake for photosynthesis, excessive stomatal opening could lead to higher pollutant absorption, necessitating stomatal closure mechanisms during peak pollution periods. The findings confirm that jackfruit trees can serve as effective bioindicators for urban air pollution monitoring, given their physiological adaptability and widespread distribution in tropical urban settings. This research underscores the potential of plant-based bioindicators in sustainable air quality assessment and urban environmental management strategies.

Keywoards: Stomatal density, bioindicator, air pollution, vehicular emissions, urban environment.

INTRODUCTION

Urban air pollution has become a major environmental issue worldwide, particularly in rapidly developing cities. Vehicular emissions [1], industrial activities[2], and urban expansion [3] significantly contribute to the decline in air quality, leading to adverse effects on human health and the environment [2], [4], [5], [6], [7], [8]. Among various approaches to monitor air pollution, biological indicators such as plants have gained increasing attention due to their ability to provide real-time environmental feedback. The stomatal density of plant leaves is one of the key physiological traits that can be influenced by air pollutants, making it a reliable bioindicator of air quality [9], [10], [11]. The role of *Artocarpus heterophyllus Lamk.* (jackfruit) as a bioindicator remains underexplored despite its wide distribution in urban landscapes. Jackfruit trees are frequently planted along roadsides due to their large, broad leaves and high dust retention capacity, making them a suitable candidate for air quality monitoring. That stomatal damage is more prevalent in plants exposed to higher pollution levels, emphasizing the importance of anatomical and physiological adaptations in response to urban environmental stress [12].

In Bandar Lampung, an emerging urban center in Indonesia, the increasing number of vehicles contributes to heightened air pollution levels, particularly in areas with dense traffic. Preliminary studies indicate that pollutant concentrations, such as carbon monoxide (CO) and nitrogen oxides (NOx), remain within national ambient air quality standards, yet their potential effects on urban vegetation require further investigation. The present study aims to assess the correlation between stomatal density in jackfruit leaves and air quality in two key urban locations—Sultan Agung Street and Pangeran Emir M Noer Street. By integrating plant-based bioindicators with air pollution analysis, this research seeks to provide an alternative approach for urban environmental monitoring while contributing to the growing body of knowledge on plant physiological responses to air pollutants.

Through this study, we hypothesize that higher stomatal density in jackfruit leaves is associated with increased exposure to vehicular emissions and that variations in stomatal characteristics can serve as an effective tool for air quality assessment. The findings from this research are expected to enhance our understanding of plant-based bioindicators, support sustainable urban planning, and offer insights into the role of urban greening in mitigating air pollution effects.

METHODS

This study employs a quantitative approach using laboratory experiments and field observations. The research aims to analyze the correlation between stomatal density in jackfruit leaves (*Artocarpus heterophyllus Lamk.)* and air quality in Bandar Lampung, focusing on two main locations: Sultan Agung Street and Pangeran Emir M Noer Street.

The population in this study consists of jackfruit leaves (*Artocarpus heterophyllus Lamk*.) growing naturally along the two research locations. The samples were selected using purposive sampling, with the following criteria:

- The leaves must be in healthy condition and free from mechanical damage.
- The jackfruit trees must be located within approximately 10 meters from the roadside.
- Three different sampling points were selected in each location to ensure data accuracy.

1. Data Collection Techniques
   - The collected leaves from each location were analyzed using the epidermal impression method to identify stomata under a microscope.
   - Samples were observed under a 400× magnification light microscope.
   - Stomatal density was calculated using the formula number of stomata per unit area (mm^2).
     - Air Quality Measurement
   - Air quality data at the research sites were obtained through direct measurement using an
   - The measured air quality parameters included:
     - Carbon Monoxide (CO) concentration
     - Nitrogen Oxide (NOx) concentration
     - Particulate Matter (PM10 and PM2.5)
   - The results were compared against the National Ambient Air Quality Standards (PP No. 41 of 1999).

2. Data Analysis Techniques
   - Stomatal density data from each location were tested for normality to ensure data distribution validity.
   - Pearson Correlation Test was conducted to determine the relationship between stomatal density and pollutant concentration.
   - The results were presented in scatter plots and linear regression graphs to illustrate the relationship patterns between variables.
   - Pollutant data were analyzed according to national standards (National Ambient Air Quality Standards – PP No. 41 of 1999).
   - The results were compared across research locations to determine the level of air pollution.

RESULT AND DISCUSSIONS

The research results indicate that the stomatal density of jackfruit leaves (*Artocarpus heterophyllus* Lamk.) varies across the two study locations, Sultan Agung Street and Pangeran Emir M Noer Street, which have different traffic intensities. The data is presented in Table 1 :

Table 1. Stomatal Density

Location	Location 1 (stomata/mm^2)	Location 2 (stomata/mm^2)	Location 3 (stomata/mm^2)	Average (stomata/mm^2)
Sultan Agung	261.57	371.61	193.62	275.06
Pangeran Emir M Noer	304.03	385.52	180.03	289.886

1. Description:
2. Low density (<300 stomata/mm^2)
3. Moderate density (300–500 stomata/mm^2)
4. High density (>500 stomata/mm^2)

Based on the observations conducted, the stomatal density and leaf condition of jackfruit (*Artocarpus heterophyllus* Lamk.) in Sultan Agung are presented in Figures 1 to 6 as follows.

Location 1 in Sultan Agung

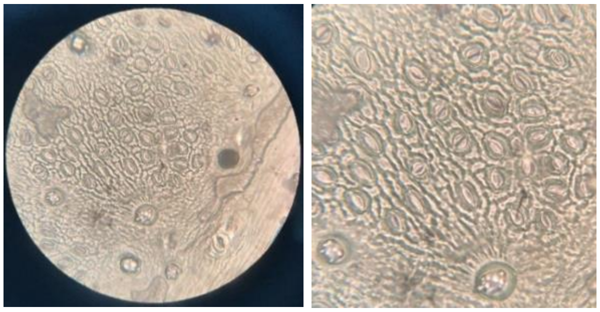

Figure 1. Stomatal density of jackfruit leaves

Figure 2. Condition of jackfruit leaves

Location 2 in Sultan Agung

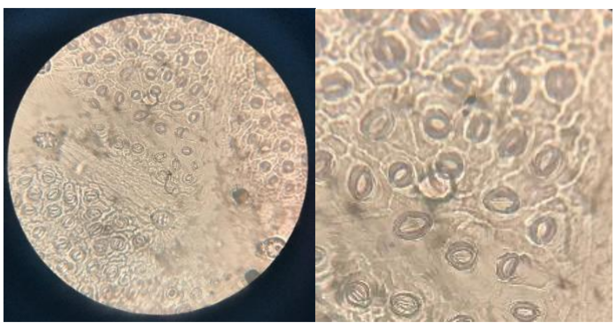

Figure 3. Stomatal density of jackfruit leaves

Figure 4. Condition of jackfruit leaves

Location 3 in Sultan Agung

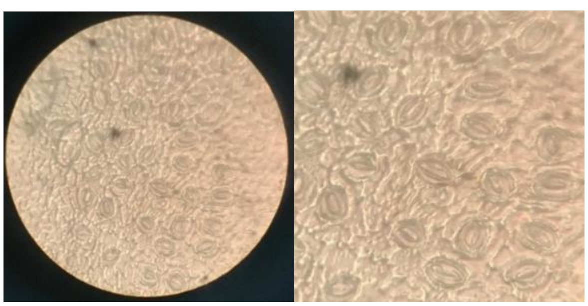

Figure 5. Stomatal density of jackfruit leaves

Figure 6. Condition of jackfruit leaves

Based on the observations conducted, the stomatal density and leaf condition of jackfruit (*Artocarpus heterophyllus* Lamk.) in Pangeran Emir M Noer are presented in Figures 7 to 12 as follows.

Location 1 Pangeran Emir M Noer

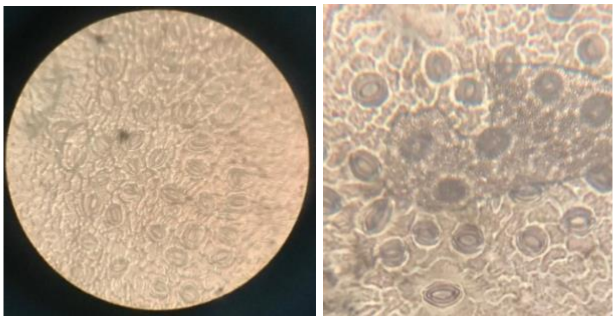

Figure 7. Stomatal density of jackfruit leaves

Figure 8. Condition of jackfruit leaves

Location 2 in Pangeran Emir M Noer

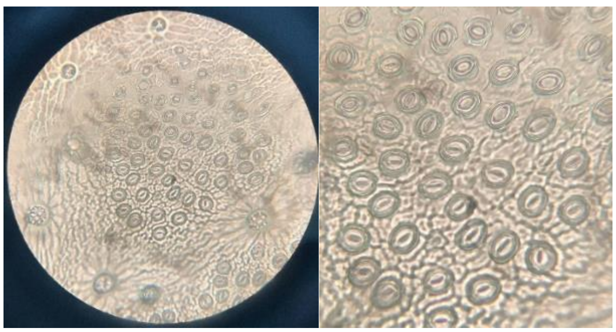

Figure 9. Stomatal density of jackfruit leaves

Figure 10. Condition of jackfruit leaves

Location 3 in Pangeran Emir M Noer

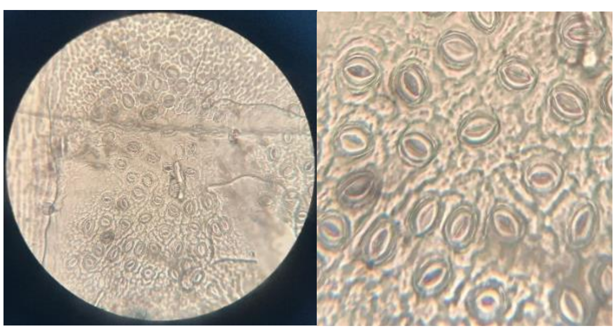

Figure 11. Stomatal density of jackfruit leaves

Figure 12. Condition of jackfruit leaves

Based on field observations, the morphological differences in jackfruit leaves between the two study locations are presented in Table 2 :

Table 2. Leaf Morphology Comparison

No.	Leaf Morphology	Street	
		Sultan Agung	**Pangeran Emir M Noer**
1.	Leaf Shape	Oval	Oval
2.	Leaf Size	Length ranges from 16.2-20cm, width 7.1-8.7cm	Length ranges from 11.51-15.5cm, width 6.5-7.7cm
3.	Leaf Apex	Pointed	Rounded-pointed
4.	Leaf Base	Blunt	Blunt
5.	Leaf Margin	Entire	Entire
6.	Leaf Arragement	Alternate	Alternate
7.	Leaf Venation	Pinnate	Pinnate
8.	Leaf Surface	Upper surface is smooth, glossy and shiny; lower surface is slightly rough	Upper surface is smooth, gloosy and shiny; lower surface is slightly rough
9.	Leaf Color	Dark green	Dark green
10.	Leaf Type	Simple	Simple

Based on the vehicle speed measurements at Sultan Agung and Pangeran Emir M Noer, the emission factors for CO (carbon monoxide) and NOx (nitrogen oxides) were determined. Table 3 presents the total emissions and a comparison of CO and NOx concentrations with the National Ambient Air Quality Standards (mg/m³).

Table 3. Total Emission Factors and Comparison of CO and NOx with National Ambient Air Quality Standards

No	Location	Total CO (mg/m^3)	Total NOx (mg/m³)	National Ambient Air Quality Standards
				Total CO(mg/m³)
1	Sultan Agung	3,521.81	107.97	30,000
2	Pangeran Emir M Noer	3,573.19	110.67	30,000

The correlation between stomatal density in jackfruit leaves and NOx and CO emission factors at Sultan Agung Street and Pangeran Emir M Noer Street is presented in Table 4 below.

Table 4. Stomata Density and Emission Factors (NOX and CO)

Location	Stomata Density (stomata/mm^2)	NOx Emission Factor (mg/m³)	CO Emission Factor (mg/m³)
Sultan Agung	371.61	38.06	1182.73
	261.57	36.23	1178.00
	193.62	33.68	1161.08
Pangeran Emir M Noer	385.52	40.49	1180.93
	304.03	35.85	1180.93
	180.03	34.33	1097.17

The differences in the average values of stomatal density observed in this study are attributed to variations in stomatal numbers in jackfruit (Artocarpus heterophyllus Lamk.) leaves across the two research locations: Sultan Agung Street and Pangeran Emir M Noer Street. The variation in stomatal number significantly influences stomatal density, which in turn reflects the environmental conditions of the plant's habitat. Increased stomatal density is an adaptive response of plants to heightened levels of vehicular exhaust emissions, which are directly associated with the volume of traffic passing through these roads upa[13], [14], [15], [16]. Even that when air quality remains within permissible standards, plants growing in polluted environments exhibit a gradual reduction in stomatal numbers as an adaptive mechanism to limit pollutant absorption [17]. demonstrated that prolonged exposure to pollutants, even at low concentrations, can lead to progressive alterations in stomatal characteristics, affecting overall plant physiological functions such as photosynthesis and gas exchange efficiency. This suggests that while the pollution levels in the studied areas remain under threshold limits, continued exposure over time may induce physiological stress on urban vegetation [18], [19].

In addition to influencing stomatal density, this study also found an increase in stomatal size as an adaptive response of plants to environmental stress caused by air pollution. The elongation of stomata functions as a compensatory mechanism to ensure optimal CO_2 uptake for photosynthesis, especially when stomatal numbers decrease over time. This adaptation enables plants to maintain metabolic efficiency despite exposure to pollutants. Furthermore, the role of stomata as bioindicators and biomonitors of air quality has been widely documented in various studies, showing that plants with higher stomatal density tend to be more effective in absorbing and accumulating airborne pollutants, such as heavy metals and fine particulate matter (PM10 and PM2.5). This condition suggests that, in addition to facilitating gas exchange, stomata play a crucial role in the physiological response of plants to environmental pollution, making them a potential indicator for urban air quality monitoring. [20], [21].

The findings of this study indicate that the increase in vehicle traffic volume correlates with an increase in stomatal density in jackfruit leaves, supporting the hypothesis that plants in polluted environments adapt by increasing the number of stomata to optimize CO_2 absorption for photosynthesis. However, while a higher stomatal density can enhance photosynthetic efficiency, excessive stomatal opening also increases the risk of pollutant uptake, including fine particulate matter (PM10 and PM2.5), heavy metals, and toxic gases such as NOx and CO. To mitigate these risks, plants in polluted environments develop additional adaptive mechanisms, such as stomatal closure during periods of high pollution, to minimize the negative effects of air contaminants on physiological processes. Urban air pollution primarily originates from vehicular emissions and industrial activities, with the transportation sector contributing approximately 60–70% of total air pollution, while industrial emissions account for only about 10–15%. ehicle volume and noise levels are interrelated, as an increase in the number of vehicles of all types leads to higher noise levels and greater air pollution [22]. The incomplete combustion of fossil fuels in motor vehicles releases exhaust gases that can alter plant anatomy and physiological functions, including stomatal modifications as an adaptive response to prolonged pollutant exposure [23], [24], [25]. In this context, the observed adjustments in stomatal characteristics of jackfruit leaves suggest that this species responds to environmental changes caused by air pollution.

Given its specific physiological responses to air quality, this study confirms that jackfruit trees have the potential to serve as bioindicators of urban air pollution. Their widespread distribution in tropical regions, combined with their ability to adjust stomatal density and morphology in response to air quality changes, makes them an ideal species for long-term environmental monitoring.

Utilizing plants as biological indicators offers an ecological and sustainable approach to air quality assessment, supporting broader urban pollution mitigation strategies while promoting green infrastructure development.

CONCLUSION

This study confirms that stomatal density in jackfruit leaves (Artocarpus heterophyllus Lamk.) can serve as an indicator of air quality variations in urban environments, particularly those influenced by vehicular emissions. The findings reveal a positive correlation between traffic intensity and stomatal density, indicating that plants adapt to elevated air pollution levels by increasing stomatal numbers to optimize CO_2 absorption for photosynthesis. However, while higher stomatal density enhances photosynthetic efficiency, it also heightens the absorption of airborne pollutants, including NOx, CO, and fine particulate matter (PM10 and PM2.5), prompting plants to develop stomatal closure mechanisms during periods of high pollution as a protective response against physiological disruptions. The comparison between Sultan Agung Street and Pangeran Emir M Noer Street demonstrates that variations in stomatal morphology can be utilized to assess pollution levels across different urban locations. Although pollutant concentrations remain within the limits set by the National Ambient Air Quality Standards (PP No. 41 of 1999), the observed physiological responses suggest that prolonged exposure to pollutants may gradually impact plant metabolism and gas exchange efficiency. Consequently, this study reinforces the potential of jackfruit trees as bioindicators of urban air pollution, which can be incorporated into vegetation-based environmental monitoring systems. By integrating plant bioindicators into air pollution analysis, this research contributes to a more sustainable and ecological approach to pollution assessment, supporting mitigation efforts and the development of green infrastructure for healthier urban environments. Further studies are needed to explore the long-term stomatal responses to seasonal variations and different pollution levels, ensuring the optimal and effective application of bioindicators in urban environmental management.

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