Physiological and biochemical responses of sugar palm (*Arenga pinnata* Merr.) at different elevation levels

Wisnubroto, M. P.[*], Rezki, D. and Hasibuan, H. S.

Department of Agroecotechnology, Faculty of Agriculture, Universitas Andalas, Dharmasraya Regency, West Sumatra, Indonesia.

Abstract Altitude influences the physiological and biochemical responses of sugar palm due to changes in weather and climatic conditions. In this study, sugar palms were observed at low (427 masl), medium (620–700 masl), and high (1,011–1,026 masl) altitudes. The results revealed that altitude had no significant effect on chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, proline, anthocyanin reductase (ANR), superoxide dismutase (SOD), peroxidase (POD), and malondialdehyde (MDA) levels. However, a trend of increasing stress with altitude was observed, indicated by a negative correlation between SOD and POD activities with chlorophyll content and ANR activity. As SOD and POD activities increased, chlorophyll content and ANR activity decreased, suggesting an adaptive response to oxidative stress at higher altitudes. Overall, sugar palms exhibited more favorable physiological and biochemical profiles when cultivated at low to medium altitudes. These findings indicated that sugar palms grow optimally in lower elevation environments and may experience increasing physiological stress with altitude, providing important insight for their conservation and potential development as a sugar-producing crop.

Keywords: Altitude, Biochemistry, Physiology, SOD, Sugar palm

Introduction

Sugar palm (*Arenga pinnata* Merr.) is one of the most valuable plant species with high economic potential in Indonesia. The sap produced from this plant can be used as a substitute for sweeteners derived from sugarcane. Sugar palm is widely distributed in Sumatra, with a planting area of 10,690 ha and a total production of 16,837 tons, equivalent to an average productivity of 1.575 t ha^{-1} (Suri *et al.*, 2024). The development of sugar palm in Indonesia is highly promising, considering the increasing demand for sweeteners over time. However, the production and growth of this plant are influenced by various environmental factors, one of which is altitude. Altitude plays an important role in determining air humidity, temperature, light intensity, and oxygen pressure,

[*]**Corresponding Author:** Wisnubroto, M. P.; **Email:** muhammadparikesit@agr.unand.ac.id

which significantly affect the physiological and biochemical processes of sugar palm.

Sugar palm is classified as a conservation plant that can grow well on less fertile or marginal land (Rinawati *et al.*, 2021). Furthermore, Suhendra *et al.* (2023) stated that sugar palm can grow at various altitudes and in diverse soil types. Meanwhile, Azhar *et al.* (2019) mentioned that sugar palm grows well at altitudes of 50–1,300 m above sea level, with an optimal range of 500–1,200 m above sea level. Other studies report that sugar palm can grow in various soil types, including clay, loam, and sandy soils; however, growth is not optimal in acidic soils with pH $\leq$ 4. In addition, suitable growing conditions include altitudes ranging from 9–2,000 m above sea level, annual rainfall exceeding 1,200 mm, and an average temperature of 25°C. Generally, this plant grows in mountainous areas, valleys, riverbanks, and undulating terrains (Apriyanto *et al.*, 2021). However, Sandalayuk *et al.* (2019) reported that sugar palm cultivated at altitudes $\geq$ 700 m above sea level exhibits lower productivity compared to those grown at 400–600 m above sea level. These findings indicate that sugar palm has an altitude tolerance range that influences its growth and development.

As in other plants, altitude can induce abiotic stress in sugar palm. Increasing altitude is generally associated with lower air temperature and higher humidity. In oil palm, altitude significantly affects physiological characteristics, where photosynthetic rate, transpiration rate, intercellular CO_2 concentration, and stomatal dimensions are lower in highland-grown plants compared to those in lowlands (Listia *et al.*, 2019). A similar pattern was reported by Fikri *et al.* (2023), who found that oil palm productivity is higher in lowland areas than in highland terraces. Furthermore, Ghazzawy *et al.* (2022) reported that date palm grown at 598 m above sea level showed optimal growth and production, whereas at altitudes > 600 m above sea level, biochemical characteristics—particularly sweetness—tended to change. Several plant species exhibit biochemical adjustments, including increased antioxidant activity and accumulation of secondary metabolites such as flavonoids, as a defense mechanism against temperature stress (Qaderi *et al.*, 2023; Rao *et al.*, 2024).

Altitude differences also influence leaf pigments, particularly carotenoids. In highland endemic species such as *Rosa arabica* and *O. syriaca*, carotenoid levels tend to increase with elevation. In addition to pigments, altitude affects the activity of antioxidant enzymes, including superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), and malondialdehyde (MDA). The activity of these enzymes generally increases with altitude (Hashim *et al.*, 2020), playing a crucial role in scavenging reactive oxygen species (ROS) generated under low-temperature stress conditions.

Although sugar palm can grow across a wide range of altitudes, optimal and maximum thresholds may influence its metabolic processes. Therefore, this study was conducted to investigate the physiological and biochemical responses of sugar palm under different altitude levels.

Materials and methods

This study was conducted from September to October 2024 in Lintau Buo Utara District, Tanah Datar Regency, West Sumatra Province, Indonesia. Sugar palm plant samples were taken at three altitude levels, namely low (L), medium (M), and high (H). Three plants were selected for each altitude level to obtain 9 plant accessions. Accession 1 is located at an altitude of 1,026 m above sea level (masl), accession 2 at an altitude of 1,016 masl, accession 3 at 1,011 masl, accession 4 at an altitude of 700 masl, accession 5 at 627 masl, accession 6 at 620 masl, and accessions 7, 8, and 9 are at an altitude of 427 masl. The distribution of sample points can be seen in Figure 1.

Sampling was carried out using a purposive sampling method with the criteria of plants that have been producing and are > 5 years old. The equipment and materials needed include a lux meter, clinometer, thermometer, hygrometer, knife, plastic, label paper, tape, filter paper, and stationery. The environmental characteristics observed include light intensity above and below the canopy, air humidity, and environmental temperature. Observations of physiological and biochemical characteristics were carried out on the variables of chlorophyll a content, chlorophyll b content, total chlorophyll content, carotenoid content, proline, nitrate reductase activity (NRA), superoxide dismutase (SOD) enzyme activity, peroxidase (POD), and malondialdehyde (MDA) content.

Chlorophyll a, b, and total levels as well as carotenoids were measured using a 21D spectronic device, where 1 gram of sugar palm leaves from each treatment was ground, and 80% acetone solution was added as much as 20 mL. The mixture is then filtered with filter paper. Spectronic 21D is turned on and left for 100 minutes. Furthermore, 80% acetone is poured into a cuvette as a standard solution. The control button is at a wavelength of 645 nm, then the absorption is set to zero. The pigment solution sample is poured into another cuvette to the limit; the absorbance number is recorded (A645). This step can be repeated for a wavelength of 663 nm (A663) and A480 for carotenoid levels. The concentration value is obtained from the following equation.

$$Chlorophyll\ a = (12{,}7\ x\ A663 - 2{,}69\ x\ A645)x\ 0{,}02$$
$$Chlorophyll\ b = (22{,}9\ x\ A645 - 4{,}68\ x\ A663)x\ 0{,}02$$
$$Total\ Chlorophyll\ Content = (22{,}9\ x\ A64 + 8{,}02\ x\ A663)\ x\ 0{,}02$$

$$Carotenoid\ Content$$
$$= \frac{\left(A480 + (0114\ x\ A663)\right) - (0{,}638\ x\ A645\ x\ Volume.\,10^3)}{112{,}5\ x\ Weight}$$
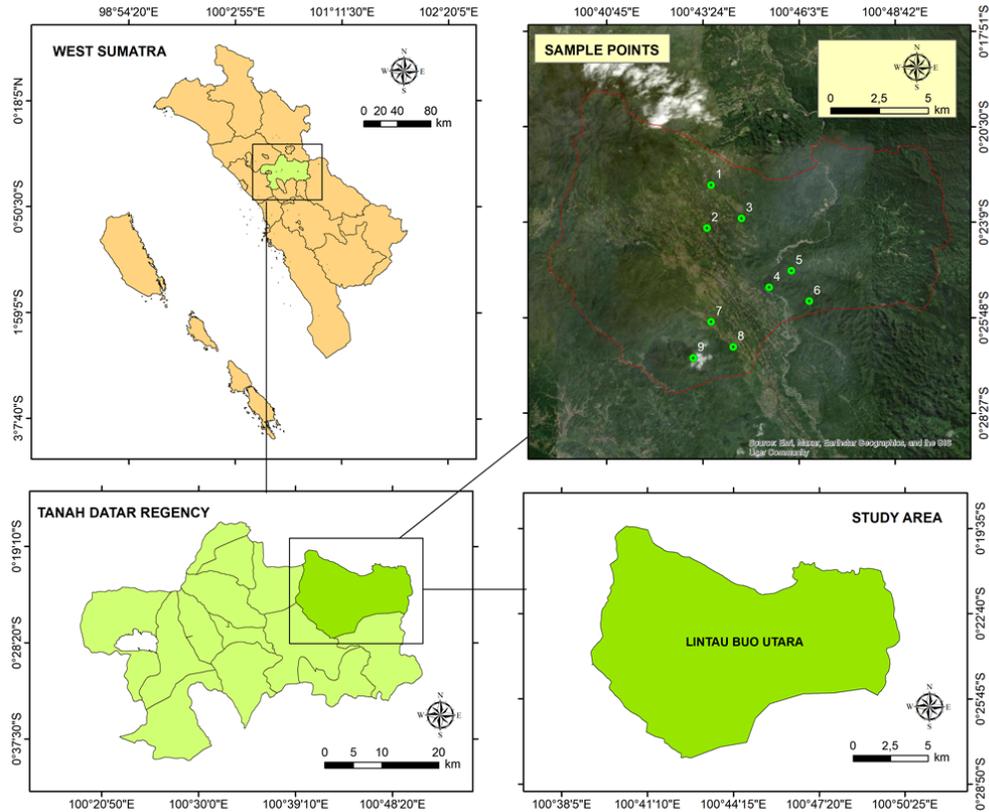

Figure 1. Map of sampling locations in Lintau Buo Utara District, Tanah Datar Regency, West Sumatra Province, Indonesia

Proline levels were observed by grinding 0.5 grams of sugar palm leaves, adding 10 mL of 3% sulfosalicylic acid solution, and filtering. Next, a ninhydrin acid solution was made by heating 1 g of ninhydrin in 24 mL of glacial acetic acid until it turned blue. 2.5 mL of phosphoric acid and 5.5 mL of distilled water were added to the ninhydrin solution and heated until dissolved. Then, 2 mL of the filtrate was reacted with 2 mL of ninhydrin acid and 2 mL of glacial acetic acid in a test tube at a temperature of 100°C for 1 hour. The reaction was ended by inserting the test tube into a beaker filled with ice. The mixture was extracted with 4 mL of toluene and shaken with a stirrer for 15-20 seconds. The red toluene was pipetted and read using Spectronic 21D at a

wavelength of 520 nm. The reading results were calculated using the following formula and expressed in units of µmol proline per gram.

$$Proline\ Content = 643649\ x\ absorbance\ reading\ result + (-5,2987)\ x\ 0,347$$

NRA observation was carried out by taking a sample of 0.2 grams of sugar palm leaves and then put into a film tube filled with 5 mL of pH 7 phosphate buffer solution and then incubating for 24 hours. Furthermore, the buffer solution was discarded and replaced with 5 mL of new buffer and 0.1 mL of 0.1 M $NaNO_3$ was added as a substrate. Then, a color reagent solution was prepared consisting of 0.2 mL of 1% SA in 3 N HCl and 0.2 mL of 0.02% NED in a test tube. After 2 hours, the color reagent was added to 0.1 mL of filtrate taken from the film tube and waited until a pink color appeared, then distilled water was added. The homogeneous solution can be transferred into a cuvette. After being homogeneous, the solution was transferred into a cuvette, and its absorbance was measured using a spectrophotometer with a wavelength of 540 nm. The NRA value is obtained from the following equation.

$$NRA = \frac{Sample\ Absorbance}{0,0142}\ x\ 5\ x\ 0,5\ x\ 0,05$$

SOD activity was measured based on the pyrogallol autoxidation method. Briefly, the reaction medium was used as a 50 mM Tris-HCl buffer pH 8.2 with 1 mM 25 EDTA. Then, 40-60 mg of sample extract protein was mixed with 100 µl of 0.2 mM pyrogallol (dissolved in 50 mM PPB pH 6.5) to start the reaction, and the decrease in pyrogallol absorbance was monitored at 420 nm. POD levels were determined by spectrophotometric method at an absorbance of 420 nm. Meanwhile, MDA was measured using spectronic 21D at 532 nm and 600 nm wavelengths. POD and MDA values were calculated based on the following equations.

$$POD\ Content = \frac{(\frac{\Delta A420}{20}\ sec\ test\ sample - \frac{\Delta A420}{20}\ sec\ blank)\ x\ 1,55\ x\ 1}{(12)(0,1)}$$

$$MDA\ Content = \frac{(\frac{difference\ between\ 532\ and\ 600\ nm\ absorbance}{155}\ x\ 10^6)}{Fresh\ leaves\ weight}$$

The observation results were analyzed using analysis of variance (ANOVA) at $\alpha = 0.05$. The real difference at each height level was further tested using the LSD test alpha 0.05. The relationship between variables was analyzed by correlation and displayed in a correlogram. The closeness of the relationship was shown by regression analysis and displayed in the form of a

regression curve. Data analysis was performed using RStudio software version 3.0.1.

Results

Environmental conditions at the research location

The average light intensity under the canopy at 3 altitude levels reached 15,116.7 lux; above the canopy, it reached 31,423.67 lux. Meanwhile, the average temperature and air humidity at three altitude levels were 28.0°C and 56.56%. However, at a low level (L), the environmental characteristics are relatively suitable for the growth of sugar palm.

At a flat height level (L), the light intensity above and below the canopy is in the optimum range of intensity required by the sugar palm, namely 1,835 lux and 1,414.33 lux with an air temperature of 27.8°C (Table 1). Meanwhile, at medium (M) and high (H) height levels, the light intensity below and above the canopy appears to exceed the optimal value of the required intensity (Table 1). The same pattern is also occurred at air temperature with a value of 30.13°C at height level M.

Table 1. Environmental observations at sampling locations

Sample	Environmental Characteristics			
	Light Intensity Under the Crown (lux)	Light Intensity Upper the Crown (lux)	Relative Humidity (%)	Temperature (°C)
Low (L)	1835.00	1414.33	54.33	27.80
Medium (M)	5088.67	74243.33	50.00	30.13
High (H)	38426.67	18613.33	65.33	26.17
optimal environmental characteristics for sugar palm				
	749 – 4830 lux (Khotimah *et al.*, 2025)		74 – 81 (Khotimah *et al.*, 2025)	19 – 27 (Muda and Awal, 2021)

Physiological characteristics of sugar palm at three height levels

The analysis results of chlorophyll a, b, and total levels gave values that were not significantly different at 3 height levels. Similar things were found in carotenoid levels, which gave values that were not significantly different (Figure 2 a and b).
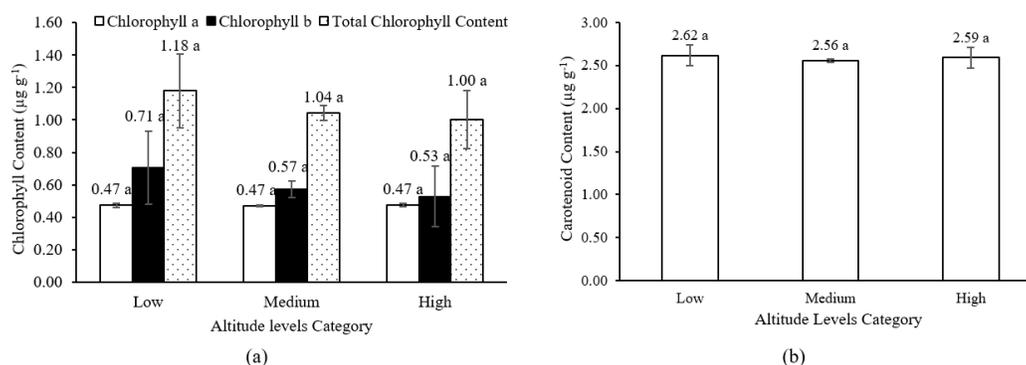
Figure 2. Leaf pigment levels of sugar palm at 3 different altitude levels; (a) chlorophyll a, b and total chlorophyll levels, and (b) carotenoid levels

Biochemical characteristics of sugar palm at three height levels

The results of the analysis of proline, NRA, SOD, POD, and MDA levels of sugar palms at 3 altitude levels did not show significant differences (Table 2). The altitude up to level H with accessions of 1,011 – 1,026 masl did not significantly impact the biochemical characteristics of sugar palms.

Table 2. Biochemical character values of sugar palm at 3 different altitude levels

Sample	Proline Content ($\mu mol\ g^{-1}$)	Nitrate Reductase Activity ($\mu mol\ NO_2^{-1}\ g^{-1}\ hour^{-1}$)	SOD Activity ($U\ mL^{-1}$)	POD Activity ($U\ mg^{-1}\ minute^{-1}$)	MDA Content ($\mu mol\ g^{-1}$)
Low (L)	0.928 a	0.56 a	0.42 a	0.34 a	5.52 a
Medium (M)	0.843 a	0.51 a	0.46 a	0.34 a	4.10 a
High (H)	0.740 a	0.45 a	0.47 a	0.37 a	4.11 a

Note: Numbers with the same letter indicate no significant difference according to the LSD test alpha 0.05.

Relationship between environmental characteristics and physiological and biochemical characteristics of sugar palm

The relationship between environmental characteristics and physiology and biochemistry can be visualized through a correlogram that describes the magnitude of the correlation between observation variables (Figure 3). Figure 3a informs that the increasingly blue circles indicate that both variables are positively correlated, with a correlation coefficient approaching 1. At the same time, the increasingly red circles indicate that both variables negatively influence each other, with a correlation coefficient approaching -1. The

negative correlation value is indicated by the MDA level with air temperature; the higher the air temperature, the lower the MDA level (Figure 3a). Air temperature as an independent variable can influence the MDA level as a dependent variable by up to 62.7% (Figure 3b). With every increase in air temperature by 1 level, the MDA level decreases by 16.5 µmol g^{-1}.
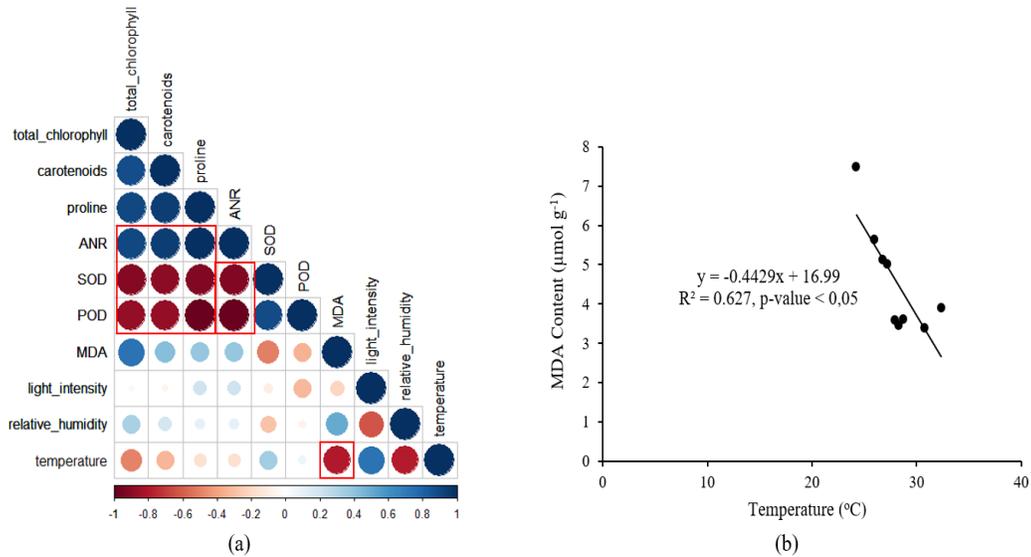

Figure 3. (a) Correlogram of environmental, physiological and biochemical characteristics of sugar palm at 3 altitude levels and (b) Relationship between air temperature and MDA levels of sugar palm

The level of closeness of the relationship between each variable is shown in Figures 4a and 4b. Chlorophyll levels affect the NRA value by 82% compared to the influence of other factors on NRA and vice versa. The higher the chlorophyll content, the higher the NRA value of the sugar palm plant. For every 1-level increase in total chlorophyll content, the nitrate reductase activity increases by 0.43.
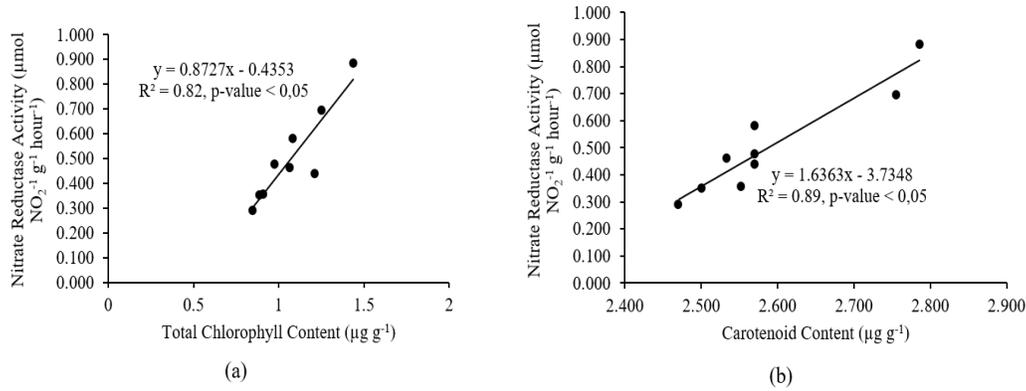
Figure 4. Effect of total chlorophyll (a) and carotenoids (b) on nitrate reductase activity

A negative correlation trend was found in the observation variables of total chlorophyll levels and nitrate reductase activity with SOD enzyme activity as well as total chlorophyll levels and nitrate reductase activity with POD levels. This negative correlation showed that an increase in chlorophyll levels and nitrate reductase activity had the potential to reduce the activity of SOD and POD enzymes in sugar palm growing at 3 different height levels. The level of closeness of this relationship can be seen in the regression curve in Figures 5a and 5b.
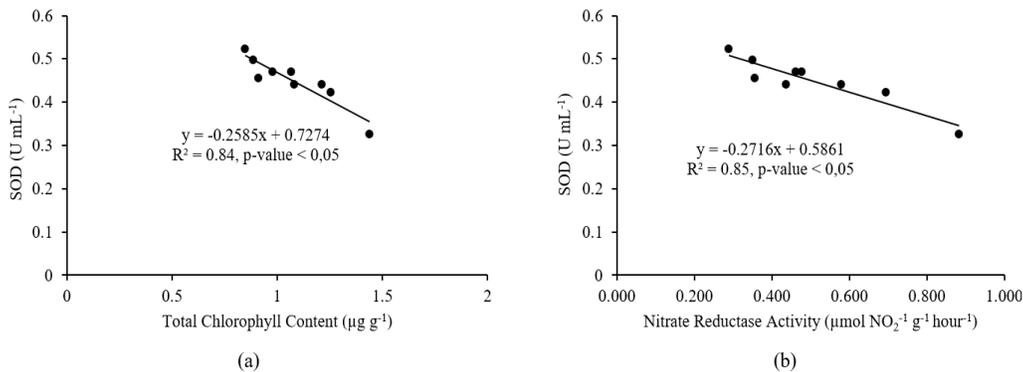

Figure 5. Relationship between total chlorophyll content (a) and nitrate reductase activity (b) to SOD enzyme activity

The relationship between total chlorophyll levels and POD levels appeared inversely proportional, where an increase in total chlorophyll levels causes a

decrease in POD levels in sugar palm. Chlorophyll is affected the decrease in POD levels by up to 77% (Figure 6). Chlorophyll levels are increased by 5 μg g^{-1} which decreased POD levels by up to 0.4 U mg^{-1} $minute^{-1}$. The same pattern is also shown by the relationship between nitrate reductase activity and POD levels, with an effect of 97%. An increase of 5 μmol NO_2^{-1} g^{-1} $hour^{-1}$ NRA, then decreased POD by up to 0.64 U mg^{-1} $minute^{-1}$ (Figure 6b).

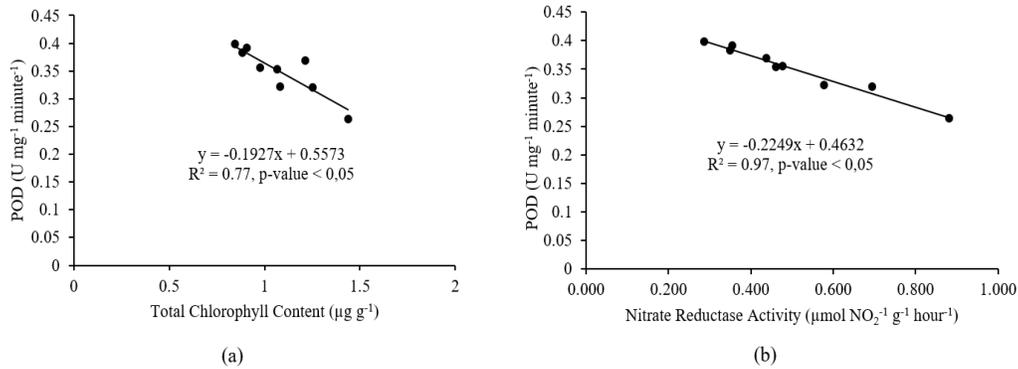
(a)   (b)

Figure 6. Relationship between total chlorophyll content (a) and nitrate reductase activity (b) to POD activity

Discussion

Environmental conditions at the research location

Environmental characteristics play an important role in plants' physiological and biochemical activities, including sugar palm. These characteristics include light intensity, temperature, and air humidity. The higher the light intensity, the higher the air temperature and the lower the air humidity. Environmental conditions that are too extreme, both extremely high and extremely low, have the potential to be limiting factors in the growth and development of sugar palm. Overall, the results of observations of environmental characteristics at three altitude levels in Lintau Buo Utara District, Tanah Datar Regency, West Sumatra Province, are classified as less suitable for the growth and development of sugar palm. The average light intensity under the canopy at 3 altitude levels reached 15,116.7 lux; above the canopy, it reached 31,423.67 lux. Meanwhile, the average temperature and air humidity at three altitude levels were 28.0°C and 56.56%. Regarding its growth requirements, sugar palm prefers a growing environment with an air

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temperature range of 19 – 27°C (Muda and Awal, 2021). However, at a low level (L), the environmental characteristics are relatively suitable for the growth of sugar palm.

At a flat height level (L), the light intensity above and below the canopy is in the optimum range of intensity required by the sugar palm, namely 1,835 lux and 1,414.33 lux with an air temperature of 27.8°C. Meanwhile, at medium (M) and high (H) height levels, the light intensity below and above the canopy appears to exceed the optimal value of the required intensity. The same pattern also occurs at air temperature with a value of 30.13°C at height level M. Meanwhile, air humidity at height levels L, M, and H is classified as unsuitable for the growth of sugar palm where the optimal humidity is 74 - 81%, as reported by Khotimah *et al.* (2025). Table 1 also informs that there are indications of increasing light intensity and altitude levels. This has the potential to trigger changes in physiological and biochemical characteristics in the body of the sugar palm plant. Increased light intensity results in heat stress, impacting the degradation of chlorophyll pigments in the leaves. Furthermore, Alarab *et al.* (2022) stated that date palm plants affected by high heat stress showed symptoms of decreased physiological activity, namely the rate of photosynthesis due to low chlorophyll levels in the leaves.

Physiological characteristics of sugar palm at three height levels

The difference in environmental characteristics at altitude determines the physiological characteristics of the sugar palm plant. These characteristics can be seen from the chlorophyll content, both chlorophyll a, b, and total chlorophyll content and carotenoid levels. Chlorophyll absorbs and uses energy from sunlight to carry out the process of photosynthesis. As previously described, increasing altitude levels trigger an increase in sunlight intensity, which can damage leaf color pigments.

The analysis results of chlorophyll a, b, and total levels gave values that were not significantly different at 3 height levels. Similar things were found in carotenoid levels, which gave values that were not significantly different This information indicates that the difference in altitude levels does not significantly affect the physiological characteristics of the sugar palm plant. However, environmental conditions tend to indicate the potential for heat stress. The same results were shown in the study of the effect of altitude on the physiological characteristics of oil palms, where altitude did not have a significant effect (Listia *et al.*, 2019). This is because plants from the palm family tend to have

adaptation mechanisms by accumulating organic compounds that can protect cells and proteins from damage due to oxidative stress caused by extreme environmental conditions. Thus, sugar palm tended to be relatively tolerant to potential abiotic stress caused by differences in growing locations.

Biochemical characteristics of sugar palm at three height levels

The increase in altitude level impacts abiotic stress in most plants. One of the signs of this stress is a change in the biochemical character of plants which includes a decrease in nitrate reductase (NRA) activity, an increase in organic compound levels in the form of proline, an increase in SOD enzyme activity, POD, and MDA levels. Proline acts as an organic molecule osmoprotectant which functions to protect cells from abiotic stress (Shiade *et al.*, 2024), such as drought and high salinity.

The results of the analysis of proline, NRA, SOD, POD, and MDA levels of sugar palms at 3 altitude levels did not show significant differences The altitude up to level H with accessions of 1,011 – 1,026 masl did not significantly impact the biochemical characteristics of sugar palms. Furthermore, Listia *et al.* (2019) stated in their research that increasing the altitude level of oil palm planting sites did not significantly reduce the activity of plant nitrate reductase. Research showed that sugar palm can grow optimally at 700 – 1,200 meters above sea level (Muda and Awal, 2021). Therefore, the accession height category of 1,011 – 1,026 masl is still optimal for the growth and development of sugar palm.

Relationship between environmental characteristics and physiological and biochemical characteristics of sugar palm

Environmental characteristics tended to affect sugar palm' physiological and biochemical processes through a series of metabolic processes and their responses to environmental changes. Sugar palm have a suitable adaptation mechanism in responding to changes in weather and climate. These mechanisms can be physiological or biochemical adaptations. The relationship between environmental characteristics and physiology and biochemistry can be visualized through a correlogram that describes the magnitude of the correlation between observation variables.

The increasingly blue circles indicated that both variables are positively correlated, with a correlation coefficient approaching 1. At the same time, the

increasingly red circles indicate that both variables negatively influence each other, with a correlation coefficient approaching -1. The negative correlation value is indicated by the MDA level with air temperature; the higher the air temperature, the lower the MDA level. Air temperature as an independent variable can influence the MDA level as a dependent variable by up to 62.7%. With every increase in air temperature by 1 level, the MDA level decreases by 16.5 µmol g^{-1}. This result contradicts the findings of Hong *et al.* (2023) that states the increase in temperature triggers an increase in MDA levels. MDA is a secondary product of lipid peroxidation that is a marker of oxidative stress in the plant body due to stress. This anomaly occurs due to the influence of other factors, such as low-stress levels and the tolerance of sugar palm to abiotic stress, which is relatively more resistant than other plants.

The variables of total chlorophyll, proline, and carotenoid levels with NRA show a positive correlation trend. The correlation has a value approaching +1, which is characterized by the increasingly blue correlogram circle. Chlorophyll levels affect the NRA value by 82% compared to the influence of other factors on NRA and vice versa. The higher the chlorophyll content, the higher the NRA value of the sugar palm plant. For every 1-level increase in total chlorophyll content, the nitrate reductase activity increases by 0.43. NRA is related to the process of converting nitrate NO_3^- into nitrite (NO_2^-) enzymatically (Wisnubroto *et al.*, 2021; Ende *et al.*, 2022), so that plants can utilize the N element as an essential component of protein, including chlorophyll. Sosnowski and Truba (2021) state that increased nitrate reductase activity indicates that nutrient absorption, especially N, is taking place optimally so that the basic components of chlorophyll are maximally available.

In addition to chlorophyll, nitrate reductase activity significantly affects carotenoid levels. Chlorophyll affects NRA values by up to 89% compared to other factors. The higher the carotenoid levels, the higher the nitrate reductase activity and vice versa. Carotenoids are chemical compounds bound to peptides, thus forming a pigment-protein complex. Thus, the higher the protein content in the plant body. As previously described, the essential component of protein is the element N, so the higher the activity of nitrate reductase, the higher the protein synthesis activity. Thus, the complex bonds in peptides also increase, one of which is the carotenoid compound.

Furthermore, a negative correlation trend was found in the observation variables of total chlorophyll levels and nitrate reductase activity with SOD enzyme activity as well as total chlorophyll levels and nitrate reductase activity with POD levels. This correlation is indicated by the color in the correlogram,

which is increasingly red and has a correlation coefficient approaching -1. This negative correlation means that an increase in chlorophyll levels and nitrate reductase activity has the potential to reduce the activity of SOD and POD enzymes in sugar palm growing at 3 different height levels.

Total chlorophyll levels significantly reduced SOD enzyme activity with an effect of up to 84%. The higher the chlorophyll levels, the lower the SOD enzyme activity was up to 0.53 U mL^{-1} per 5 µg g^{-1} chlorophyll. NRA also showed a similar effect on SOD activity, where the higher the NRA, the lower the SOD activity will be, with an effect level reaching 85%. Every 5 µmol NO$_2$$^{-1}$ g^{-1} hour^{-1} increase in NRA reduces SOD activity by up to 0.77 U mL^{-1}. The statement (Khayatnezhad and Gholamin, 2021; Wisnubroto *et al.*, 2023) that an increase in SOD activity indicates that the plant is experiencing stress, and one of the impacts of this stress decreased in chlorophyll levels and low nitrate reductase activity due to the emergence of ROS when under stress.

The relationship between total chlorophyll levels and POD levels appeared inversely proportional, where an increase in total chlorophyll levels decreased in POD levels in sugar palm. Chlorophyll affected the decrease in POD levels by up to 77%. Increasing chlorophyll levels by 5 µg g^{-1}, decreased POD levels by up to 0.4 U mg^{-1} minute^{-1}. The same pattern is also shown by the relationship between nitrate reductase activity and POD levels, with an effect of 97%. An increase of 5 µmol NO$_2$$^{-1}$ g^{-1} hour^{-1} NRA impacts decreasing POD by up to 0.64 U mg^{-1} minute^{-1}. Like SOD, the expression of POD enzyme activity occurs when plants experience stress (Khayatnezhad and Gholamin, 2021). The stress causes protein degradation due to ROS, which triggers damage to the nitrate reductase enzyme and chlorophyll, causing nitrate reductase activity and chlorophyll levels to decrease.

Judging from the relationship pattern between nitrate reductase activity and chlorophyll levels with SOD and POD activities, it indicates the potential for stress in sugar palm at different altitude levels of growth. At altitude level L, chlorophyll levels and nitrate reductase activity are higher than at altitude level H. Although the decrease is insignificant, sugar palm will show symptoms of stress along with the increase in altitude level, which is marked by an increase in antioxidant activity in the plant body. Based on these results, the metabolic process of sugar palm tends to be more optimal when planted at altitude level M.

Overall, differences in altitude levels do not significantly affect the biochemical characteristics of sugar palm in North Lintau Buo District. This shows that sugar palm are classified as tolerant and have a biochemical

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adaptation mechanism through increased antioxidant activity. There is a tendency for sugar palms to experience abiotic stress when at an altitude level > 700 meters above sea level, indicated by the negative correlation value between nitrate reductase activity and total chlorophyll levels with SOD and POD enzyme activities. An increase in altitude levels has an impact on increasing SOD and POD activities and decreasing nitrate reductase activity and chlorophyll levels.

Further research is needed regarding the maximum tolerance limit of altitude level on the metabolic process of sugar palm. In addition, it is necessary to develop biochemical character studies from the non-enzymatic side. This study can be used as a reference for developing sugar palm cultivation in the Lintau Buo Utara District.

Acknowledgements

Conflicts of interest

The authors declare no conflict of interest.

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