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Physiological of Various Genotypes of Cayenne pepper (Capsicum frutescens L.) Under Heat Stress

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Abstract. Cayenne pepper (*Capsicum frutescens L.*), a member of the Solanaceae family, is vulnerable to rising temperatures caused by global warming, which may reduce productivity and impair plant growth. This study evaluated the adaptation of four cayenne pepper genotypes (Pelita, Dewata, Bara, and Taruna) to high-temperature stress under greenhouse conditions. A split-plot design was applied, with temperature regimes as the main plot, consisting of normal daily temperature and heat stress conditions (±4°C–8°C above normal temperature), while genotypes were assigned as sub-plots. Observed parameters included physiological traits, such as stomatal conductance and transpiration rate, and morphological traits, including plant height, stem diameter, flowering time, harvesting age, and fruit weight. Data were analysed using ANOVA followed by a 5% significance test. The results demonstrated that high-temperature stress significantly affected both physiological and morphological characteristics of cayenne pepper plants. Temperature stress generally reduced fruit weight compared with normal daily temperature conditions. Responses to heat stress were observed in stomatal conductance, transpiration rate, plant height, stem diameter, leaf morphology, flowering age, harvest age, and fruit yield. Among the tested genotypes, Taruna exhibited superior physiological adaptation through stable stomatal conductance, chlorophyll content, photosynthetic activity, and leaf morphology under stress conditions. However, the Dewata genotype produced the highest fruit weight per plant under elevated temperature conditions compared with Pelita, Bara, and Taruna. These findings provide valuable insights for developing cayenne pepper varieties adaptive to climate change, with emphasis on physiological stability and yield performance as key selection criteria.

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1. Introduction

Cayenne pepper (*Capsicum frutescens* L.), a nutrient-rich vegetable from the Solanaceae family, contains essential compounds such as protein, fat, carbohydrates, vitamins A and C, and alkaloids like capsicum, flavonoids, and essential oils, which offer significant health benefits (Bete and Taena, 2018). High temperature stress is a critical abiotic factor limiting plant growth and agricultural productivity worldwide. It negatively affects photosynthesis by reducing chlorophyll content, damaging the photosynthetic apparatus, and impairing carbon assimilation. These disruptions ultimately reduce plant biomass and retard development (Zandalinas *et al.*, 2018). Extended periods of high temperature can alter plant morphology and phenology. Symptoms often include reduced leaf area, shortened internodes, and early flowering or senescence, which collectively diminish yield potential (Kumar *et al.*, 2020).

Temperatures of 35–41°C and stress duration (4–12 hours) accelerate germination but reduce shoot length, roots, number of leaves, and chlorophyll on cayenne pepper (Utami, 2018). Liang *et al.* (2023), Found that high temperatures cause flower and fruit abscission, affecting yield, heat tolerance is polygenic and correlates with better vegetative growth.

The plant's growth is influenced by internal factors, such as enzymes and hormones, and external factors like humidity, temperature, and sunlight (Mamahit, 2017). Temperature critical threshold for yield in chili pepper (*Capsicum annuum* L.) at a temperature of 32.86°C causes a 50% decrease in yield, and an increase to 39°C reduces yield by up to 87.5% of chili production (Rosmaina *et al.,* 2022). However, global warming poses a challenge to production as high temperatures can reduce plant productivity, cause physiological stress, and, in extreme cases, result in plant death (Soepandi, 2014). High temperatures can lead to reduced photosynthesis, membrane instability, and yield loss, such as bud abortion at 33°C and decreases in fruit size and weight at 38/30°C (day/night) (Hasanuzzaman *et al.*, 2013). Identifying heat-tolerant genotypes is essential for sustaining cayenne pepper production in high-temperature environments (Rupiansih *et al.,* 2018).

2. The Methods

This study was conducted in a greenhouse located in the experimental garden area of the Biology Department, Faculty of Mathematics and Natural Sciences, and the Faculty of Agriculture, Universitas Riau, Binawidya Campus, Km 12.5, Simpang Baru Subdistrict, Tampan District, Pekanbaru City. The research took place from July 2023 to November 2023.

The tools used included hoes, machetes, measuring tapes, buckets, hand sprayers, watering cans, scales, rulers, writing instruments, polybags, thermometers, a spectrophotometer, a portable photosynthesis system (LI-COR LI-6800), a chlorophyll meter, a light microscope (Olympus), seedling trays, and other supporting materials. The materials employed in this study were cayenne pepper varieties (Cap Panah Merah: Bara, Taruna, Dewata, and Pelita), planting media consisting of a 1:1 mixture of topsoil and manure, base fertilizers (TSP, KCl, and Urea), NPK fertilizers, Gandasil B, and pesticides, including curacron with prefonofos as the active ingredient, along with other supplementary materials. The experiment was designed using a split-plot arrangement within a completely randomized design. The factors evaluated in this study were as follows:

- Main plot: daily temperature, stress temperature (±4°C–8°C from normal temperature).
- Sub-plot: cayenne pepper genotypes Pelita, Dewata, Bara, and Taruna.

These factors were combined into 8 treatment combinations, each replicated three times, resulting in 24 experimental units. Each experimental unit comprised 5 plants, yielding a total of 120 plants. Observations were made on physiological parameters such as stomatal conductance and transpiration rate, as well as growth variables, including plant height, stem diameter, flowering time, harvest time, and fruit weight.

3. Result and Discussion

Physiological Response of Several Cayenne Pepper (*Capsicum frutescens* L.) Varieties to High-Temperature Stress. The physiological responses of several cayenne pepper (*Capsicum frutescens* L.) varieties to high-temperature stress were evaluated using multiple parameters to analyze the physiological and morphological characteristics of these varieties.

3.1. Stomatal conductance

The main plot treatment, which involved temperature, did not have a significant effect on stomatal conductance. However, the subplot treatment, which consisted of different varieties, showed a significant effect on stomatal conductance. The interaction between temperature and cayenne pepper varieties did not significantly influence the stomatal conductance of the evaluated genotypes. The results of the follow-up BNJ test at the 5% significance level are presented in Table 1.

Table 1. Average stomatal conductance of several cayenne pepper (*Capsicum frutescens* L.) genotypes under high-temperature stress.

Temperature	Stomatal Conductance of each variety (mol H_2O m^{-2} s^{-1})				Average
	CPP	CPD	CPB	CPT	
Normal	0.1a	0.2a	0.2a	0.2a	0.2a
Stress	0.2a	0.2a	0.3a	0.2a	0.2a
Average	0.2a	0.2a	0.2a	0.2a	0.2

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.

CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

The results of the analysis indicated variations in stomatal conductance among cayenne pepper genotypes under high-temperature stress. Based on analysis of variance (ANOVA) followed by the Tukey test (BNJ) at the 5% significance level, no significant differences were found among the genotypes. This suggests that the physiological response, in terms of stomatal conductance, was relatively uniform across the tested genotypes under both daily and high-temperature stress conditions. Compared to the control condition (daily temperature), there was a tendency for a decrease in average stomatal conductance across all genotypes due to high-temperature stress.

The CPB (Cayanne pepper Bara) genotype showed a higher increase in stomatal conductance compared to other genotypes. This may indicate the genotype's potential adaptation to high-temperature stress conditions. Although no statistically significant differences were found, this finding suggests that certain genotypes may have superior physiological capabilities in maintaining stomatal conductance. This mechanism for maintaining stomatal conductance may serve as an adaptive strategy for plant survival under high-temperature stress conditions.

3.2. Transpiration rate

Based on the results of the variance analysis (ANOVA), the main plot factor (temperature) had no significant effect on the transpiration rate of the four cayenne pepper (*Capsicum frutescens* L.) genotypes. However, the subplot factor (variety) and their interaction showed significant effects on the transpiration rate. The results of the Tukey test (BNJ) at the 5% significance level are presented in Table 2.

The analysis revealed variations in the transpiration rate among cayenne pepper genotypes under high-temperature stress. In general, high-temperature stress resulted in an increase in transpiration rate across almost all genotypes compared to normal conditions. The percentage increase in transpiration rate due to temperature stress was around 50% (+50) when compared to normal temperature. This indicates a high physiological response by the plants to maintain temperature balance through water evaporation.

The CPP (Cayenne Pepper Pelita) genotype exhibited the highest increase in transpiration rate, suggesting a potential adaptation to high-temperature stress. In contrast, the CPT (Cayenne Pepper Taruna) genotype showed a relatively stable transpiration rate, without significant increase or decrease, which may indicate water-use efficiency. These findings suggest that different genotypes exhibit varying adaptation capabilities to high-temperature stress, with genotypes showing higher transpiration rates likely having more active cooling mechanisms, while those with stable transpiration rates tend to be more water-efficient.

Table 2. Average transpiration rate of several cayenne pepper *(Capsicum frutescens* L.) genotypes under high-temperature stress.

Temperature	Transpiration rate of each variety (mmol H_2O m^{-2} s^{-1})				Average
	CPP	CPD	CPB	CPT	
Normal	62.0cd	52.1e	48.3e	83.6ab	61.5b
Stress	95.5a	74.1bc	57.7de	82.8ab	77.6a
Average	78.8a	63.1b	53.0c	83.2a	69.5

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.

CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

3.3. Plant height

Based on the results of the variance analysis, the main plot factor (temperature), the subplot factor (variety), and the interaction between the main plot and subplot significantly affected the plant height of several cayenne pepper (*Capsicum frutescens* L.) genotypes. The results of the Tukey test (BNJ) at the 5% significance level are presented in Table 3.

Table 3. Average plant height of several cayenne pepper (*Capsicum frutescens* L.) genotypes under high-temperature stress

Temperature	Height of each variety (cm)				Average
	CPP	CPD	CPB	CPT	
Normal	0.9b	1.7ab	1.6ab	1.5ab	1.4a
Stress	1.8ab	2.2ab	2.7a	1.5ab	2.1a
Average	1.4c	1.9ab	2.2a	1.5c	1.7

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.

CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

The analysis shows that high-temperature stress generally increased plant height compared to non-stressed conditions or normal temperature. This suggests that some genotypes exhibit adaptive responses, such as increased plant height, which is believed to be an escape mechanism to avoid the adverse effects of high-temperature stress through stem elongation. The CPP (Cayenne Pepper Pelita) genotype exhibited the highest increase in plant heigh under high-temperature stress compared to the control. This indicates that CPP has a better adaptation capacity to high temperatures. The CPD (Cayenne Pepper Dewata) and CPB (Cayenne Pepper Bara) genotypes showed more moderate increases in height, suggesting a more moderate adaptive response compared to CPP.

In contrast, the CPT (Cayenne Pepper Taruna) genotype experienced a decrease in plant height, indicating poorer tolerance to high-temperature stress. Interaction between temperature stress and genotype significantly affected plant height. CPP and CPD genotypes tended to maintain or increase their height more effectively than CPT and CPB. These differences highlight the genetic variation in adaptation capacity to high-temperature stress. The study demonstrates distinct plant height responses to high-temperature stress among various genotypes. The CPP genotype had the best adaptation, while CPD and CPB showed moderate increases. The CPT genotype showed the lowest adaptation in terms of plant height.

3.4. Stem diameter

Based on the results of the variance analysis, the main plot factor (temperature) did not significantly affect the stem diameter of the cayenne pepper plants, while the subplot factor (variety) and the interaction between the main plot and subplot factors (temperature and variety) significantly affected the stem diameter of several cayenne pepper (*Capsicum frutescens* L.) genotypes. The results of the Tukey test (BNJ) at the 5% significance level are presented in Table 4.

Table 4. Average stem diameter of several cayenne pepper (*Capsicum frutescens* L.) genotypes under high-temperature stress

Temperature	Stem diameter of each variety (cm)				Average
	CPP	CPD	CPB	CPT	
Normal	0.5b	0.6b	0.4b	1.1a	0.6a
Stress	0.5b	0.5b	0.4b	0.5b	0.5a
Average	0.5b	0.5b	0.4b	0.8a	0.6

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.
CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

The analysis of the impact of high-temperature stress on stem diameter revealed a decrease under high-temperature conditions compared to normal temperatures. This indicates that high temperatures significantly affect stem growth in most genotypes, particularly those less tolerant to stress. The genotypes of Cayenne Pepper Pelita (CPP), Dewata (CPD), and Bara (CPB) showed relatively similar reductions in stem diameter, ranging from 0.4 cm to 1.1 cm, suggesting that these genotypes exhibit a reasonable level of tolerance to high-temperature stress. On the other hand, Cayenne Pepper Taruna (CPT) experienced the most drastic decrease of approximately 1.1 cm to 0.5 cm, indicating that CPT is more susceptible to the negative effects of high-temperature stress. The interaction between temperature and genotype had a significant effect on stem diameter. Under non-stress conditions, CPD and CPP had the largest stem diameters. The results show a significant reduction in stem diameter under high-temperature stress for all genotypes, with the greatest decrease observed in CPT, while CPP, CPD, and CPB showed more moderate declines.

3.5. Flowering and harvesting age

Based on the analysis of variance, the main plot factor, temperature, and the subplot factor, variety, along with their interaction, significantly affected the flowering and harvesting age of several cayenne pepper (*Capsicum frutescens* L.) genotypes. The results of the Tukey test (BNJ) at the 5% significance level are presented in Table 5.

The flowering age decreased by 29.8 days to 18.3 days under high-temperature stress compared to daily temperatures, indicating an accelerated generative phase as an escape strategy to avoid prolonged stress. The CPD (cayenne pepper Dewata) genotype showed minimal decrease, around 0.1 day, indicating excellent tolerance. The CPP (cayenne pepper Pelita) genotype experienced a moderate decrease of 5 days, indicating moderate adaptation to high-temperature stress. The CPT (cayenne Taruna) genotype, being intolerant to high temperatures, resulted in plant death.

The analysis of the effect of high-temperature stress on harvesting age also showed a decrease, approximately 80.5 days to 56 days, reflecting an accelerated reproductive phase as an adaptation strategy to high-temperature stress. Among the genotypes, the CPB genotype had the highest harvesting age with an increase 1,1 days, indicating very good tolerance. The CPD and CPP genotypes also showed an increase in harvesting age, indicating moderate tolerance. The CRT genotype showed the most negative response to high-temperature stress, as the plants were unable to continue their generative phase (resulting in death).

Table 5. Average flowering and harvesting age of several cayenne pepper (*Capsicum frutescens* L.) genotypes under high-temperature stress

	Temperature	Age of each variety (day after planting, DAP)				Average
		CPP	CPD	CPB	CPT	
Flowering	Normal	27.3bc	20.0d	31.9b	40.0a	29.8a
	Stress	22.5cd	19.9d	30.6b	0.0e	18.3b
	Average	24.9b	20.0c	31.3a	20.0c	24.0
Harvesting	Normal	74.8c	71.4d	76.7b	99.2a	80.5a
	Stress	77.1c	69.3e	77.8b	0.0f	56.0b
	Average	75.9c	70.3c	77.3a	49.6d	68.3

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.

CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

3.6. Fruit mass

Based on the analysis of variance, the main plot factor, which is temperature, the subplot factor, which is variety, and their interaction significantly affected the fruit weight analysis of several genotypes of cayenne pepper (*Capsicum frutescens* L.), with the results of the BNJ follow-up test at the 5% significance level presented in Table 6.

Table 6. Average fruit mass per plant of several cayenne pepper genotypes (*Capsicum frutescens* L.) under high-temperature stress

Temperature	Mass of each variety (g)				Average
	CPP	CPD	CPB	CPT	
Normal	10.3a	10.7a	7.5bc	5.8d	8.5a
Stress	5.2d	8.3b	6.3cd	0.0e	5.0b
Average	7.7b	9.5a	6.9b	2.9c	6.7

Numbers followed by the same letter in the same row and column indicate no significant difference according to the Tukey test (BNJ) at a 5% significance level.

CPP: Cayenne Pepper Pelita; CPD: Cayenne Pepper Dewata; CPB: Cayenne Pepper Bara; CPT: Cayenne Pepper Taruna

The analysis of fruit mass response to daily temperature and high-temperature stress showed a decrease under heat stress compared to daily temperature conditions. All genotypes exhibited a reduction in fruit weight per plant under high-temperature stress compared to daily temperature conditions. The decrease in fruit weight varied among the genotypes, with the largest reduction observed in the CPT genotype, indicating that this genotype is highly sensitive to high temperatures, even leading to plant death. Conversely, the CPB genotype experienced the smallest reduction, showing better tolerance to high-temperature stress compared to the other genotypes.

In comparison among genotypes under daily temperature conditions, the CPD genotype had the highest fruit weight, while the CPT genotype had the lowest. Under high-temperature stress, the CPD genotype still demonstrated relatively better performance compared to other genotypes, despite experiencing a decrease. The CPT genotype showed the poorest performance in both temperature conditions, with a drastic performance decline under heat stress. The average fruit weight per plant across all genotypes decreased from daily temperature to high-temperature stress conditions. The CPD genotype proved to be the most heat-tolerant, while CPT was the most vulnerable. This interpretation indicates physiological response variation among cayenne pepper genotypes to high-temperature stress, which is crucial for consideration in plant breeding programs aimed at adaptation to climate change.

4. Conclusion

The physiological responses and growth of four genotypes of cayenne pepper plants under temperature stress were observed through stomatal conductance, transpiration rate, plant height, stem diameter, flowering and harvesting age, and fruit weight. Overall, temperature stress reduced the fruit weight of cayenne pepper compared to daily temperature conditions. The Dewata cayenne pepper genotype produced the highest fruit weight per plant under temperature stress compared to the Pelita, Bara, and Taruna genotypes.

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