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ORIGINAL STUDY

Assessing the Impacts of Global Warming on Mangrove Plants Growth in Malaysia

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Abstract

Climate change issues have sparked intense debate around the world in recent years. Malaysia faces critical issues with global warming, which has changed the local climate, threatening critical ecosystems, including mangrove forests, and creating challenges in their habitat. This study was conducted to investigate the morphological and physiological attributes of the mangrove *Rhizophora apiculata* in response to air temperature for the selection of tree species that can adapt to climate change. The seedlings were grown in controlled growth chambers with temperatures, of 21,28, and 38 °C, under elevated CO_2 at 650 ppm for three months. The plants were watered with three liters of 28-ppt saline water every 48 h. Thus, after two weeks, the mangrove plant samples recorded positive results for all parameters of high temperature. The differences in temperature resulted in significant differences and positive responses between elevated CO_2 and decreased temperature, which led to the samples surviving for all parameters and the growth being very slow. However, when the temperature is raised, the result is negative, and almost all of the samples perish. These results suggested that the low level of photosynthetic capacity might be attributed to the decreased CO_2 fixative reaction system and photosynthetic pigment contents. Additional physical and climatic factors have an impact on what determines the increase or decrease in *R. apiculata* growth.

Keywords: Climate change, Global warming, Temperature, Photosynthetic, Growth

1. Introduction

The global environment is changing due to the elevated atmospheric carbon dioxide concentration (CO_2), concomitant increasing temperatures and many abiotic factor interactions [1,2] (see Fig. 1). These factors being determinants in the photosynthetic rates and growth rates in plants [3,4]. Any changes they present in the atmospheric composition and climate will significantly affect planetary ecosystems [5,6]. Over the last century, atmospheric CO_2 concentration has increased from 280 to 420 ppm (see Fig. 1) rise of mean annual surface air temperature over the last century a clear effect of recent atmospheric changes [12] (see Fig. 1).) . As previous studies have indicated making this an eminent and undeniable global environmental change (GEC), with the current rate of increase averaging at $1 \cdot 5$ μmol mol^{-1} $year^{-1}$ [7–9]. It is expected that CO_2 concentrations could reach 650 ppm, by the end of the century as global population and economic activity increases [10], leading to warmer global temperatures. Its extent, however, is subject to the factors causing radiative forcing and the complex feedbacks between different elements and the climate system. Also,

Abbreviations & symbols: GEC, Global environmental change; ppm, parts per million; ppt, parts per thousand; CO_2, Carbon dioxide; T, Temperature; DMRT, Duncan's multiple-range tests.

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elevated CO_2 and other greenhouse gasses like methane, chlorofluorocarbons, and nitrous oxide are exacerbated in the effects on critical ecosystems. Recent model projections suggest a global mean surface air temperature increase of 1–4.5 °C by 2100 AD [11], making the 0.3–0.6 °C rise of mean annual surface air temperature over the last century a clear effect of recent atmospheric changes [12]. However, important details in (a) diurnal and seasonal patterns, (b) frequency, timing and duration of extremes (e.g. high or low in temperature predictions, late or early frosts), and (c) climatic variability can be obscured by these broad mean annual changes [13]. One example is that recent scenarios predict most warming in mid- and high-northern latitudes in late autumn and winter, and little or none (or even cooling in mid-latitudes) in summer Fig. 2, which could affect growing season length. Indeed, there is already evidence of a change in growing season length [14]. Another example is the strong evidence that, over land, the increase in nighttime minimum temperature has been about twice the increase in the maximum [15]. Plant growth will greatly have affected by the continuing change in diurnal cycles compared to an even change in temperature over 24 h. These broad global mean temperature predictions obscure aspects critical to natural and managed ecosystems [1].

Mangroves are remarkable ecosystems that are valuable economically and ecologically. They are located at the interface of land and sea and offer a considerable array of goods and services. Mangrove ecosystems are vital for food security and protection of coastal communities. They provide wide diversity of forest products, nurseries for aquatic species, fishing grounds, carbon sequestration, and crucial natural coastal defences for mitigating the impacts of erosion and storms. Global climate change and the associated risks of sea level rise and extreme weather events have increased the importance of mangrove ecosystems. Calls for conservation have also increased in recent years with the increasing evidence that mangroves may have an important role as natural buffers in protecting coastlines from the impacts of storms and extreme waves [16]. Climate change has a high probability to have a strong impact and exacerbate existing pressures on coastal ecosystems, including mangroves. At present, anthropogenic climate change is widely regarded as one of the greatest threats to natural ecosystems worldwide. Effect of anthropogenic climate change includes elevation of atmospheric carbon dioxide and rise in relative sea level and sea water temperature. These phenomena possibly increase with the frequency and magnitude of extreme weather events and associated elevated storm surges and wave height [17,18].

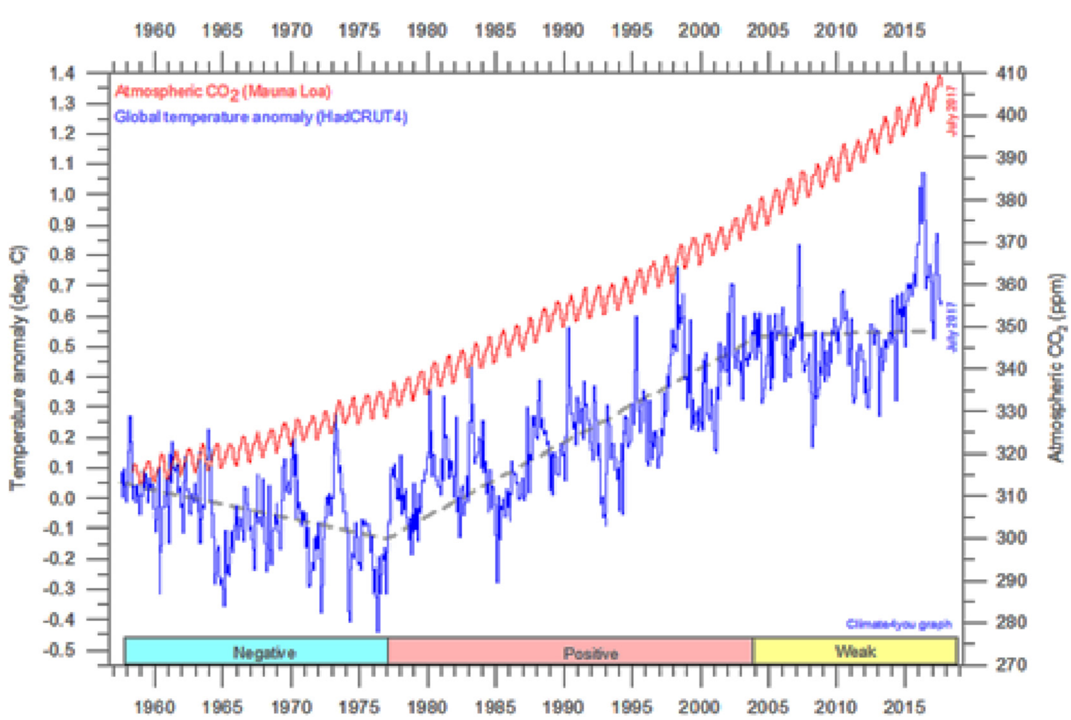

Fig. 1. Diagram showing the HadCRUT4 monthly global surface air temperature estimate (blue) and the monthly atmospheric CO_2 content (red) [19].

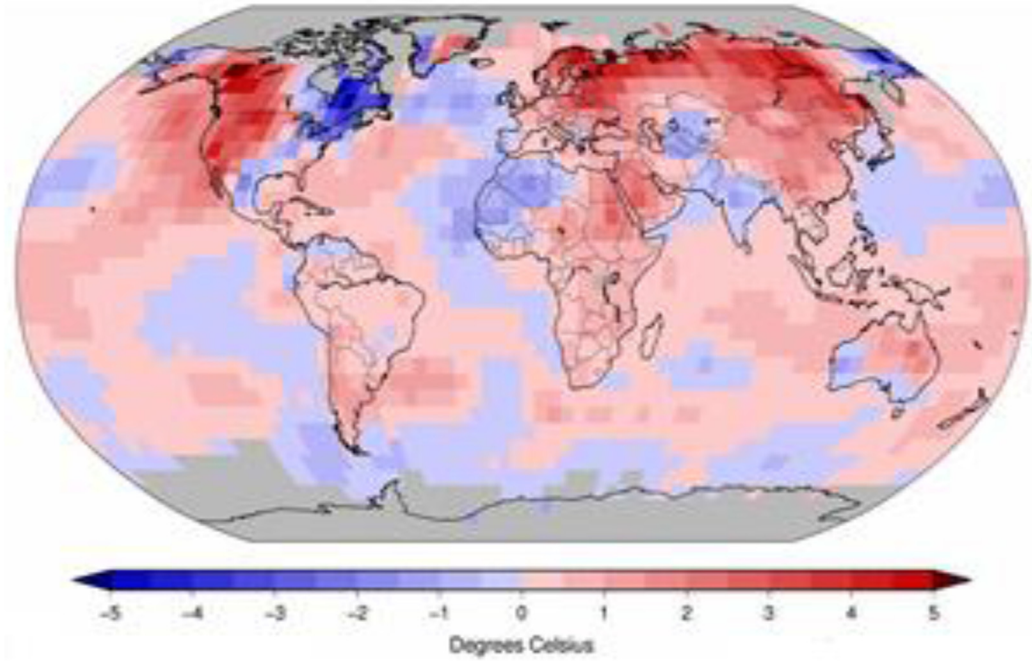

Fig. 2. Land & Ocean temperature departure from average mar 2015 (with respect to a 1981–2010 base period) [20].

1.1. Global warming in Malaysia

Weather in Malaysia is tropical because it's nearness to the equator, which stretches from latitudes 0° 60′ N to 6° 40′ N and from longitudes 99° 35′ E to 119° 25′ E. Malaysia's climate is categorized as equatorial (tropical rainforest) climate, being hot and humid throughout the year. This climate is characterized by maritime monsoon winds which are subject to interference by mountains in Peninsular Malaysia, Borneo, and Sumatra [21]. The monthly mean air temperature is 26–28 °C in the coastal lowlands and monthly relative humidity is between 75 and 90% [22]. A Climate of Peninsular Malaysia and East Malaysia differ. The climate in the former is directly affected by wind from the mainland, as opposed to the more maritime weather. Meanwhile, the latter faces the Southwest Monsoon from late May to September and the Northeast Monsoon from November to March. The Northeast Monsoon brings more rainfall compared to the Southwest Monsoon, originating from China and northern Pacific. Temperature changes in Malaysia ranges from +0.3 °C to +4.5 °C and rainfall changes range from −30-+30%. The mean temperature in the lowland's ranges from 26 to 28 °C with little variation in different months or across different latitudes [22].

The climate change impact is concern in Malaysia. 2012 Climate Change Performance Index (CCPI) ranks Malaysia among the least in climate protection performances. This constitutes potential threats not only to national food security but also, the country's export earnings from plantation crops. This is because any unfavorable climate negatively affects agricultural productivity [23]. Evidence abounds on the fact that Malaysia has been witnessing long-term inconsistent changes in its climate pattern with rapid acceleration in recent decades. Most of such fluctuations are revealed in El Nino disasters, which caused dry, hot weather leading to unusual minimal amounts of rainfall in the respective years [21].

The conservation and restoration of mangroves and associated coastal ecosystems play important roles in climate change adaptation strategies. Mangroves are not only valuable in climate change mitigation efforts but are also influential in adaptation strategies to changing climates [2,24]. Due to the affect mangroves have in adapting to climate change, more investments should be funneled to its development plans, as climate change adaptation is a growing concern in most international development agendas [15]. Thus, the objective of this study is to determine the effects of different temperature under elevated CO_2 that expected at the end of this century, on the growth of the most dominant and commonly distributed mangrove forest from the Rhizophoraceae family found in Malaysia [25], Wherefore the mangrove forests should be preserved, particularly due to their economic importance and their important role in preserving the ecosystem and diversity of organisms.

2. Materials and methods

2.1. Growth facility

This research study was conducted at the "Tropical Ecophysiology Lab.", in UKM, Bangi, Malaysia (2° 55′ 12.03″N, 101° 47′ 2.99 E). The facility consists of Plant Growth Chamber model (GC-202C), the plant growth chamber monitored and controlled the relative humidity (±1.0% at 80%), lighting (1000 μmol m− 2 s− 1 PAR), temperature set at 21/18 °C, 28/25 °C and 38/35 °C (day/night) and CO_2 sensors (650 ± 30 ppm) for the whole project duration, which took three months. The mangrove plant seedlings with soil were collected at the age of three months from Kuala Gula in Perak (4.924012, 100.459581). These mangrove seedlings were transplanted inbox size (42–62 cm).

The mangrove seedlings were planted in two groups with seven samples in each box. Two weeks later, the samples were checked in terms of physical growth. All the plants that were rated as 'in good health' were transferred to the plant growth chambers. The first group was exposed to levels of the plant growth chamber at temperature 21, 28 38 °C + CO_2 650 ppm, depending on the temperature recorded in Malaysia (24–35 °C) Fig. 3, so the temperature was increased and decreased ±3 °C Fig. 4, according to Malaysian temperature that mentioned in earlier studies. Which will be useful in breeding cultivars for future climates and improving mangrove plant accuracy to predict mangrove performance in a future high CO_2 (650 ppm) environment with frequent heat waves [26]. Meanwhile, the plants were watered with two litres of saline water (28 ppt) every 48 h and were not given any fertiliser.

All dead or damaged plant material was removed from the mesocosms, and all visible fauna (e.g. snails and crabs) were removed to avoid confounding effects of soil burrowing, herbivory, and other activities. Each mangrove seedling was labelled according to groups and treatment. Any changes in the seedling health were also recorded qualitatively.

2.2. Experimental design and growth measurement

The plant growth parameters were measured to study the response of the mangrove plants to an elevated CO_2 concentration and air temperature. The measurement of the number of leaves, plant height, number of branches, and Diameter of stems, all the morphological parameters, were done manually using the foot rule, and Log rule calliper, the photosynthesis rate were measured by using a Li-cor 6400 at 11 am for all Li-cor measurements, before each measurement, leaves were equilibrated in the cuvette at saturating PPFD (1000 μmol m− 2 s− 1 PAR), temperature set at 28 °C, CO_2 − 400 μmol mol^{-1} and Flow

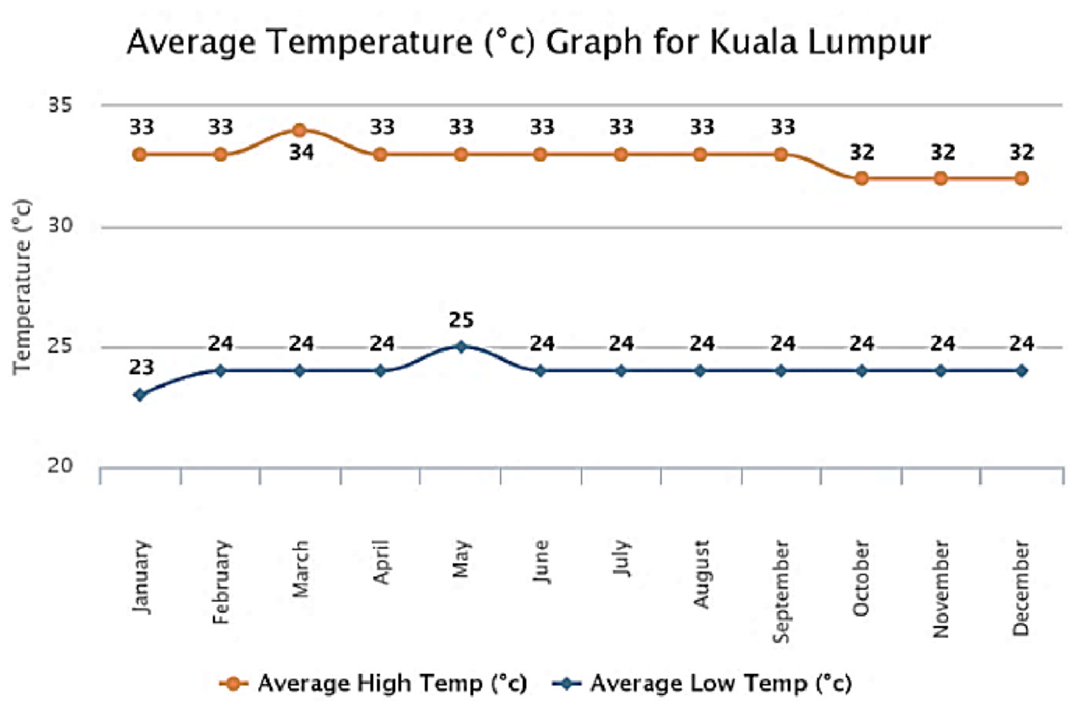

Fig. 3. PRECIS Average annual temperature anomaly [22].

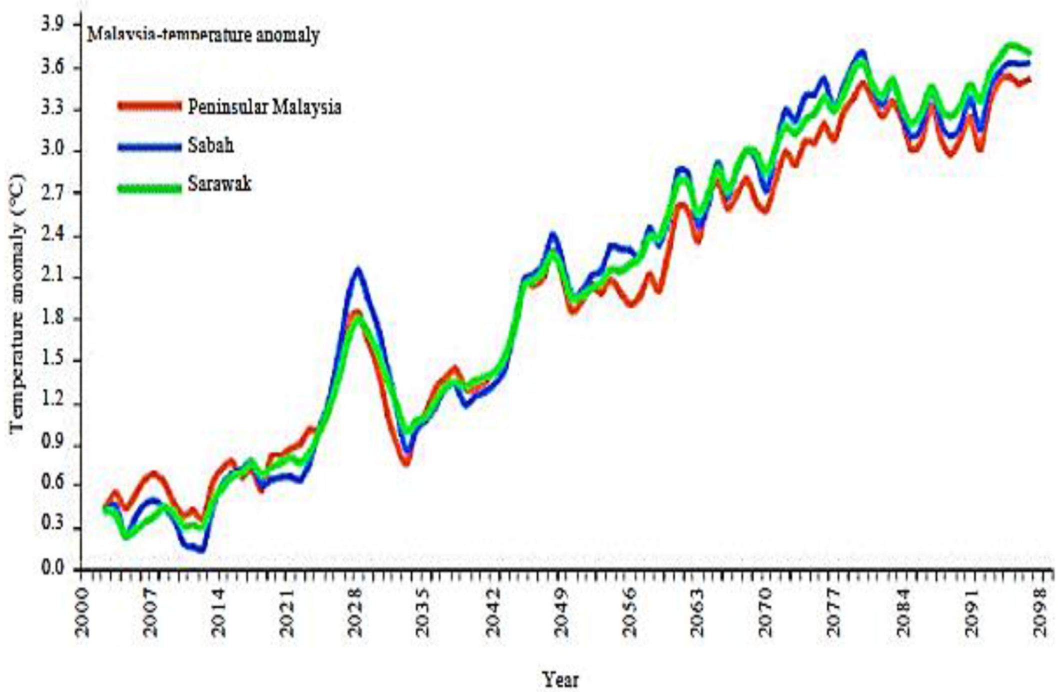

Fig. 4. PRECIS simulation (2001–2099) annual temperature anomaly [22].

rate − 300 mmol s^{-1} for most systems, and 200 mmol if photosynthesis is low. Determination of chlorophyll concentration was conducted using standard procedure on the reduction of the acetone volume [27]. Where 0.1 g of mangrove plants leaves were chopped into small pieces (about 2 mm), the leaves were put into a test tube, after which 20 ml 80% acetone was added to the test tube. The mixture was homogenised by a shaker and then incubated in the dark for 48 h. Concentrations of chlorophyll *a* and chlorophyll *b* were analysed using a spectrophotometer at the wavelength of 663 nm and 645 nm, respectively. The chlorophyll concentrations were calculated using [28,29] the following equations:

$$C_{chl\text{-}a} = 12.7A_{663} - 2.69B_{645}$$

$$C_{chl\text{-}b} = 22.9\ A_{645} - 4.68\ B_{663}$$

$$\text{Total chlorophyll} = C_{chl\text{-}a} + C_{chl\text{-}b}$$

Fresh and dry weights of the seedlings were measured using a digital scale, of which the dry weight was obtained after the samples were dried in the oven at 65 °C for seven days. The measurement was done three times. The first quantitative measurement was made on the 1st of July 2016 and the second on 17th of August 2016 (after 45 days) and the measurements were made until the final measurements on 1st of October 2016 (after 90 days). The data was analysed to examine the plant growth changes within eight weeks.

2.3. Data analysis

The experimental data was subjected to a variance analysis (ANOVA) via SAS (Release 9.4) software and Duncan's multiple-range tests (DMRT) determined a significant difference at $\alpha = 0.05$ level.

3. Results and discussion

The results show after two weeks, the mangrove plant samples recorded positive results for all parameters of high temperature. The differences in temperature resulted in significant differences and positive responses between elevated CO_2 and decreased temperature, which led to the samples surviving for all parameters and the growth being very slow. However, when the temperature is raised, the result is negative, and almost all of the samples perish.

3.1. Seedlings preparation and growth measurement

Seedlings growth parameters (plant height, the number of branches, and stem diameter) between treatments different temperature displayed various responses depending on the number of days of

Table 1. Growth parameters of mangrove seedlings R. apiculata subjected to elevated CO_2 concentrations and different air temperature.

Parameters	CO_2 concentration (650 ppm)								
	1 Day			45 Days			90 Days		
	Temperature 38 °C	Temperature 28 °C	Temperature 21 °C	Temperature 38 °C	Temperature 28 °C	Temperature 21 °C	Temperature 38 °C	Temperature 28 °C	Temperature 21 °C
Plant height(cm)	58.5 ± 0.5^{b}	55 ± 0.33^{c}	46.5 ± 0.53^{e}	60.5 ± 0.45^{a}	56 ± 0.61^{c}	47 ± 0.94^{e}	59 ± 0.99^{b}	56.33 ± 0.2^{c}	49 ± 0.93^{d}
Number of branches	8.7 ± 0.57^{b}	7 ± 0.34^{c}	4.7 ± 0.56^{d}	11 ± 0.57^{a}	7.33 ± 0.23^{c}	6.7 ± 0.1^{c}	11 ± 0.95^{a}	8 ± 0.19^{b}	7 ± 0.57^{c}
Number of leaves	11.3 ± 0.57^{a}	7.66 ± 0.11^{c}	7.3 ± 0.53^{c}	10.7 ± 0.55^{a}	4 ± 0.23^{d}	9 ± 0.18^{b}	7 ± 0.1^{c}	3 ± 0.12^{e}	8.3 ± 0.45^{b}
Diameter of stems	2.55 ± 0.02^{c}	2.2 ± 0.01^{e}	2.67 ± 0.01^{b}	2.56 ± 0.02^{b}	2.2 ± 0.012^{e}	2.69 ± 0.01^{a}	2.54 ± 0.02^{cd}	2.28 ± 0.02^{d}	2.71 ± 0.02^{a}

Note: Mean ± standard deviation (SD) followed by different letter of the same rows parameter of treatment is significantly tested using (DMRT) at $\alpha = 0.05$ level.

treatments. Observations on plant height, the number of branches, and stem diameter showed increased significant differences between the treatments after 1–45 days of exposure. Subsequent observation after 45–90 days of treatments revealed various responses depending on different temperature and number of days of treatments Table 1.

At 90 days of exposure, the mean height of plants under temperature 21 °C increased. Whereas the plants below temperature 38 °C decreased. Table 1. The difference in temperature resulted in a significant difference in the number of leaves in which of the plants further down temperature 21 °C at 1–45 days was increased but at 90 days was decreased. On another hand, the plants under temperature 38 °C continued to decline until most samples died Table 1. To illustrate, the result of Number of branches was not significant between 45 and 90 days for the plants below temperature 38 °C. The increase in the number of branches for the plants under temperature 21 °C at 90 days was slightly significant, Table 1. At 90 days of exposure, the mean diameter of stems under temperature 21 °C increased. Whereas the plants further down temperature 38 °C decreased Table 1.

3.2. Photosynthetic rate, biomass and chlorophyll concentration measurement

The result shows that the photosynthesis rate (*An* in μmol CO_2 $m^{-2}s^{-1}$), process was poor and inefficient under elevated CO_2 concentration and different temperature. Photosynthesis responses declined gradually and slowed down at 1–45 days depending on different temperature and the number of days of treatment. At 90 days of exposure, the Photosynthesis responses declined under temperature 38 °C, whereas the plants under temperature 21 °C recovered in photosynthesis responses Fig. 5.

The result found that the total chlorophyll under different temperature displayed various responses depending on the number of days of treatments. Total chlorophyll increased gradually at 1–45 days for all treatments. At 90 days of exposure, the total chlorophyll declined significantly under temperature 38 °C, whereas the plants further down temperature 21 °C declined slightly. Fig. 6.

Observation of the fresh and dry shoot weight and fresh and dry root weight of mangrove plant showed a significant difference in all parameters. The fresh mangrove shoot weight is higher for temperature 21 °C at 84.1 g compared to 56.8 g in temperature 38 °C Table 2. The dry shoot weight of

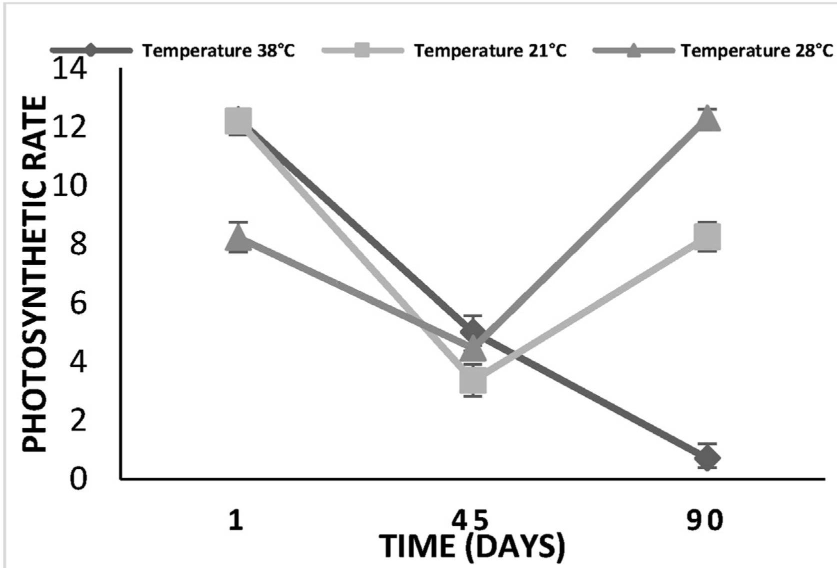

Fig. 5. Photosynthesis rate responses to different temperature at elevated CO_2 (650 ppm) of mangrove seedlings R. apiculate.

the plants is higher in temperature 21 °C, which is 14.7 g compared to 6.1 g at temperature 38 °C.

The mean fresh mangrove root weight at temperature 38 °C averaged at 31.6 g, while the temperature 21 °C at 73.9 g. The dry root weight at temperature 38 °C averaged at 13.5 g while in temperature 21 °C the average was higher at 23.3 g. The percentage increase in the growth of the mangrove plant in ascending order is fresh shoot weight, fresh root weight, dry root weight, and dry shoot weight.

The results showed significant differences in the parameters studied and affected by different temperature, various responses were displayed depending on a number of days of treatments. There was an observed response on the morphological parameters, especially on the number of leaves that saw a significant decrease, the physiological parameters were affected the plant reaction increased the total chlorophyll to increase the photosynthesis rate for adaptation and resistance to variable conditions, especially after the first 45 days. That means, the elevated atmospheric carbon dioxide is useful for the plant photosynthesis, but more than the optimum rate has become counterproductive [8,10]. The increase in temperature leads to an imbalance between the respiration and photosynthesis rate, is considered

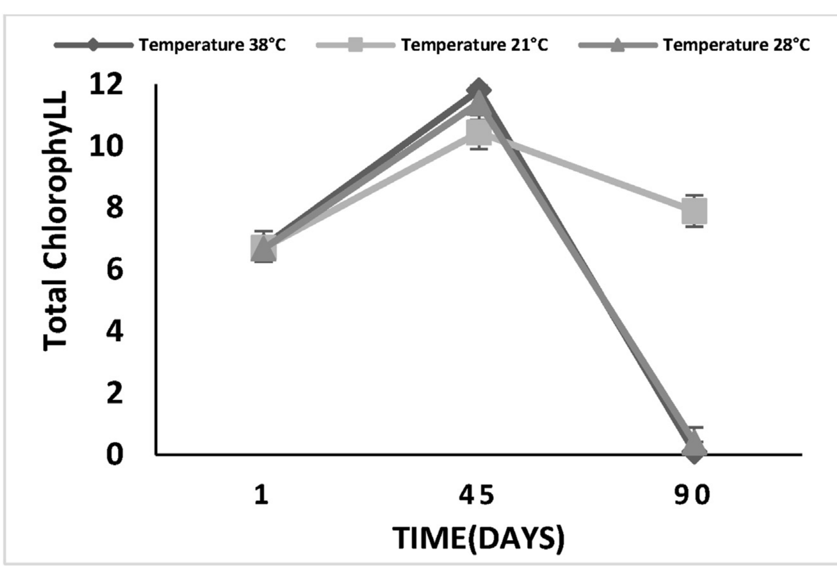

Fig. 6. Total Chlorophyll responses to different temperature at elevated CO_2 (650 ppm) of mangrove seedlings R. apiculate.

Fig. 7. The impact of elevated CO_2 and high temperature on mangrove plants inside the growth chambers displayed various responses depending on a number of days of treatments (A) Plant growth chamber (B) mangrove plants responses at 45 days in temperature 38 °C (C) mangrove plants responses at 90 days in temperature 38 °C, and (D) Mangrove plants responses at 90 days in temperature 21 °C.

Table 2. Responses of mangrove seedlings R. apiculata to elevated CO_2 conditions (650 ppm) and air temperature at the end of the experiment.

	Shoot		Roots	
Treatment	Fresh weight (g)	Dry weight (g)	Fresh weigh (g)	Dry weight (g)
Temperature 38 °C	56.8 ± 0.7^c	6.1 ± 0.1^c	31.6 ± 0.57^b	13.5 ± 0.4^b
Temperature 28 °C	58 ± 0.11^b	12.7 ± 0.07^b	28.8 ± 0.04^c	11.3 ± 0.12^c
Temperature 21 °C	84.1 ± 0.1^a	14.7 ± 0.2^a	73.9 ± 0.3^a	23.3 ± 0.7^a

Note: Mean ± standard deviation (SD) followed by different letter of the same column of treatment is significantly tested using (DMRT) at $\alpha = 0.05$.

a toxic factor, that damage the protein components of the protoplast, the destruction of chlorophyll, yellowing of leaves and thus inhibiting growth, which affected the photosynthesis rate [2,30]. This leads to fact that means the high-temperature presence has a negative impact on mangrove growth that was clear at the end of the study (90 days).

Most of samples died in this treatment. This indicates that the increase in temperature has a physiological effect on the plant, through the effect on the biological activities within the plant, especially enzymes [6,10] (Rubisco enzyme responsible for CO_2 fixation in Calvin cycle). However, the Rubisco limits photosynthesis when electron transport limitations dominate and there can be a rapid fall-off of the photosynthetic rate at high temperatures. Therefore, the impact on the control of carbon fixation by manipulation of one enzyme would differ depending on growth conditions [26,31]. As for the low temperature, its effect was very slow, leading to slow growth and the survival all the plants, which is why the studied morphological parameters did not show great differences compared to samples in high temperature, but there was a clear effect on photosynthesis at elevated CO_2 and low temperature. The results of this study were identical to Yamori 2013 [31].

Climate change on mangrove plants is considered dangerous by interference between biotic and abiotic factors in global warming. Especially during the early phases of growth. Where these results provide confirmatory evidence that the effect of the elevated CO_2 and temperature is negative and dangerous and will not only affect the geographical distribution of mangrove plants but also their survival. Moreover, the other factors may have a different effect, so the study should be increased in this field to improve the knowledge of the climate factors impact, which could affect growing season length. Indeed, evidence of changes in growing season length exists [14], along with the effect time periods have on diurnal cycles, which have greatly affected plant growth compared to even temperature changes over 24 h and the extent of heat stress [1,2].

4. Conclusion

Generally, this research study showed that rising temperature levels have a significant impact on the growth rate. It is imperative to understand CO_2 responses in varying temperature ranges due to the history of GEC and its future and the different temperature ranges in different regions of the world. However, the impacts of T and CO_2 are not the only factors affecting plants, light, water, and nutrient supply are equally critical in assessing and interpreting the effects of increased CO_2. Nevertheless, the rapid responses to elevated carbon dioxide and temperature levels during the early phases of growth as in seedling establishment may be important determinants in the regeneration of species.

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