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Effect of different water regimes and plant growth regulators on growth, physiology and yield of banana (*Musa acuminata* cv. Berangan) in tropical climate

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ABSTRACT

A field investigation under tropical climate was undertaken in the research plot of the Universiti Putra Malaysia, Selangor, Malaysia to study the effects of exogenous application of plant growth regulators on growth performance, physiology changes and biochemical analysis of banana plants (*Musa acuminata* cv. Berangan) under irrigated and rainfed condition. The experiment was laid out as split-plot in randomized complete block design. Results showed that, banana plants grown under the rainfed condition significantly reduced morphological characters such as plant height, pseudo-stem, canopy diameter, but enhanced accumulation of proline and malondialdehyde content in leaves tissue of stress-treated plants. Physiological characters which include total chlorophyll content, relative water content and electrolyte leakage were measured and has indicated significant effect under two different water regimes. Application of plant growth regulators on Berangan banana under different water regimes able to tolerate water stress conditions by changes in vapour pressure deficit as affected by decreasing stomata opening besides enhanced net photosynthesis to produce higher yield of banana fruits.

Keywords: Water regime, water stress, banana, productivity, proline

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1 Introduction

Drought stress is one of the environmental stresses due to climatic change caused by water deficiency which may affect the yield and productivity of agriculture crop in many regions around the world (Riccardi et al., 2016). The changes and uneven distribution of rainfall in Malaysia fluctuate heavily from -30 to +30% coupled with the rise of temperature by 0.3 to 4.5 °C and rise in sea level is expected to be about 95 cm over a hundred years (Alam et al., 2011). The banana plant requires uniform warm and moist conditions for optimum growth and yield (Ismail et al., 2004). Banana plants are very sensitive to dry soil condition in which emerging leaves and growing fruits are affected by water stress conditions (Thomas and Turner, 1998). Water regime is a primary driver of water flow over a given time and predictability of inundation and drying phases (Rea and Ganf, 1994). Zingaretti et al. (2011) reported that during vegetative

stage of growth, water is essentially required by plant to obtain maximum yield, and that inadequate water uptake in this stage may reduce crop productivity. Under stressful condition, plant growth was affected due to changes in physiological and biochemical activity in the plant. Ingram and Bartels (1996) stated that either by endogenous molecular systems or exogenous application of compounds to mitigate the stress, were able to protect the plant cell from severe damage.

Exogenous application of brassinolide (BR) as growth regulator may influence processes of growth and development in plants in response to mitigate the abiotic stresses (Montoya et al., 2005). In addition, BR increased tolerance against high temperatures in *Brassica napus* (Singh and Shono, 2005). Improving the plant growth performance and crop productivity by using anti-transpirant becomes important in the modern agriculture for increasing water stress use efficiency and water stress resistance by tending stabilizing cell structure. Anti-transpirant materials potentially reduce transpiration rate and increasing turgidity of leaves as well as stomata guard cell (Davenport et al., 1972). Magnesium carbonate ($MgCO_3$) is suitable to be used as anti-transpirant that closes stomata to reduce transpiration rate and train plants by gradually for hardening in increasing drought resistance. In addition, the normal concentration of carbon dioxide (CO_2) in the atmosphere is approximately 0.04%, which means that most cultivated plants fail to achieve the optimum level of photosynthetic rate. Treatments with calcium carbonate ($CaCO_3$) 79.19% on broccoli plant able to give direct effects of increasing CO_2 and enhanced the plant growth and development (Abdel, 2014).

Foliar sprayed fine particles (<10 μm) of $CaCO_3$ that can easily be adsorbed directly through the stomata of plant leaves that has potential to increase and sustain improved plant metabolism. The mode action of $CaCO_3$ particles in the leaf intercellular spaces is to break down and release gaseous CO_2 besides increase CO_2 levels within the plant leaf structure in order to enhance photosynthetic efficiency. Carmen et al. (2014) noted that the application of Lithovit as foliar fertilizer consist of calcium carbonate on the leaf surface of tomato plant resulted in highest photosynthesis intensity.

Hence, in relation to water stress due to shortage of water, the main objective of this study is to evaluate the reactions of banana plant as influence by application of plant growth regulator (PGR) or minerals on growth, physiology, biochemical changes and yield under water stress conditions in the tropical climate.

2 Materials and Methods

2.1 Experimental site, plant materials and design

Field experiment was conducted at Field 15, Faculty of Agriculture, Universiti Putra Malaysia (UPM), Serdang, Selangor. *Musa acuminata* cv. Berangan plantlets were obtained from Permata Holdings Sdn. Bhd. which is located at Kuala Pilah, Negeri Sembilan. The experiment was laid out as split-plot in randomized complete block design (RCBD) with three replications. Water regime treatments were assigned to the main-plot and plant growth regulator treatments were assigned to the sub-plots. Prior to the start of the experiment, the physicochemical properties of soil of the experimental site were determined data not shown.

2.2 Treatments and plant maintenance

Banana plants were subjected to two different water regimes: rainfed (average rainfall was simulated) and irrigated by micro-sprinkler system as control treatment for a continuous periods about 12 months. For Irrigated treatment, the soil moisture has been allowed to fluctuate only at field capacity range, so soil water potential was controlled in the range between -10 and -20 kPa as indicated by Tensiometer (Model: Irrometer LT 0702685048307) at a depth of 15 cm below the surface. The leaves of the whole plantlets were foliar sprayed with three treatments of PGR: (i) BR as control, (ii) $MgCO_3$ + $CaCO_3$ (1:1, v/v) and (iii) BR + $MgCO_3$ + $CaCO_3$ (1:1:1, v/v). The solutions for BR, $MgCO_3$ and $CaCO_3$ were prepared by dissolving 6.88 g, 0.23 g and 3.96 g into 1 L of distilled water, respectively. Every treatment (200 mL) was applied at two weeks interval on upper and lower surface of the leaf of established Berangan banana. The plantlets were supplied with macronutrients and micronutrients in form of chemical fertilizer.

2.3 Determination of plant growth traits

Plant height was taken from the soil surface level until the first internode located at the top of plant shoots using measuring tape. Canopy diameter was taken using measuring tape at end to end of leaves canopy. The data were measured at monthly basis. Meanwhile, pseudo-stem diameter was measured by using vernier calliper.

2.4 Measurement of leaf gas exchange

The rate of the net photosynthesis, stomata conductance, transpiration rate and vapour pressure deficit (VPD) were determined at four months after transplanting by an equipment that analyse infrared light

and operate in a closed system (Model: L1-6400, Li-Cor, USA). Data was collected by choosing fully developed healthy leaf. All the readings were taken at the same day within 1 h.

2.5 Determination of chlorophyll content

Chlorophyll content was determined following Coombs et al. (1985) method. Four gnows of banana leaf were done on each leaf by using cork borer. Samples were put into vial (readily covered with aluminium foil) which contained 20 mL of 80% (v/v) acetone. The samples were kept in dark place about 7 d until all the chlorophyll was extracted from leaves. Analysis to determine chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll content (Chl a+b) were determined by using spectrophotometer (Model: UV3101 PC, Shimadzu, Japan) at wavelength of 664nm and 647nm. Chl a, Chl b and Chl a+b contents were calculated as follows:

$$\text{Chl}_a = 13.19(\text{A}_{664}) - 2.57(\text{A}_{647}) \quad (1)$$

$$\text{Chl}_b = 22.1(\text{A}_{664}) - 5.26(\text{A}_{647}) \quad (2)$$

$$\text{Chl}_{a+b} = \frac{3.5(\text{Chl}_a + \text{Chl}_b)}{4} \quad (3)$$

where, Chl_a, Chl_b, and Chl_{a+b} are Chlorophyll a, Chlorophyll b and Chlorophyll a+b, respectively in mg cm^{-2} fresh leaf area. A_{647} and A_{664} represent absorbance of the solution at 647 and 664 nm, respectively, while 13.19, 2.57, 22.1 and 5.26 are the absorption coefficients, 3.5 was total volume used in the analysis taken from the original solution (mL) and 4 was the total discs area (cm^2).

2.6 Relative water content determinaiton

Relative water content (RCW) of leaves was estimated according to the method of Weatherley (1950) and expressed in percentage. Samples of the fresh leaf (0.5 g) were saturated in 100 mL distilled water for 24 h at 4 °C in the dark and their turgid weights were recorded. Then, oven-dried at 65 °C within 48 h and their dry weights were recorded. RWC was calculated as follows:

$$\text{RWC}(\%) = \frac{(\text{FW} - \text{DW})}{(\text{TW} - \text{DW}} \times 100 \quad (4)$$

where, FW, DW and TW are fresh weight, dry weight and turgid weight, respectively.

2.7 Determination of electrolyte leakage

The electrolyte leakage (EL) of membrane was assessed as their membrane permeability according to Lutts (1996). Leaf discs (1 cm in diameter), were taken from the well-developed leaves and washed with deionized water then placed in individuals vials containing 10 mL of deionized water. These samples were incubated at room temperature (25 °C) on a shaker (100 rpm) for 24 h. Electrical conductivity (EC) of bathing solution (EC_1) was read after incubation. The same samples were placed in an autoclave at 120 °C for 20 min, and the second reading (EC_2) was determined after cooling to room temperature. The electrolyte leakage was expressed following the formula:

$$\text{EL} = \frac{\text{EC}_1}{\text{EC}_2} \times 100 \quad (5)$$

2.8 Determination of proline and lipid peroxidase activity

Determination of proline content was carried out as described by Bates et al. (1973). The plant material (0.5 g) was grinded with 10 mL 3% sulfosalicylic acid. The homogenate was filtered. 2 mL of acetic acid and 2 mL of acidic ninhydrin reagent were added to a 2 mL aliquot. The mixture was thoroughly stirred and incubated in a boiling water bath for 1 h. Then it was transferred to ice bath and warmed to room temperature. Toluene (4 mL) was added to the mixture and the extinction of upper toluene level was measured at 518 nm by using a spectrophotometer (Model: Shimadzu UV-160A Visible Recording Spectrophotometer, Japan).

Determination of lipid peroxidation was made in terms of malonyldialdehyde (MDA) content, a product of lipid peroxidation was conducted by following Heath and Packer (1968). One gram fresh banana leaf sample was macerated in 3 mL of 0.1% thrichloroacetic acid (TCA) and then, homogenate was centrifuged at 10000×g for 20 min. A 0.5 mL, aliquot of the supernatant was mixed with 1.5 mL solution of 20% TCA containing 0.5% Thiobarbituric acid (TBA). The mixture was heated at 95 °C for 30 min and cooled quickly on ice bath and the warming to room temperature. The extinction was measured at 532 nm and 600 nm by using a spectrophotometer (Model: Shimadzu UV-160A Visible Recording Spectrophotometer, Japan). Lastly, the MDA content was calculated and expressed as μmol MDA per gram fresh weight.

2.9 Statistical analysis

All data collected from the experiment were recorded and analysed using analysis of variance (ANOVA) by SAS 9.4 to determine the significant difference between the treatment means. Differences between Means were separated using least significant difference (LSD) at $P<0.05$ level. Correlation analysis

was also performed to establish relationship between physiological parameters and yield of banana.

3 Results and Discussion

3.1 Plant growth traits

Plant growth and productivity of banana plant is greatly affected by water regime which effect suppresses cell expansion and cell growth of the plant. Results in the Table 1 showed that there were no significance interaction ($p<0.05$) between water regime and plant growth regulator (PGR) treatments on the various growth traits and yield of banana plant. Plant treated under rainfed condition significantly reduced in plant height by 26.98%, pseudo-stem diameter by 8.58%, canopy diameter by 25.62% and yield by 18.85% as compared to irrigated plant. Singer et al. (2003) stated that water stress can reduce plant growth and retard the development of plant reproductive organs of *Phaseolus vulgaris* due to the changes in the distribution of assimilates in the plant cells. Previous studies by Wu et al. (2008) noted that the plant height of citrus seedlings was reduced up to 25% under water stressed condition. In addition, the reduction in growth and development of plant considered a decline in the rate of cell division process and more leaf senescence in *Abelmoschus esculentus* under water stress condition (Bhatt and Rao, 2005). Baher et al. (2002) had the same opinion that even though the water stress was not severe, the plant growth and dry matter production of *Satureja hortensis* L. might be decreased due to decline in the cell enlargement. However, decrease in total leaf area and total leaves number under water stress might have effect on the canopy diameter of banana plant.

The application of BR + $CaCO_3$ + $MgCO_3$ treatment under both water regimes significantly increased plant height by 13.67%, pseudo-stem diameter by 7.98% and yield by 17.87% as compared to the control treatment. However, canopy diameter did not differ in between all treatments. Basically, weak morphological characteristics will consequently reduce growth and yield of banana plant under rainfed condition. When banana plant experienced severe water deficiency, all the leaves will fall prematurely and reduced the growth of pseudo-stem diameter tissues (Stover and Simmonds, 1987). Plant stress significantly decreased the total leaf area and total leaf number besides dry matter weight and dry fruit yield of pepper plant also decreased as a result of plant under water stress condition (Ismail et al., 2002).

3.2 Leaf gas exchange

In Table 2, results showed that there were no significant interaction between different levels of water regime and PGR on photosynthesis and transpiration rate, whereas stomata conductance and VPD were showed significance interaction between these factors. Significant increased in canopy diameter size was reflected by the increase in total leaf number under irrigated plant indicates an increase in the photosynthetic capacity of the plant. Comparison of two treatments at main plot revealed rainfed plants significantly lower in Ps by 7.31% compared to irrigated plants, while transpiration rate did not differ in both comparison of treatments. Among the sub-plot treatments, BR + $CaCO_3$ + $MgCO_3$ significantly increased in net photosynthesis by 9.03%, but transpiration rate significantly reduced by 34.05% compared to BR as control treatment. Cornic and Massacci (1996) stated that physiological characteristics of plant such as photosynthesis and transpiration rate may change during plant under water stress condition. Khalil (2006) reported that reducing transpiration rate able to prevent the excessive loss of water to the atmosphere via stomata. In turn effect of reduced photosynthesis and assimilate partitioning in leaves of pepper plant under water stress condition caused reduction in plant growth and yield (Aloni et al., 1991; Dorji et al., 2005). Therefore, banana plant is relatively sensitive to water deficiency which able to affect the efficiency of photosynthesis and transpiration rate.

In principle, increases in stomata conductance which regulates CO_2 entering and water vapour existing through the stomata of a leaf and subsequently enhance photosynthesis rate. Fig. 1(a) showed the stomata conductance had significant interaction between different water regime and PGR treatments. Under rainfed condition, $CaCO_3$ + $MgCO_3$ gained the lowest mean value of 0.11 mmol $m^{-2}s^{-1}$ and BR were the highest mean value of 0.57 mmol $m^{-2}s^{-1}$, but irrigated plants showed BR + $CaCO_3$ + $MgCO_3$ gained the lowest mean value of 0.21 mmol $m^{-2}s^{-1}$. Generally, reduces stomata conductance due to increase CO_2 concentration which also may reduce stomata aperture. Zhu et al. (2011) mentioned that increases in CO_2 concentrations will decrease stomata conductance, but carbon assimilation in the intercellular cell could be maintained at levels seen.

From the perspective of plants, VPD is the difference between the vapour pressure inside the leaf compared to the vapour pressure of the air, however the changes of VPD of banana plants were depending on how plants react to humidity in the growing particular environment. Based on Fig. 1(b), water stressed plants under rainfed condition showed that $CaCO_3$ + $MgCO_3$ with mean value of 0.883 mol H_2O $m^{-2}s^{-1}$ were significantly higher by 13.49% compared to $CaCO_3$ + $MgCO_3$ of irrigated plants. Rainfed condition particularly subjected to the effects of weather conditions such as low rainfall high temperature especially during day time which may increase VPD. Sinclair et al. (2007) reported that it was very difficult to separate the impact of VPD and temper-

Table 1. Effect of different water regime and plant growth regulator (PGR) treatments on plant height, pseudo-stem diameter, canopy diameter and yield.

Treatment factors	Plant height (cm)	Pseudo-stem diameter (cm)	Canopy diameter (cm)	Yield (kg)
Main plot means				
Rainfed	242.11b	22.69b	270.33b	12.31b
Irrigated	331.56a	24.82a	363.44a	15.17a
$LSD_{0.05}$	65.25*	2.12*	12.45**	1.93*
Sub plot means				
BR	265.67b	23.32b	308.17	12.65b
$CaCO_3$ + $MgCO_3$	292.83a	22.77b	321.67	13.66ab
BR + $CaCO_3$ + $MgCO_3$	302.00a	25.18a	320.83	14.91a
$LSD_{0.05}$	16.18**	0.76***	NS	1.53*
Interactions	NS	NS	NS	NS

Table 2. Effect of different water regime and plant growth regulator (PGR) treatment on net photosynthesis, stomata conductance, transpiration rate and vapour pressure deficit (VPD).

Treatment factors	Photosynthesis (μmol CO_2 $m^{-2}s^{-1}$)	Stomata Conductance (mmol $m^{-2}s^{-1}$)	Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)	VPD (mol H_2O $m^{-2}s^{-1}$)
Main plot means				
Rainfed	22.667b	0.383	2.284	0.68
Irrigated	24.455a	0.345	1.962	0.668
$LSD_{0.05}$	1.08**	NS	NS	NS
Sub plot means				
BR	22.695b	0.580a	2.499a	0.399b
$CaCO_3$ + $MgCO_3$	23.243b	0.335b	2.220a	0.831a
BR + $CaCO_3$ + $MgCO_3$	24.744a	0.177c	1.648b	0.792a
$LSD_{0.05}$	0.99*	0.09***	0.57*	0.05***
Interactions	NS	**	NS	***

Table 3. Effect of different water regime and plant growth regulator (PGR) treatments on chlorophyll a (Chl a), chlorophyll b (Chl b), chlorophyll content (Chla+b) , relative water content (RWC), electrolyte leakage (EL), proline and malonyldialdehyde (MDA) content.

Treatment factors	Chl a (mg cm^{-2})	Chl b (mg cm^{-2})	Chl a+b (mg cm^{-2})	RWC (%)	EL (%)	Proline (μmol $mg^{-1}FW$)	MDA (μmol $mg^{-1}FW$)
Main plot means							
Rainfed	4.789b	1.384b	5.402b	59.23b	73.62a	35.63a	0.866a
Irrigated	5.583a	1.679a	6.355a	86.54a	62.32b	32.66b	0.611b
$LSD_{0.05}$	0.34*	0.13*	0.18**	9.08**	6.66*	0.25***	0.02***
Sub plot means							
BR	5.487a	1.664a	6.257a	70.34b	67.18b	33.30b	0.803a
$CaCO_3$ + $MgCO_3$	4.786c	1.336c	5.357c	73.84a	69.86a	35.49a	0.726b
BR + $CaCO_3$ + $MgCO_3$	5.287b	1.594b	6.021b	74.48a	66.87b	33.64b	0.687c
$LSD_{0.05}$	0.17***	0.06***	0.09***	3.37*	1.93*	0.43***	0.01***
Interactions	***	***	***	NS	NS	***	***

Means followed by the same letter within a column are not significantly difference at P = 0.05 by least significant difference (LSD) with n=18. *, ** and *** significantly difference at P = 0.05, 0.01 and 0.001, respectively and NS= not significant.

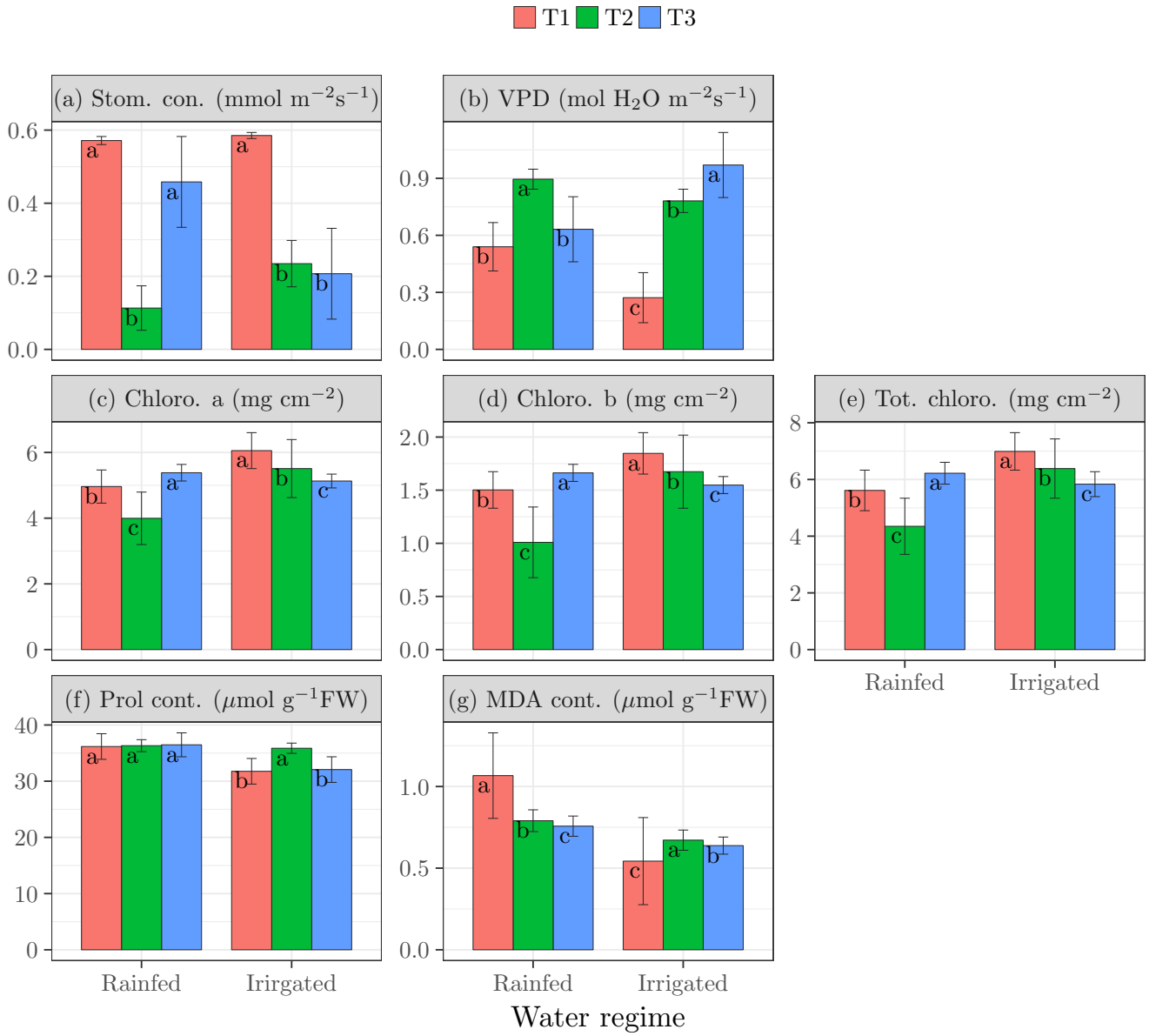

Figure 1. Effect of different water regime and plant growth regulator (PGR) treatments on (a) stomata conductance, (b) vapour pressure deficit (VPD), (c) chlorophyll a (Chl a), (d) chlorophyll b (Chl b) and (e) total chlorophyll (Chl a+b), (f) proline, and (g) malonyldialdehyde (MDA) content in the leaves. Mean values with the same letter are not significantly difference at P = 0.05 by least significant difference (LSD) with n=18. T1: BR, T2: $CaCO_3$ + $MgCO_3$ and T3: BR + $CaCO_3$ + $MgCO_3$.

ature directly on plants. However, BR of irrigated plants showed the lowest mean value of 0.269 mol H_2O $m^{-2}s^{-1}$ under both water regime as compared to others PGR.

3.3 Physiological attribute and biochemical content

Table 3 showed that there were no significance interaction between different levels of water regime and PGR treatmets on RWC and EL, whereas Chla+b, proline and MDA content showed significance interaction between these factors. The analysis of variance at main plot level revealed that rainfed plants significantly reduced in RWC by 27.31%, but significantly increased the percentage of EL by 11.3% as compared to irrigated plants. Similar result were found by Reddy and Vora (1986) that significant decreased in RWC in wheat plant under water stress condition and this might be due to decrease in internal water content of protoplasm. Blokhina (2003) stated that plant membranes which control the rate of ion movement in and out of cells are subject to changes often associated with the increases in permeability and loss of integrity under environmental stresses. Quan et al. (2004) also found significant increased percentage of EC in maize plant (*Zea mays* L.) under water stressed as compared to plant grown under well-watered conditions. Among the sub-plot treatments, BR + $CaCO_3$ + $MgCO_3$ had showed significantly higher in RWC by 4.14% compared to BR as control treatment. The lowest percentage of EL was gained BR by 67.18%, followed by BR + $CaCO_3$ + $MgCO_3$ by 66.87% and $CaCO_3$ + $MgCO_3$ by 69.86%.

Environmental stress such as drought condition may decline the content of Chl a, Chl b, and Chla+b in all sunflower plant due to water stress condition (Manivannan et al., 2007). Fig. 1(c) presented that BR as control treatment under rainfed condition significantly reduced the Chl a content by 18.69% compared to BR under irrigated condition with mean value of 6.05 mg cm^{-2}. Meanwhile, $CaCO_3$ + $MgCO_3$ under rainfed condition gained the lowest Chl a content with mean value of 4.01 mg cm^{-2} in the leaves tissues. The results of the Chl b are shown in Fig. 1(d). In particular, for irrigated treatment significantly higher in Chl b content in the leaves tissues compared to rainfed condition. Plant treated with BR under irrigated condition gained the highest Chl b content with mean value of 1.837 mg cm^{-2} which significantly increased by 23.29% compared to BR under rainfed condition. On the contrary, $CaCO_3$ + $MgCO_3$ under rainfed gained the lowest Chl b content with mean value of 1.002 mg cm^{-2} compared to other treatments.

Fig. 1(e) showed that $CaCO_3$ + $MgCO_3$ under rainfed condition with mean value of 4.38 mg cm^{-2} significantly reduced by 30.73% the Chla+b content as compared to $CaCO_3$ + $MgCO_3$ of irrigated plants. However, BR of irrigated plants gained the highest Chla+b content with mean value of 6.09 mg cm^{-2} compared to other treatments. The result was corresponding with what has been found by Ashraf and Mehmood (1990) that stated Chla+b content of the leaf for *Brassica* species declined under water stress conditions. Similar result was reported by Makhmudov (1983) that moisture stress in wheat plant may reduce the Chla+b content in the leaves.

Level of proline as affected by different water regime and PGR is shown in Fig. 1(f). The level of proline in well-irrigated plants remained low from 3.111 μmol g^{-1} to 35.342 μmol g^{-1} for BR and $CaCO_3$ + $MgCO_3$, respectively. Under rainfed condition, the level of proline was maintained at higher level (35.49 μmol g^{-1} to 35.75 μmol g^{-1}) than the level measured for well-irrigated plants. According to Zlatev and Stoyanov (2005) proline accumulation increased in the plant tissue when limited water in soil around the root besides it was useful as drought injury sensor which involved in stress tolerance mechanism as well as to avoid detrimental effects of water stress. Vendruscolo et al. (2007) also noted that higher proline content in wheat plants after water stress application.

Fig. 1(g) showed the level of MDA contained in banana plants grown under rainfed condition was maintained at higher level (0.74 μmol g^{-1} to 1.06 μmol g^{-1}) than the level measured for well-irrigated plants (0.54 μmol g^{-1} to 0.66 μmol g^{-1}). BR + $CaCO_3$ + $MgCO_3$ applied on rainfed plants significantly increased by 18.98% compared to well-irrigated plants. Sairam and Saxena (2000) stated that increasing water stress level may increase the level of MDA content from lipid peroxidation activity due to metabolic damage which resulting greater membrane injury and pigment bleaching.

3.4 Relationship between vapour pressure deficit and stomata conductance

Correlation analysis showed that VPD and stomata conductance under different water regime conditions and PGR had significant negative correlation (Fig. 2(a)). The stomata conductance started to decrease from a value of 0.64 mmol $m^{-2}s^{-1}$ to 0.11 mmol $m^{-2}s^{-1}$ when the VPD of banana started to increase from 0.25 mol H_2O $m^{-2}s^{-1}$ to 0.97 mol H_2O $m^{-2}s^{-1}$ under different water regime treatments. These results suggested that decreased in stomata conductance by stomata closure was leading to increase of VPD which indicating that the VPD driven transfer of water vapour from the leaf was becoming limited by stomata closure. Farquhar (1978) reported that somehow the response of increasing VPD, it was directly sense decreases the stomata conductance. Schulze et al. (1972) stated that stomata response to VPD is higher in dry than in wet soil.

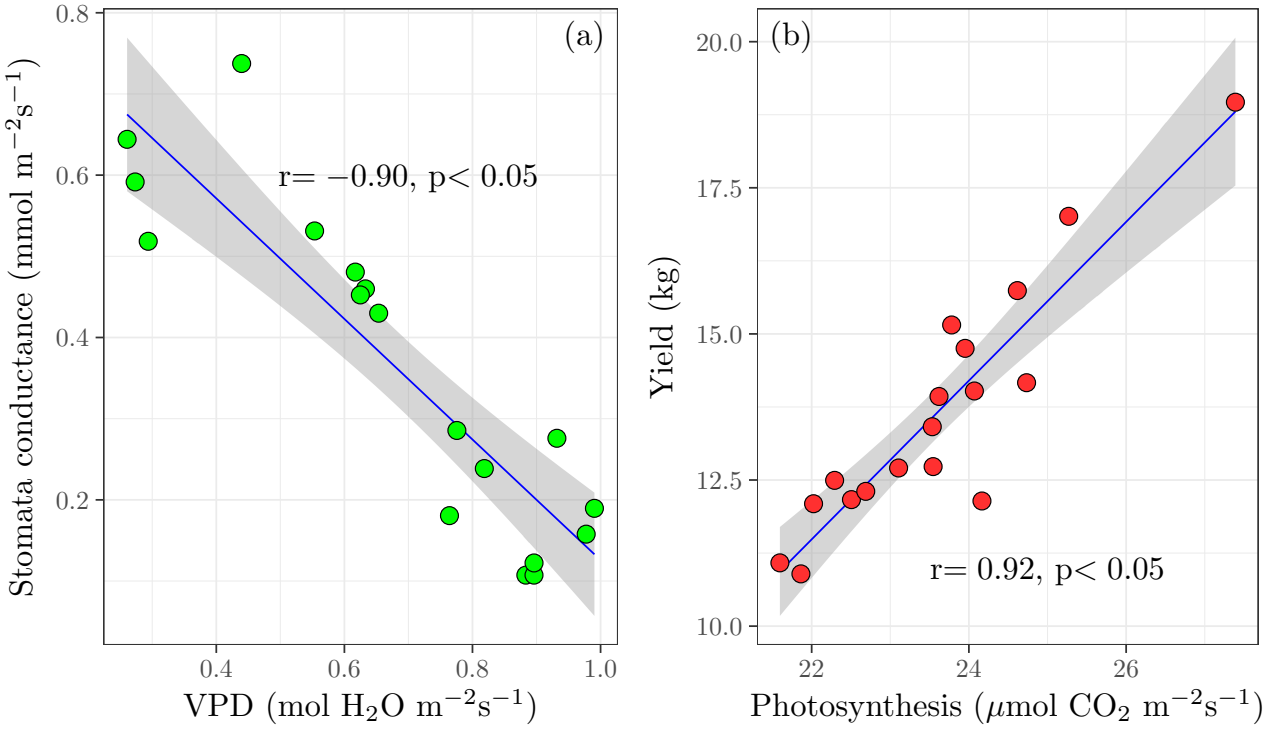

Figure 2. The correlation analysis between (a) vapour pressure deficit (VPD) and stomata conductance and (b) photosynthesis and yield as influenced by different water regime and plant growth regulator (PGR) treatments.

3.5 Relationship between photosynthesis and yield

Fig. 2(b) showed correlation analysis between photosynthesis and yield under different water regime condition and PGR had significant and positive correlation. The total weight of yield started to increase from a value of 11.20 kg to 19.0 kg when the photosynthesis rate of banana plant started to increase from 21.57 μmol CO_2 m^{-2}s^{-1} to 27.33 μmol CO_2 m^{-2}s^{-1} under different water regime treatments. These results suggested that an increase in photosynthesis rate directly proportional to yield production of banana. Constantly irrigate plants leads to be good in photosynthetic rate as a result for better yield of banana. Ke (1979) observed that in soils below 70% total available moisture, banana plants had lower chlorophyll, leaf dry mass, leaf conductance, photosynthetic rate and yield than plants in soil above 80% total available moisture.

4 Conclusion

Rainfed significantly reduced major growth parameters of plant height, pseudo-stem diameter and canopy diameter, but enhanced accumulation of proline and MDA content in leaves tissue. Application of $CaCO_3$ + $MgCO_3$ and Br + $CaCO_3$ + $MgCO_3$ on banana leaves increased VPD, but reduced stomata conductance. In addition, photosynthesis rate increased could be attributed from the increases in leaf area as well as photosynthesis rate simultaneously increased with total yield. However, Br + $CaCO_3$ + $MgCO_3$ shown increased in major growth characteristics, photosynthesis rate and yield of banana under irrigated treatment. Banana productivity is greatly reduced due to water stress were estimated which may affect the growth and development of banana. Foliar application of BR with combination of $CaCO_3$ and $MgCO_3$ is recommended to regulate mechanism of drought adaptation of banana (cv. Berangan) under field condition without negative effect on the harvested yield.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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