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Growth Responses of Okra (*Abelmoschus esculentus* L. Moench) to Selected Plant Growth Regulators

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ABSTRACT

This study was conducted to evaluate the effects of two types of plant growth regulators (PGRs) which are gibberellins (GA_3) and Paclobutrazol (PBZ) on the growth and photosynthetic pigment (chlorophyll) of Okra (Abelmoschus esculentus L. Moench*) plants. Exogenous applications of GA_3 and PBZ with different concentrations (i.e. 20, 40, 80 and 100 mg/L) were sprayed on two-week-old Okra plants under the nursery stage. The control plants were only treated with distilled water. The stem diameter (mm) of treated and control plants was measured weekly. At the end of the experimental period, data on growth characteristics such as plant height (cm), leaf area (cm^2) and number of leaves were recorded. The estimation of chlorophyll was measured using the SPAD-502 Chlorophyll Meter. Results showed that the plant morphological characteristics of Okra plants were significantly affected by the application of GA_3 and PBZ ($P<0.0001$). In addition, stem growth (expressed as stem cross-sectional area- mm^2) of Okra plants was significantly increased with increasing GA_3 concentrations. In contrast, applying PBZ reduced Okra plants' stem growth. This study highlighted the major effects of GA_3 and PBZ on the growth of Okra plants when planted under tropical climate conditions.*

Keywords: growth, PGRs, chlorophyll, GA_3, PBZ

1. INTRODUCTION

Okra (*Abelmoschus esculentus* L. Moench) is a well-known crop as 'Ladies Finger' and can be considered one of the world's oldest cultivated vegetable crops [1]. This crop originated and was discovered in the Abyssinian, an area that can be known recently as Ethiopia [1, 2]. Okra can be considered a flowering plant in the Malvaceae family and belongs to the herbaceous annual plants. It is widely cultivated worldwide, either in tropical, subtropical, or temperate regions. It also has green seeds that are soft and edible, containing rich sources of vitamins such as calcium, potassium, and other minerals [3]. Studies reported that fresh Okra contains energy, including water (90%), carbohydrate (7%), protein (2%) fibers such as hemicellulose, alpha-cellulose, pectin, lignin, fat, as well as a wax matter [3, 4]. Okra is also one of the most popular vegetable crops in Malaysia, especially on the Northern Peninsula. It can be found throughout the year and is very popular among farmers because it is easy to grow and has a broader range of adaptability. In 2021, it was reported that the planted area of Okra has been estimated to be around 3,283 hectares, producing 62,796 metric tons in Malaysia [5].

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Besides being a vegetable, Okra is also of medicinal and industrial importance. According to Xia et al., [6], who investigated the bioactive compound of Okra, they found that this crop had antioxidant, neuroprotective, anti-diabetic, anti-hyperlipidemia, and anti-fatigue properties, which can be described as an important edible vegetable for human consumption and health. Okra also contains fiber suitable for paper and cardboard for industrial purposes [7]. Many studies also found that biomass from the okra plant is a renewable, biodegradable, cost-efficient and low-density source for the production of bast fibers, and other industrial cost-efficient eco-friendly materials [7]. However, it was found that okra plant stems are normally discarded after the plants were not productive without suitable utilization.

Plant Growth Regulators (PGRs) play a crucial role in vegetable production by influencing various aspects of plant growth, development, and yield [8-10]. PGRs are considered organic compounds that modify plant physiological processes in small amounts. Application of PGRs has rapid effects on vegetative growth and yield of the crops. As it has various advantages like less time-consuming to treat the plant and being environment friendly. There are various types of PGRs that have been used in vegetable production, as reported in many studies [10-12]. However, in this study, we focus on two major types of PGRs: gibberellins (GA_3) and paclobutrazol (PBZ). Even though there are many reports on the use of PGRs in okra plants [8, 10, 13], the physiological mechanisms behind the effects of PGRs on okra plants under tropical climates are still not fully understood, especially under tropical growing conditions. Among PGRs, GA_3 are essential in regulating plant growth and development [14, 15]. Many forms of gibberellins are found in roots and young leaves, but GA3 is the most popular form. GA_3 brings many benefits to plant growth, such as increasing the elongation of stems and segments, producing seed germination, and promoting enzyme production during germination and involvement in fruit settings [9, 15].

In vegetable production, gibberellins have improved crop uniformity, germination, ease of harvesting and storage [16-18]. In contrast, the PBZ effect consists of chemical antagonists to GA_3. The PBZ acts as a plant growth retardant and is a compound used to reduce plant growth without changing the growth and pattern development or being phytotoxic [19]. By preventing plants from producing gibberellins, PBZ can slow down plant development by inhibiting internode connection and cell elongation. However, limited information is available on the effects of paclobutrazol and its potential usefulness to vegetable crops in tropical conditions. Therefore, the objectives of this study were to evaluate the impact of exogenous applications of GA_3 and PBZ on Okra plants (*Abelmoschus esculentus* L. Moench) under tropical climate conditions by studying its effect on vegetative growth characteristics and photosynthetic pigment (chlorophyll) of this vegetable crop.

2. MATERIAL AND METHODS

2.1 Preparation of Planting Materials

This study was conducted at the Institute of Sustainable Agrotechnology (INSAT) Sungai Chuhchuh Campus Padang Besar, Universiti Malaysia Perlis (UniMAP), Malaysia. The seeds of Okra (*Abelmoschus esculentus* L. Moench) were pre-germinated in the germination trays consisting of burned rice husk as germination media. Two weeks after germination, uniform seedlings of Okra with similar height and size were selected and transplanted to 15-liter growing pots containing topsoil, organic matter and fine sand at a 1:1:1 ratio. The seedlings already had 4 to 5 leaves on the main stem at this stage. All the plants were manually irrigated by applying 1 L of water daily. The seedlings were placed under the growing nursery with 50% netting shade cover for the hardening process until the plants were ready for PGRs application.

2.2 Application of PGRs

After one week of the hardening stage, different solutions of PGRs (i.e. GA_3 and PBZ) with various concentrations (20, 40, 80, and 100 mg/L) were applied to the leaves and stems of the Okra plants using 3-liter hand bottle spray (Table 1). Before that, both of PGRs were diluted using distilled water based on the recommendation of the chemical suppliers. To avoid any spray drift, the neighbouring plants with different treatments were covered using a clear plastic sheet. The control plants were only sprayed with distilled water. The application of PGRs (Table 1) was applied in the early morning and was conducted fortnightly for two consecutive months to give maximum effects to the plants.

Table 1: List of different concentrations of PGR treatments on Okra (*Abelmoschus esculentus*) plants under nursery.

Treatments	Concentration
Control	Distilled water
T1	20 mg/L of GA_3
T2	40 mg/L of GA_3
T3	80 mg/L of GA_3
T4	100 mg/L of GA_3
T5	20 mg/L of PBZ
T6	40 mg/L of PBZ
T7	80 mg/L of PBZ
T8	100 mg/L of PBZ

2.3 Experimental Design, Data Collection and Statistical Analysis

All the plants were arranged in Complete Randomised Design (CRD) with five (5) replicates per treatment. The stem diameter (mm) measured using a digital calliper and expressed as stem cross-sectional area (mm^2) was recorded weekly. At the end of the study period, the plant height (cm), and number of leaves, including fresh (g) and dry weight (g), were manually recorded. Besides that, non-destructive estimation of chlorophyll content was also recorded using a hand-held SPAD-502 Chlorophyll Meter follows the method by Ali et al. [20] and Limantara et al. [21]. All the recorded data were subjected to Statistical analysis (One-Way ANOVA) using a Statistical Analysis System (SAS) [22].

3. RESULTS AND DISCUSSION

3.1 Effects of PGRs on stem development of Okra plants

Figure 1 shows the effect of GA_3 and PBZ on the weekly mean stem cross-sectional area (mm^2) of Okra plants. The PGR treatments (either GA_3 or PBZ) were highly significant ($P<0.0001$) for all measurement weeks, indicating there was a strong effect of the application of GA_3 and PBZ on the stem development of Okra plants. The effect of GA_3 on the stem growth of Okra plants can be seen in the second week after the application (Figure 1), especially in the treatment of 80 mg/L and 100 mg/L of GA_3. With GA_3 application, the mean stem cross-sectional area (mm^2) was significantly increased. This effect persisted until week seven (7), especially in the plants treated with 100 mg/L of GA_3. As noted in many pieces of literature, gibberellins (i.e. GA3) can affect various aspects of cell growth and development, especially by promoting plant cell elongation [18, 23]. In addition, gibberellins have also been involved in stimulating cell division in the cambium, a layer of meristematic tissue responsible for the growth in the girth of stems. This leads to an increased number of cells, contributing to stem enlargement [24]. In contrast with the application of GA_3, PBZ treatment may have reduced the stem growth or enlargement of Okra plants compared with untreated Okra plants (Figure 1). It seems that the PBZ application had limited cell enlargement and cell division of Okra plants and it was occurred in the subapical meristematic of zone of the stem [25]. The results of the present study differed from Benjawan et al., [26] who found that PBZ did not affect stem diameter of Okra var' Har Lium'.

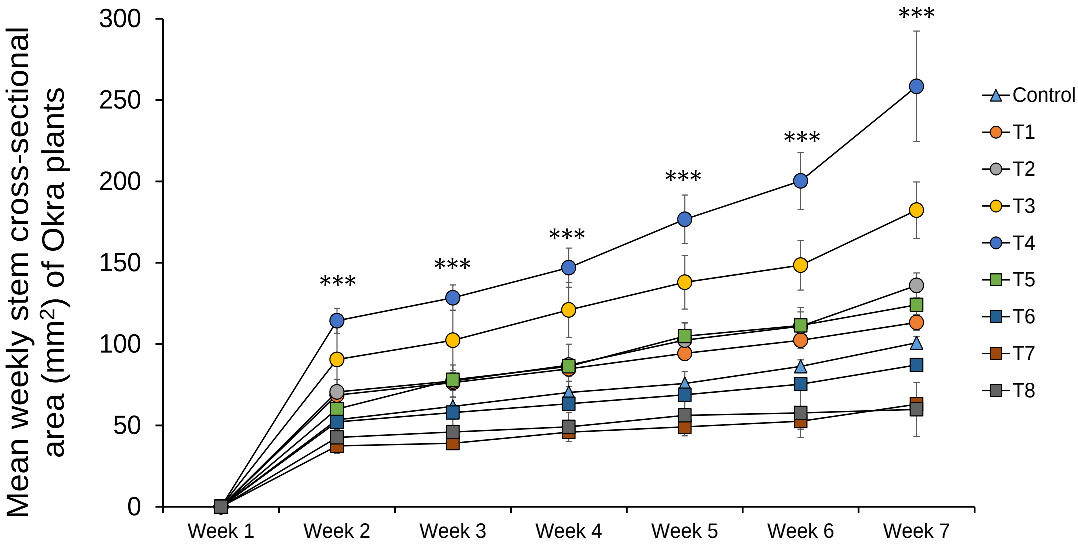

Figure 1: The effect of GA_3 and PBZ on the weekly stem cross-sectional area (mm2) of Okra plants. *** indicates significantly different between treatments at $P<0.0001$ according to Duncan's Multiple Range Test (DMRT) starting at 2nd week after application of both PGRs.

3.2 Effects of PGRs on plant height of Okra plants

Overall, results in Table 2 showed that the mean plant height (cm), mean leaf area (cm^2), mean leaf number and mean SPAD index of Okra plants were significantly affected ($P<0.0001$) by the application of GA_3 and PBZ. It was found that the application of GA_3 has increased the height of Okra plants by almost 38% compared to untreated plants (control). Our result also showed that increasing the GA_3 concentration will further increase the height of Okra seedlings (Table 2). The highest of Okra seedlings was recorded on the plants treated with 100 mg/L of GA_3. Contrasting results were recorded using the PBZ application. Increasing the PBZ concentration will decrease the height of Okra seedlings (Table 2). The shortest was recorded in the plants sprayed with 100 mg/L of PBZ. Application of PBZ at the highest concentration (100 mg/L) may have reduced the height of Okra by 38% compared to control, untreated plants. Results in our study are consistent with numerous recent reports that found the application of GA_3 had increased the height of Okra plants [27-32]. In plants, the gibberellins (especially GA_3) play an important role in controlling plant height by increasing cell division and elongation, resulting in increased height of plants [9].

Gibberellin has a function in plant growth as an increase in the length of the plant segment brought on by the cells that grow larger and more numerous. As a result, plants that get gibberellin can lengthen their stems [33]. On the other hand, the application of PBZ significantly reduced ($P<0.0001$) the height of Okra plants (Table 2). In our study, the reduction in plant height of Okra plants with the application of PBZ was similar to the previous findings [26, 34-37]. According to Desta & Amare [19], PBZ inhibits cell elongation and internode extension that retards plant growth by inhibiting gibberellins biosynthesis. Cell division occurs when gibberellin synthesis is suppressed, but the newly formed cells do not elongate. The end result is compressed shoots with the same number of internodes and leaves [19].

3.3 Effects of PGRs on leaf area and number of Okra plants

The leaf area (cm^2) of Okra plants was increased with increasing the application rate of GA_3, especially at 100 mg/L (Table 2). However, it was found that the mean leaf area of Okra (cm^2) was reduced with increasing the rate of PBZ. The mean leaf area of Okra was significantly reduced with the application of 80 and 100 mg/L of PBZ. Our result on leaf area is similar to the study reported by Jasmine and John [38], which also found that the application of GA_3 had increased the leaf area of Okra plants. According to Ritonga et al. [39], gibberellins control leaf size by modulating cell expansion and division and are correlated with cell volume, behaviour, and other plant organs. Therefore, the final leaf size is determined by the number of cells generated during the cell division phase of leaf development, which can be influenced by the level of gibberellins [40]. In contrast with GA_3, Okra plants treated with higher concentrations of PBZ (i.e. 80 and 100 mg/L) had smaller leaf areas than other treatments (Table 2). The primary effect of paclobutrazol on plant leaf area is reduced leaf size and expansion [41, 42]. This is particularly notable in plants that are sensitive to the growth-inhibiting effects of paclobutrazol. Reduced gibberellin production leads to shorter internodes (the spaces between leaves on a stem) and smaller, more compact growth overall. Our result is similar to the study of Benjawan et al. [26], which also found that the application of PBZ reduced the leaf area of the 'Har Lium' Okra cultivar.

Even though the overall effect was significant (P<0.0001) for the mean number of leaves (Table 2), different concentrations of GA_3 did not significantly affect the number of leaves of Okra. This result contrasts with previous studies that found that GA3 significantly affected the number of Okra leaves [31, 43]. Okra plants' mean number of leaves was significantly higher with the application of 20 and 40 mg/L of PBZ. In addition, our results also showed that the overall effect of PBZ was significant (P<0.0001) for the mean number of leaves, indicating that different concentrations of both PGRs may have different effects on the number of leaves of Okra plants (Table 2). A contrasting finding was reported by Malshe et al. [36], who found that PBZ increased the number of leaves in Okra plants in higher concentrations. The differences in results are possibly due to the differences in the Okra cultivar and growing condition used in this study. Overall, our results indicate that the GA_3 had affected the leaf area but did not profoundly affect the number of leaves of Okra plants.

3.3 Effects of PGRs on Chlorophyll estimation of Okra plants

In general, the SPAD Chlorophyll index of Okra plants was significantly affected by the application of PGR (P<0.0001, Table 2). The means SPAD index of Okra plants was significantly higher with the application of PBZ, but it was reduced with an increasing rate of GA_3 (Table 2). Application of GA_3 with the concentration of 20 mg/L and 100 mg/L significantly reduced the mean chlorophyll index of Okra plants compared with control. However, the mean chlorophyll index was significantly higher with a similar concentration. Our results indicate that the increased chlorophyll index of PBZ treated Okra plants was related to the number of chloroplasts mentioned by Xia et al. [42]. According to Berova et al. [44], chlorophyll concentration per unit leaf area was enhanced by PBZ due to a greater concentration of chlorophyll in a much smaller leaf area. Our study agrees with the previous reports that found similar evidence in Okra plants [34, 35].

Table 2: The effects of gibberellins (GA_3) and paclobutrazol (PBZ) on the growth parameters of Okra (*Abelmoschus esculentus*) plants.

Treatment	Mean plant height (cm)		Mean leaf area (cm^2)		Mean number of leaves per plant		Mean SPAD index	
Control	35.40	d	770.40	b	11.50	cd	50.20	cd
T1	35.66	d	647.30	ab	11.40	cd	57.20	ab
T2	43.90	c	920.60	ab	11.50	cd	46.18	de
T3	48.80	b	963.90	ab	9.60	cd	45.76	de
T4	56.48	a	1250.90	a	13.60	bc	43.52	e
T5	30.94	e	781.60	b	18.00	a	46.70	de
T6	27.48	ef	576.60	b	17.25	ab	56.08	ab
T7	25.20	fg	162.90	c	11.00	cd	53.65	bc
T8	21.85	g	145.90	c	7.40	d	59.78	a
***P*-value**	$P<0.0001$		$P<0.0001$		$P<0.0001$		$P<0.0001$	

Means with the same letter are not significantly different from each treatment ($P \leq 0.05$ ANOVA followed by Duncan's Multiple Range Test).

4. CONCLUSION

In this study, it was found that the PGRs such as GA_3 and PBZ significantly affected the plant morphological characteristics and photosynthetic pigment (i.e. chlorophyll) of Okra (*Abelmoschus esculentus* L. Moench) plants when planted under tropical climate conditions. Increased concentrations of GA_3 and PBZ may increase or reduce (respectively) the plant characteristics of Okra plants (Figure 1 and Table 2). In vegetable production such as Okra, the use of PGRs and their concentrations plays an important role in improving the growth and production of okra plants. However, more studies need to be conducted to improve our physiological understanding of the effects of PGRs on this vegetable crop. Besides that, applying any PGRs in Okra or other vegetables needs to be used with caution to give maximum effect on vegetable crop production and avoid any toxicity to the environment.

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