Pertanika J. Trop. Agric. Sci. 48 (2): 339 - 357 (2025)

PERTANIKA JOURNALS

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Plant Growth Regulators Application to Enhance Flowering and Fruit Production in Gac (*Momordica cochinchinensis*)

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ABSTRACT

Gac fruit (*Momordica cochinchinensis*) has garnered substantial interest due to its potential as a rich source of lycopene and β-carotene, prompting higher demand for large-scale production. However, the development of its female flowers is hindered by the dioecious nature of the gac plant, demanding manual pollination to enhance fruit yield. In addition, the female flower of the gac plant starts late, depending on environmental variables such as temperature, moisture, and photoperiod. Accelerating flowering onset and augmenting pollination could substantially amplify gac fruit production, provided a comprehensive comprehension of exogenous plant growth regulators is attained. Accordingly, the current study investigates the role of plant growth regulators at various concentrations in developing female flowers and fruit production in gac plants. A field planting experiment was conducted using a five-replication factorial randomized complete block design (RCBD). The combination treatments comprised two factors of interest, which were four different types of plant growth regulators (indole-3-acetic acid [IAA], gibberellic acid [GA], benzyl adenine [BA], and maleic hydrazide [MH]) at four different concentration rates (0, 40, 80, and 120 ppm). Notably, Gac plants treated with MH at concentrations of 40 and 80 ppm exhibited significant performance in node and pistillate count, ovary diameter, early onset of first flower anthesis, and fruit yield. These findings underscore the potential of MH as a potent growth regulator for enhancing gac fruit production. Nonetheless, more research on

ARTICLE INFO

Article history:
Received: 24 June 2024
Accepted: 28 August 2024
Published: 17 February 2025

DOI: https://doi.org/10.47836/pjtas.48.2.01

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ISSN: 1511-3701
e-ISSN: 2231-8542

agronomic practices, control environment modifications, and postharvest handling is required for the profitable production of the gac fruit.

Keywords: Benzyl adenine, gac fruit, gibberellic acid, indole-3-acetic acid, maleic hydrazide, pollination

INTRODUCTION

Momordica cochinchinensis, commonly known as gac, is a distinguished Cucurbitaceae family member. Thrive is a perennial vine that flourishes in home gardens, intertwining effortlessly between lattices and branches, indicating its adaptability and ease of cultivation (Aoki et al., 2002; Vuong, 2000). Revered as the "fruit from heaven," Gac fruit possesses a variety of nutritional benefits, including its ability to promote well-being, longevity, and vitality. Studies in recent years have found this fruit to contain high levels of carotenoid antioxidants, particularly lycopene and beta-carotene (Bhumsaidon & Chamchong, 2016; Burke et al., 2005; Müller-Maatsch et al., 2017; Tran et al., 2016; Vuong et al., 2006;;). There are eight times more lycopene in the aril than in tomatoes and five times more beta-carotene in carrots (Aoki et al., 2002; Chuyen et al., 2015; Singh et al., 2001). Gac fruit has demonstrated significant commercial potential through various value-added products, including juice, oil, and powder (Do et al., 2019). These products enhance culinary dishes and serve as dietary supplements, promoting health benefits linked to the fruit's phytochemical composition, particularly its carotenoids such as lycopene and β-carotene (Vuong et al., 2006). The increasing availability of gac fruit products in global markets reflects a growing consumer interest in health-oriented foods. A study by Pham et al. (2022) projected that the global market for gac fruit products will grow at a compound annual growth rate (CAGR) of 8.5% from 2020 to 2025, driven by rising demand for natural and functional foods. Key markets for gac products include China, India, and the United States, highlighting its significant export potential (Pham et al., 2022).

Additionally, gac fruit is promoted as a highly nutritious fruit due to its carotenoids, which present natural antioxidants that help prevent certain cancers. Therefore, improving production to meet the increasing demand for gac fruit as a health product is essential. However, the dioecious nature of gac plants, where male and female flowers are found on separate plants, poses significant challenges for fruit production (Bharathi & John, 2013; Parks et al., 2013; Tran et al., 2020). Insect-mediated pollination in gac fruit faces several challenges, including a short blooming period, minimal nectar, and the need to visit multiple plants for successful pollination. This necessitates hand pollination to achieve optimal fruit yield and quality, outperforming insect-mediated and natural pollination in terms of fruit size and sensory attributes (Parks et al., 2013; Pessarakli, 2016). Current horticultural practices in gac fruit plantations often result in suboptimal male-to-female plant ratios and delays in flowering observed in seed-propagated plants, further complicating efficient pollination and fruit production.

Although gac's horticultural potential is compelling, inadequate cultivation guidelines leave growers grappling with a variety of uncertainties, including the male-to-female plant ratio and delays in flowering observed in seed-propagated plants. Nevertheless, augmented gac fruit production will only be achieved through careful attention to flower initiation, pistillate flower quantity and quality, and fruit setting rates. Research on the modulatory effects of growth regulators has revealed the intriguing possibility of inducing bisexual flowers, thereby signaling a potential paradigm shift in gac cultivation (Puzari, 1999; Sanwal et al., 2011). It has been demonstrated that using growth regulators in the leaves of Cucurbitaceae family crops can regulate various physiological processes, especially flowering and sex expression alteration (Rajbhar, 2023).

Plant growth regulators (PGRs) are chemical substances transported by vascular tissues, enhancing the source-sink relationship and stimulating photo-assimilates' translocation to endorse fruit development and eventually increase productivity (Nayak, 2022). The critical role of exogenous and endogenous growth regulators, such as cytokinins, gibberellins, ethylene, and auxins, in plant sex determination has been investigated, especially in the Cucurbitaceae family (Thomas, 2008; Yamasaki et al., 2005). Endogenous plant hormones can be influenced or induced by exogenous plant hormones (Hikosaka & Sugiyama, 2015), ensuring the accuracy of the flowering period through a complex network of genes that integrate endogenous and environmental signals (Campos-Rivero et al., 2017). Once pollination occurs during the anthesis period, cell division is induced by the synthesis and action of endogenous growth regulators, especially auxin (Dorcey et al., 2009); therefore, it would trigger fruit development (Kumar & Kumar, 2016).

Sex ratio and sequence of flowering are determined by environmental factors, including auxins, gibberellic acid, ethylene, and ascorbic acid levels (Bharathi & John, 2013). Sex alteration in plants can be attained by modifying mineral nutrition, temperature, photoperiod, and phytohormones (Baset et al., 2014; Ha, 2014; Megharaj et al., 2017). It is where hormones play a significant role in sex alteration (Thomas, 2008; Grumet & Taft, 2012). The substantial effect on sex expression was discovered when the foliar application of naphthalene acetic acid (NAA), GA, maleic hydrazide (MH), indole acetic acid (IAA), silver nitrate, ethrel, boron, kinetin and morphactin was applied to bitter gourd plants at the two to four leaf stage (Prakash, 1976). Furthermore, Gosai et al. (2020) reported major increases in early pistillate flower appearance on cucumber treated with 100 ppm MH and ethephon. Conversely, although exogenous application of GA at 20 to 40 mg/l was discovered to increase pistillate and staminate flower numbers, comparatively high concentrations of 60 mg/l GA increased only pistillate flowers (Ghosh & Basu, 1983). However, spraying ethephon onto male spiny gourd plants at any concentration did not impact the plants, while applying 400 ppm silver nitrate, $AgNO_3$, led to the greatest number of bisexual flowers (Naik et al., 2018). Sanwal et al. (2011) also stated that female gac

plants treated with 500 mg/l $AgNO_3$ could induce the highest hermaphrodite flowers with pollen viability comparable to typical male plants.

In recent years, the hybridization of several Mormordica species, including the gac fruit plant, has been conducted (Mohanty et al., 1994), and studies on plant growth regulator effects on the gac fruit plant have indicated the possibility of developing new varieties with bisexual flowers (Puzari, 1999; Sanwal et al., 2011). The intricate interplay between hormones, environmental factors, and mineral nutrition determines the phenotypic expression of sex in plants, fostering a transformative journey toward unlocking the plants' genetic potential. Nevertheless, minimizing the risks associated with plant growth regulator residues depends on the specific regulator used, the application rate, and the crop type, requiring agricultural practitioners and farmers to follow proper application practices, adhere to recommended waiting periods before harvest, and regularly monitor applications. Understanding the maturity stages of gac fruit is crucial in optimizing harvest timing and ensuring maximum yield and quality. Gac fruit undergo several maturity stages, each characterized by distinct physical attributes. Initially, the fruit exhibits a green skin color, gradually turning orange as it matures.

By maturity index 4, the skin becomes a vibrant orange to reddish-orange, with the pulp inside transforming from pale yellow to a deep orange-red. The firmness of the fruit at this stage is firm but slightly yielding, making it ideal for harvest. However, there is currently insufficient information regarding the effects of the application of plant growth regulators on sex expression modification and fruit production in gac plants. Using growth regulators and meticulous scientific inquiry, this study attempts to overcome some of these difficulties faced in gac fruit production to meet both small- and large-scale demand. Thus, the current study aims to determine the application of different plant growth regulators and their concentrations in promoting female flower development and fruit production of gac plants.

MATERIALS AND METHODS

Field Plot Preparation and Agronomic Practices

Field planting started in February 2020 at the Bukit Kor, Universiti Malaysia Terengganu, Marang, where a plot measuring 24.5 m × 28 m was plowed and rotavated. The planting area comprises Nami series soil and is located at latitude 5° 21’ North and longitude 103° 2’ East, with an altitude of about 32 m above sea level (asl). The site is in a tropical rainforest with an average annual rainfall of 2552.5 mm, average temperature of 27.8°C (min 23.4°C and max 30.5°C), and 81.7% relative humidity. This particular crop requires a sturdy trellis to support the climbing vine, which must be regularly trained. For this study, the related trellis set comprised Balau plane woods of 5.08 × 5.08 cm and 2 m tall with a 2.5 m horizontal wood attached and netting between two vertical pillars, where

one replication was equal to one plant with one trellis unit. There was approximately 2 m distance between the trellis sets in a single row and column (Figure 1). Female and male gac cuttings as planting material were propagated before planting, and each successfully propagated plant was transplanted to the field after five weeks.

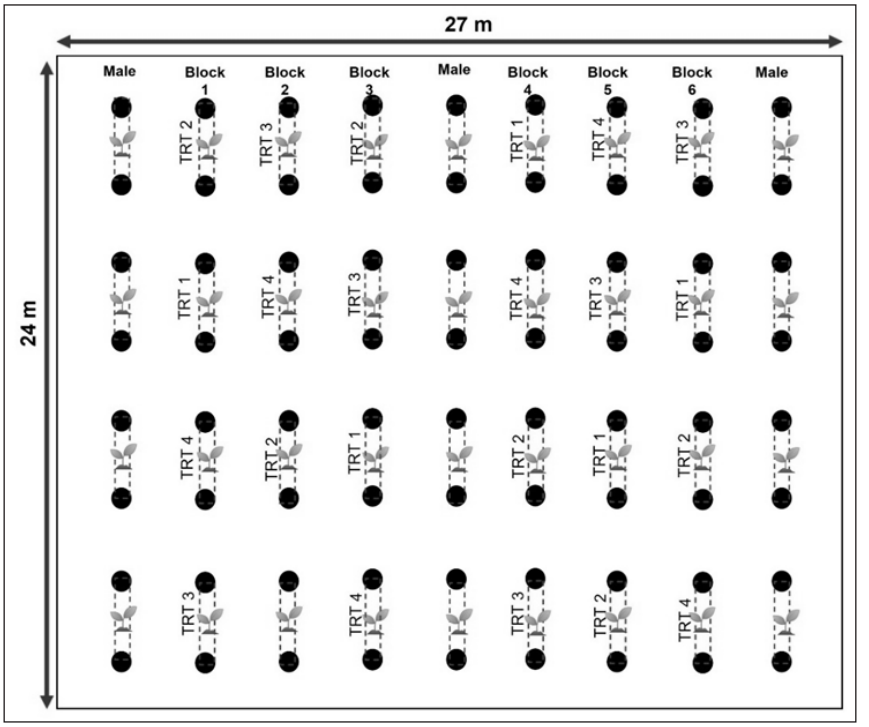

Figure 1. Experimental layout of gac cultivation plot

The planting preparations were completed before transplanting, such as applying 10 t/ha compost manure and the setup of weed mats and irrigation systems. Fertilizers were applied at the rates of 100 kg/ha urea: 20 kg/ha triple super phosphate (TSP): 72 kg/ha muriate of potash (MOP) during planting until flowering, and 48 kg/ha urea: 20 kg/ha TSP: 72 kg/ha MOP, from flowering until harvesting. Weeding was performed every month before fertilizer application. This research applied a holistic approach to pest and disease control, integrating physical, biological, and cultural practices to manage pests and diseases effectively. Physical controls included removing infected plants and using yellow sticky traps to capture flying insects. Biological controls involved the application of neem oil, a natural pesticide known for its efficacy against a wide range of pests and its minimal impact on non-target organisms. By employing these methods, we aimed to reduce the reliance on chemical pesticides, promoting a sustainable and environmentally friendly approach to pest and disease management.

After completing the necessary preparations, including the application of compost manure, the setup of weed mats, and the installation of irrigation systems, the gac cuttings were transplanted to the field after five weeks of propagation. The subsequent planting process, from February 2020 onwards, marked the commencement of the study. Throughout the cultivation period, spanning over one and half years, the crop's growth and development were meticulously monitored and managed, adhering to the established protocols for fertilization, pest and disease control, and trellising techniques.

Plant Growth Regulators Application

The female gac plants were sprayed with IAA, GA, BA, and MH at four different concentration levels (0, 400, 800, and 1200 ppm) during the pre-flowering stage, which was about 30 days after shoot sprouting. Morphological differentiation between male and female gac plants was conducted before the experimental treatment by observing flower structures. Larger flower buds identified female plants with ovary structures, while male plants exhibited smaller flower buds without ovary structures. There were 65 female plants that comprised the study's experimental units, consisting of 13 combination treatments with five replications and 12 male plants that served as pollen producers. The PGRs were sourced from reputable suppliers: IAA and MH were obtained from Sigma-Aldrich (USA), GA, and BA from Merck (Germany). Stock solutions of each PGR were prepared by dissolving the powdered compound in a small volume of ethanol, followed by dilution with distilled water to achieve the desired concentration. Spraying was conducted in the early morning to ensure optimal absorption until the solution thoroughly covered the entire plant. For the control group, the plants were not sprayed with any plant growth regulators.

Data Collection

The number of nodes, number of pistillates, ovary diameter, days to first flower, days from pollination to harvest, and number of fruits per plant were collected during the planting period. Other than that, the number of nodes at the first flower initiation of every plant was counted manually and recorded. During flowering until the end of the harvesting period, the number of pistillate was counted using a visual count daily for each plant. The ovary diameter was measured for the first five flowers of each plant using a digital caliper, and the data was recorded during flower anthesis. Days to the first flower were recorded for each plant during flower anthesis and pollination. The days from pollination to harvest for each fruit set were recorded upon pollination until harvest at maturity stage four. Data was recorded for only the first five flowers that appeared and were successfully pollinated until harvesting. The flowers were tagged, and the pistillate flower anthesis and harvesting dates were recorded. Gac fruit undergoes several maturity stages, each marked by specific changes in color, texture, and biochemical composition, with five distinct stages identified by Tran et al. (2016) (Figure 2).

Figure 2. Gac fruits with different maturity index

The gac fruits, manually harvested at maturity index 4, had bright and vivid orange-red peel colors, with vibrant orange to reddish-orange skin, bright red or deep orange pulp, and a firm but slightly yielding texture. The fruits are harvested at maturity stage four because this stage represents the optimal point for several important physicochemical properties (Tran et al., 2016). At this stage, the gac fruit exhibits the highest levels of beneficial compounds, such as lycopene and beta-carotene, which are important for their antioxidant properties. The texture is also ideal for processing and consumption. Harvesting at this stage ensures the best nutritional content, flavor, and texture quality, making it suitable for fresh consumption and further processing. Additionally, data on the number of fruits per plant were recorded daily and summed up during the harvesting period.

Experimental Design

The study was designed using a factorial randomized complete block design (RCBD) with five replications (one plant of each replication) to investigate the impact of two factors on the gac vine 30 days after shoot sprouting. The factors included four types of plant growth regulators (IAA, GA, BA, and MH) and four concentration rates of the plant growth regulators (0, 40, 80, and 120 ppm). The data obtained from the experiment were analyzed using a two-way analysis of variance (ANOVA), and significant treatment means were separated using Duncan's multiple range test (DMRT) at $p < 0.05$ (SAS, version 9.3). The effects of the concentration of each plant growth regulator type on the dependent parameters were evaluated and compared using a pooled Least Significant Difference (LSD) test at $p \leq 0.05$. For plant growth regulator types and concentrations that displayed significant interaction, the effects differed by concentration. To understand the nature of the interaction between the different plant growth regulators and their concentrations on the dependent variables, additional partitioning of the interaction sum of the square was performed, followed by regression analysis. Pearson's correlation coefficients were calculated using

the Procedure Correlation (PROC CORR) procedure, and the interpretation of correlation coefficient values was based on the study by Schober et al., (2018). The correlation coefficients were used to determine the strength and direction of the relationship between the independent and dependent variables.

RESULTS AND DISCUSSION

The current study demonstrated that four selected plant growth regulators at different concentrations resulted in various growth and development performances during the planting period. Significant interaction was observed between the different plant growth regulators and concentrations on the number of nodes, number of pistillates, ovary diameter, days to first flower, days from pollination to harvest, and number of fruits per gac plant except the total fruit weight per plant (Table 1). However, no significant regression effects were seen between the number of nodes, number of pistillates, ovary diameter, days to first flower, days from pollination to harvest and number of fruits per gac fruit plant, with the concentration rates of the plant hormones. Thus, the effects of the different concentrations on the number of nodes, number of pistillate, ovary diameter, days to first flower, days from pollination to harvest and number of fruits per plant for each plant hormone type were compared using a pooled least LSD test at $p \leq 0.05$ (Figure 3).

Table 1
The main interaction effects of plant growth regulator types (IAA, GA, BA, MH) and concentrations (0, 40, 80, 120 ppm) on growth and yield parameters of gac plants

Factor	Number of nodes	Number of pistillate	Ovary diameter (mm)	Days to the first flower	Days of pollination to harvest	Number of fruits/ plant	Total fruit weight/ plant (kg)
Plant growth regulators (PGR)							
IAA	36.0 a^z	19.9 b	10.94 b	63.7 a^z	57.2 a	12.83 ab^z	9.90 a
GA	33.3 a	18.3 b	10.80 b	59.5 ab	57.7 a	11.42 b	9.37 a
BA	35.9 a	25.5 a	11.04 b	58.9 ab	57.6 a	13.17 ab	10.38 a
MH	35.8 a	24.8 a	11.48 a	56.3 b	57.2 a	14.17 a	11.69 a
Concentrations (C) (ppm)							
0 (Control)	30.7 b	18.7 b	10.62 b	70.7 a	59.3 a	9.33 b	6.87 b
40	41.8 a	24.9 a	11.25 a	54.7 b	57.2 b	14.67 a	12.55 a
80	34.8 b	21.6 ab	11.32 a	56.3 b	56.8 b	12.58 a	10.03 a
120	33.8 b	23.3 a	11.05 a	56.8 b	56.4 b	15.00 a	11.90 a
PGR x C	*	*	*	*	*	*	ns

Note. Significant at $p \leq 0.05$ and not significant at $p > 0.05$
z = Means with the same letter within a column, and the factor is not significantly different at $p=0.05$ using Duncan's Multiple Range Test (DMRT). *, ns=Significant and not significant at $p \leq 0.05$, respectively

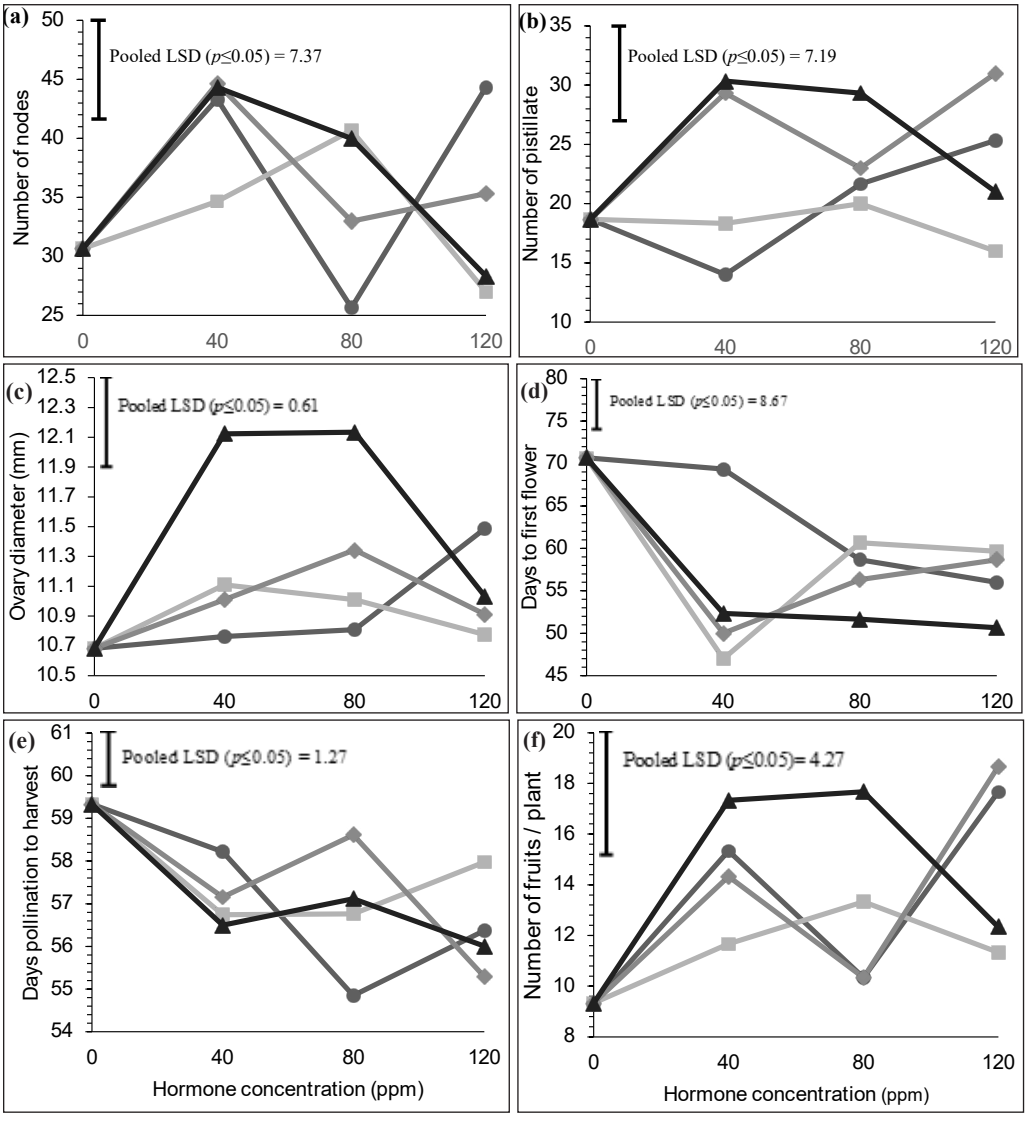

Figure 3. Number of nodes (a); number of pistillates (b); ovary diameter (c); days to first flower (d); days from pollination to harvest (e); and number of fruits/ plant (f) on gac plants with different types of plant growth regulators IAA (●), GA (■), BA (♦) and MH (▲) and plant growth regulators concentrations at 0, 40, 80 and 120 ppm concentrations. n = 5

Generally, it was observed that the higher node numbers were for the plants treated with IAA at 40 and 120 ppm, BA at 40 ppm, and MH at 40 ppm concentrations (Figure 3[a]). However, there were no differences in node numbers for plants treated with GA at 80 ppm and MH at 80 ppm, with optimal node numbers around 40 to 44.3. It has been reported that bottle gourd plants treated with 10 ppm IAA exhibited an increase in the number of nodes

and leaves (Rahman, 1992). Additionally, 60 ppm GA application on muskmelon resulted in a higher number of nodes than other plant growth regulators (Chaurasiya et al., 2016). At the same time, Gosai et al. (2020) reported that MH at 100 ppm increased the number of nodes and primary branches in cucumber. Application of BA at 10 ppm or more on peas showed that BA influences the growth and development of peas, particularly in relation to the number of nodes and flowering (Sprent, 1968). There are a number of mechanisms by which these plant growth regulators affect node formation, such as IAA promoting cell elongation and division, GA stimulating stem elongation, MH stimulating branching, and BA promoting cell division and differentiation. These interactions demonstrate the complex regulation of plant hormones and their impact on plant morphology.

As displayed in Figure 3(b), gac plants treated with BA at 40 ppm and 120 ppm and MH at 40 ppm and 80 ppm exhibited 44.3% and 49.7% higher number of pistillate, respectively, than the control. However, the pistillate numbers of the gac plants with control treatment demonstrated no significant differences with those treated with IAA and GA at 40, 80, and 120 ppm, BA at 80 ppm, and MH at 120 ppm concentrations. These findings are comparable with the study by Hikosaka and Sugiyama (2015), where the application of BA at 2000 ppm increased pistillate numbers in cucumber. Similarly, Hidayatullah et al. (2009) also reported that MH at 450 µmol/L increased the number of pistillates by three-fold compared to the control. The application of MH at 450 µmol/L or 100 ppm was stated to help enhance endogenous auxin hormones, signaling intersects with other hormonal pathways to promote pistillate flower development (Gosai et al., 2020). Our results align with these studies, indicating that lower concentrations of BA and MH can also positively affect pistillate numbers in gac plants.

Additionally, a number of nodes showed significant, positive, and strong correlations (R= 0.745) with a number of pistillate on gac fruit plants treated with four plant hormones at different concentrations (Table 2). This finding followed studies reported by Kumari et al. (2018) and Manisha and Pal (2014) in cucumber, where there was a positive and substantial relationship between the number of nodes and the number of pistillates of the first flower. Plant growth, including the number of nodes and pistillate, was influenced by photosynthetic activity and assimilation. It would translocate to multiple sinks, enhancing growth and overall yield (Eifediyi & Remison, 2010). The information on the correlation between plant growth variables is crucial for enhancing yield production, especially the number of nodes and pistillate (Manisha & Pal, 2014). These findings suggest that the application of IAA, GA, BA, and MH at varying concentration levels can effectively stimulate cell elongation and division, thereby influencing plant growth dynamics (Gosai et al., 2020; Rademacher, 2000). Understanding the relationship among variables through correlation studies may provide insight into strategies for optimizing fruit quality and productivity (Prabhakar & Kushwah, 2017).

Table 2
Correlation coefficients (r) for each pair of parameters in gac fruit plant treated with indole-3-acetic acid (IAA), gibberellic acid (GA), benzyl adenine (BA), and maleic hydrazide (MH) at 0, 40, 80 and 120 ppm concentration

	Number of pistillate	Ovary diameter (mm)	Days to the first flower	Days of pollination to harvest	Number of fruits/ plants	Total fruit weight/ plant (kg)
Number of nodes	0.75**	0.38^{ns}	-0.34^{ns}	-0.14^{ns}	0.68*	0.72**
Number of pistillate	--	0.45*	-0.39^{ns}	-0.19^{ns}	0.73**	0.78**
Ovary diameter (mm)	--	--	-0.37^{ns}	-0.20^{ns}	0.38^{ns}	0.46*
Days to the first flower	--	--	--	0.53*	-0.51*	-0.53*
Days of pollination to harvest	--	--	--	--	-0.34^{ns}	-0.35^{ns}
Number of fruits/plants	--	--	--	--	--	0.91***

Note. For the correlation coefficient, n = 24. *,**, ***, ns = moderate, strong, very strong correlation and not significant at $p \leq 0.05$

Meanwhile, the ovary diameter of gac fruit treated with MH at 40 and 80 ppm concentrations was larger than that of the other plant growth regulator combination treatments and 12% higher than the control (Figure 3[c]). In addition, the gac fruit treated with IAA at 120 ppm, BA at 80 ppm, and MH at 40 and 80 ppm concentrations had higher ovary diameters by 6% to 12.7%, respectively, compared to the control. The application of MH contributes to alterations in the auxin level, resulting in enhanced fruit size (Gosai et al., 2020) since auxin is responsible for cell division, elongation, and differentiation. During the anthesis period, ovary growth and cell division experienced a temporary slowdown until pollination and fertilization occurred (Gillaspy et al., 1993). Fertilized ovules typically reinitiate cell division, initiating fruit development. However, ovary diameter would increase throughout flower anthesis until fruit maturation and ripening by the effect of plant growth regulators (Tantasawat et al., 2015). These findings were upheld by the correlation coefficient results showing a significant, positive and moderate correlation (R=0.446) between ovary diameter and a pistillate number of gac fruit plants treated with four types of plant hormones at different rates (Table 2). It also indicated that a higher ovary diameter would affect a higher pistillate number when treated with IAA, GA, BA, and MH at 0, 40, 80, and 120 ppm. Pistillate number and ovary diameter might be related to photosynthetic activity and assimilation, contributing to plant growth and development (Eifediyi & Remison, 2010).

The gac plant with the control treatment experienced significantly longer days to first flower than all the other plant growth regulators with combination treatments of IAA, GA, BA, and MH, at 40, 80, and 120 ppm, except for the gac plant with IAA at 40 ppm treatment (Figure 3[d]). Gac plants treated with GA at 40 ppm took significantly less

time to flower anthesis than those treated with other treatments yet were similar to those treated with BA at 40 ppm and MH at 40, 80, and 120 ppm. The plant's first flower treated with GA at 40 ppm emerged 23 to 24 days earlier than the control. Comparable to the findings reported in Ahmad et al.'s (2019) study, bitter gourd sprayed with GA at 100 ppm demonstrated the shortest duration for first flower emergence, occurring four to five days earlier than the control. There was also a shorter period for the first flower emergence of cucumber treated with MH at 200 ppm (Kaur et al., 2016). Generally, the treatments with plant growth regulators demonstrated shorter days to first flowering, which would benefit fruit production (Gosai et al., 2020).

The gac plant treated with IAA at 80 ppm experienced a 4.5 to 1.5 days shorter duration from pollination to harvest compared with the other combination treatments. However, it is similar to the BA at 120 ppm and MH at 120 ppm treatments, as illustrated in Figure 3(e). Conversely, the day's pollination to harvest of the gac fruit plant with controls was longer than the gac fruit plant treated with IAA at 80 and 120 ppm, GA at 40, 80 and 120 ppm, BA at 40 120 ppm, and MH at 40, 80 and 120 ppm concentration. However, the gac fruit plant with control had similar days of pollination to harvest, with IAA 40 ppm and BA 80 ppm. After pollination, fruit growth and development commonly involve plant hormone synthesis and regulation, especially GA and auxin (Obroucheva, 2014; Ozga & Reinecke, 2003). Note that IAA promotes fruit cell elongation and, thus, the rapid increase and exponential growth of cell size in cucumbers (Liu et al., 2020). Some studies have revealed that the auxin concentration peak coincides with the cell elongation growth rate (Pattison et al., 2014).

In addition, Rylott and Smith (1990) discovered that cytokinin stimulated active cell division within the embryo, attracting assimilates from other plant parts in the developing pods. Accordingly, the assistance of plant growth regulators might be one factor that accelerates fruit growth development after pollination. On the other hand, days to the first flower have a significant, positive and moderate correlation with days pollination to harvest (R=0.531) of gac fruit plant treated with four plant hormones at different concentrations (Table 2). These findings indicate that the extended period of the first flower's appearance influenced the longer period of pollination needed to harvest gac fruit. A similar result was reported by Kumari et al. (2018) in cucumber, where there was a significant and positive relationship between days to first pistillate flower and days of pollination to harvest.

According to the results of the current study, the number of fruits on the gac fruit plant treated with BA at 120 ppm was significantly higher than a plant with control, IAA at 80 ppm, GA at 40, 80 and 120 ppm, BA at 40 and 80 ppm, and MH at 120 ppm concentration (Figure 3[f]). However, the gac fruit plant treated with BA 120 ppm had a similar number of fruits to plants of IAA at 40 and 120 ppm and MH at 40 and 80 ppm (Figure 3). The weight of the fruit and the quantity of fruits produced per plant would affect the crop yield, thus influencing the primary economic output (Ghani et al., 2013).

The current study indicated that the gac plants treated with IAA at 40 and 120 ppm, BA at 120 ppm, and MH at 40 and 80 ppm had the highest number of fruits produced per plant. This concurs with the results of Ahmad et al. (2019) and Akter and Rahman (2013), where cucumbers treated with IAA at 200 ppm and 10 ppm had more fruits than the control. It is also reported that the application of MH at 200 ppm may influence auxin levels, which enhances the fruit set and development of cucumbers (Pattison et al., 2014; Gosai et al., 2020). The utilization of plant growth regulators such as auxin, GA, and cytokinin may be involved in the photosynthesis activities and thus contribute to improving plant growth and development, with higher fruit quality and production.

According to the main and interaction result shown in Table 1, there was no significant interaction effect between types of plant hormone and concentration on total weight per plant and the average gac fruit weight of each plant. There were also no significant differences between gac fruit plants treated with IAA, GA, BA, and MH plant hormones in terms of total weight per plant and average gac fruit weight per plant. The average weight of each plant and the average gac fruit weight per plant were approximately 10.33 kg and 788.5 g of each gac fruit weight, respectively. However, the total weight per plant with control was significantly lower than the gac fruit plant with 40, 80 and 120 ppm concentration plant hormone. In addition, the average gac fruit weight per plant of the control treatment was significantly lower than the average gac fruit weight of 40 and 80 ppm concentration plant hormone. However, it was similar to the average weight of 120 ppm plant hormone concentration. The total weight per plant and average weight per fruit upon the application of exogenous plant hormone was proven to increase compared to control in various reports (Ahmad et al., 2019; Baset et al., 2014; Hidayatullah et al., 2009; Mahala et al., 2014; Nagamani et al., 2015; Tantasawat et al., 2015).

Based on the current study, the fruit number of gac fruits plants treated with different types of plant hormone and concentration showed significant, positive and moderate to strong correlation with the number of nodes (R=0.683) and number of pistillate (R=0.729) and days to first flower (Table 2). However, there was also a notable, negative, and moderate correlation (R=-0.511) between the number of gac fruits per plant and the days until the first flowering when the plants were treated with various plant hormone types and concentrations. Similar results were found on total weight per plant, where there was a significant and positive relationship with the number of nodes and the number of pistillate, but a significant and positive relationship with days to the first flower (Table 2). The coefficients varied among weak, moderate, and strong correlations. These indicated that higher gac fruit numbers per plant and total weights per plant result in a higher number of nodes, a higher number of pistillates, and a shorter period of first flower emergence. A similar result was recorded by Kumari et al. (2018) and Manisha and Pal (2014) in cucumbers.

In addition, total weight per plant demonstrated a significant, positive and strong correlation with the number of fruits (R=0.910) and a moderate correlation with the average fruit weight (R=0.612) of gac fruit harvested per plant. These results indicated that the greater the number of fruits harvested, the higher the total weight of fruits per plant. The higher total weight of fruits would also affect the higher average gac fruit weight harvested at maturity index 4. The variables of number of nodes, internodes, and number of pistillate closely relate to photosynthesis synthesis, assimilations, and partitioning (Abd El-Hafeez & Ali, 2013; Silva et al., 2019). This process would affect fruit quality and production due to biomass allocation to source and sink organs. Several studies stated that yield per plant had a significant and positive correlation with the number of fruits per plant (Kumari, Kumar et al., 2018; Manisha & Pal, 2014; Tran, 2017). Moreover, several studies stated that photosynthesis synthesis and assimilations are affected by the application of plant hormones or plant growth regulators, thus improving plant growth and development (Müller & Munné-Bosch, 2021; Shah, 2011). The utilization of plant hormones such as auxin, gibberellin, and cytokinin may be involved in photosynthesis activities and contribute to the improvement of plant growth and development, with higher fruit quality and production.

In the current study context, each plant growth regulator (PGR) applied had specific effects on the internal hormonal balance and, consequently, on the physiological functions of the gac plant. Auxins, like IAA, promote cell elongation and division, which result in increased node formation and earlier flowering. Gibberellins, such as GA, are known to stimulate stem elongation and can increase node numbers and fruit sets under certain conditions. Cytokinins, such as BA, promote cell division and differentiation, enhancing the number of nodes and pistillate flowers. MH, or maleic hydrazide, acts as a growth retardant that enhances branching and node formation by interfering with auxin transport. The internal hormone levels were modulated by applying these extraneous growth regulators, influencing photosynthesis, assimilate partitioning, and overall plant growth and development. This hormonal manipulation ultimately improved the yield and quality of gac fruits in this study.

CONCLUSION

Most growth and development variables such as internode length, ovary diameter, number of fruits, and total fruit weight demonstrated better performances in the gac plants treated with plant growth regulators than in the control. Gac plants treated with plant growth regulators also exhibited faster first flower anthesis, first harvest, and shorter duration from pollination to harvest. Furthermore, the plant growth regulators displayed the most frequent optimal performance in the number of nodes and pistillate, ovary diameter, early first flower anthesis, and number of fruits, which were those with MH at 40 and 80 ppm. It proves that the application of MH at 40 and 80 ppm on the gac plant could significantly

enhance growth and development as well as hasten gac fruit production. The study on the effects of exogenous plant growth regulators on endogenous plant hormones of gac fruit production and quality should thus be explored further in future research.

ACKNOWLEDGMENTS

It was a great pleasure to work with the Faculty of Fisheries and Food Science at Universiti Malaysia Terengganu, who graciously provided us with the necessary facilities and resources to ensure the success of our study. The faculty's expertise and knowledge were invaluable, and their support was essential in achieving our goals. We are grateful for their collaboration and look forward to continuing our work together in the future.

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