

Optimal fertilizer requirement of Gac to enhance growth, yield and carotenoid content

Azimah Hamidon¹, Ramisah M. Shah^{1*}, Razifah Mohd Razali², Suhaizan Lob¹, Fatma Azwani Abdul Aziz³

¹Faculty of Food Science and Agrotechnology, Universiti Malaysia Terengganu, 21030, Kuala Terengganu, Terengganu, Malaysia

²Faculty of Science and Marine Environment (Chemical Science), Universiti Malaysia Terengganu, 21030 Terengganu, Malaysia

³Institute of Tropical Agriculture and Food Security (ITAFoS), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

ARTICLE HISTORY

Received : 18 September 2025

Accepted : 26 February 2026

Online : 30 September 2026

KEYWORDS

aril,
fruit quality traits,
lycopene accumulation,
nutrient management,
fertilizer dosage

✉* CORRESPONDING AUTHOR

Dr. Ramisah Binti Mohd Shah
Faculty of Food Science and
Agrotechnology, Universiti Malaysia
Terengganu, 21030, Kuala
Terengganu, Terengganu, Malaysia
Email: ramisah@umt.edu.my

ABSTRACT

Gac is widely recognized and in high demand as a nutritional product due to its rich carotenoid content, particularly lycopene and beta-carotene. However, information regarding the cultivation and optimal fertilizer requirements for *Momordica* species, including Gac, is limited. This study aims to determine the most effective fertilizer dosages to enhance Gac growth and maximize fruit quality, including carotenoid content. Four different combinations of single-fertilizer rates (Urea, Triple Superphosphate, and Muriate of Potash) were assessed on different growing stages. All Gac plants exhibited increased growth parameters during the growth phase. Treatments 1 and 4 demonstrated notably faster and greater vine growth compared to Treatments 2 and 3. Treatment 2 exhibited delayed growth and produced the lowest branch number, while Treatment 4 recorded the highest leaf count. However, no significant differences were observed in fruit characteristics (average fruit weight, total weight, fruit length, diameter, and aril weight) among the treatments ($p > 0.05$). At the same time, the number of fruits per plant varied significantly, with Treatment 4 indicating a 38.8% increase over Treatment 2 and results similar to those of Treatments 1 and 3. Lycopene analysis revealed that fruits from Treatment 1 had significantly higher levels ($p = 0.0012$) than those from all other treatments. Conversely, β -carotene levels in Treatments 1, 2, and 3 were comparable, at 312.88, 286.34, and 258.40 mg/g fresh weight (FW), respectively. In conclusion, Treatment 1 provided the most balanced fertilizer regime, promoting stable vegetative growth, comparable fruit yield, and significantly higher lycopene accumulation, indicating its suitability as the optimal fertilizer strategy for Gac cultivation under the conditions of this study.

© 2026 UMK Publisher. All rights reserved.

1. INTRODUCTION

Gac, also known as *Momordica cochinchinensis*, is an indigenous Southeast Asian plant belonging to the Cucurbitaceae family (Muchjajib & Muchjajib, 2015). The plant is well known for its longevity and vitality due to its highly nutritious fruit with numerous benefits. Commonly, the Gac fruits are used as a colorant in traditional dishes in Vietnam. For the past decade, several investigations have discovered the high levels of phytonutrients in Gac fruit, particularly lycopene and β -carotene. These phytonutrients have been proven to possess the capacity to prevent and treat various types of cancer (Zheng et al., 2015; Kubola & Siriamornpun, 2011). The Gac aril contains natural lycopene levels that are approximately 70 times higher than those typically found in tomatoes (Rahman et al., 2024; Ariyaratna et al., 2024). A high lycopene content suggests that the fruits have potential applications in prostate treatment and in reducing the risk of prostate cancer. Another study discovered that Gac fruit can

reduce severe health consequences caused by vitamin A deficiency, such as night blindness, anemia, and xerophthalmia (Müller-Maatsch et al., 2017). Despite these benefits, information regarding the best approach to cultivating the plant remains scarce. As such, studies to optimize the cultivation of the underutilized Gac fruit could address the rising demand for this nutritional product.

Cultivating this species is possible from seeds, cuttings, or root tubers, and it grows as dioecious vines, with distinct male and female plants. The recommended fertilization type and amount depend on soil type and crop yield responses in certain areas. As mentioned previously, information on cultivation requirements and empirical data on the nutritional needs of *Momordica* species are, as of now, limited (Bharathi & John, 2013). Generally, organic materials derived from livestock waste in the soil are used to promote the growth of the Gac plant.

Typically, this approach incorporates organic

compost or barnyard fertilizer into the soil at each planting location, with a recommended dosage of 10-12 tons per hectare (Bhunja et al., 2021). While precise fertilizer recommendations are not available, applying 40-45 kg/ha of Urea (N), 40 kg/ha of Triple Superphosphate (P_2O_5), and 40 kg/ha of Muriate of Potash (K_2O) is considered an economically efficient approach by many (Bharathi & John, 2013). To achieve optimal yield in crops related to Gac, proper nutrient management is essential. In bottle gourd (*Lagenaria siceraria*), a closely related species of Gac, balanced fertilization has been demonstrated to greatly influence the growth and productivity. Barua et al. (2018) found that applying 130 g urea, 152 g triple super phosphate (TSP), and 42 g muriate of potash (MOP) per planting pit, together with Trichoderma-enriched bio-organic fertilizer (3 kg pit⁻¹ with 25% N + 100% PK), resulted in the highest yield under field conditions. Likewise, Revathi et al. (2024) reported that applying 70:100:100 kg ha⁻¹ of N:P₂O₅:K₂O produced the maximum fruit yield (116.3 q ha⁻¹) of bottle guard. Moreover, pre-harvest factors such as cultural practices and fertilizer type and quantity have been presented to significantly affect vitamin C and lycopene contents in other crops like tomato (*Solanum lycopersicum*) (Ilupeju et al., 2015).

Nitrogen overfertilization in cucumbers was found to negatively alter metabolite profiles by reducing levels of essential amino acids and lipids without increasing yield (Lee et al., 2024). Meanwhile, a study on squash demonstrated that balanced fertilizer application enhanced both yield and phytochemical content (Vanessa et al., 2024). This indicates that excessive fertilizer use can impair fruit quality and productivity. Although the nutritional value of Gac fruit is well established, experimental studies on nutrient management, particularly how fertilizer inputs affect key phytonutrients such as lycopene and β -carotene, remain limited. Therefore, this study aims to determine the optimal fertilizer requirement for Gac cultivated at Bukit Kor, based on both physical growth performance and biochemical quality characteristics.

2. MATERIALS AND METHODS

2.1. Study area and experimental site

The experiment was conducted at Universiti Malaysia Terengganu (UMT), Bukit Kor campus, Marang, Terengganu, on Nami series soil. The site is located at 5°21'N latitude and 103°2'E longitude, with an elevation of 32 m above sea level. The region has a tropical climate, with average annual rainfall of 2,552.5 mm, a mean temperature of 27.8°C (range: 23.4-30.5°C), and relative humidity of 81.7% (Malaysian Meteorological Department). Pre-treatment soil analysis identified the soil as sandy loam with 56% sand, 29% silt, and 15% clay.

2.2. Field plot preparation and crop establishment

The 27 m × 30 m field was divided into six replications (one plot per replication), each measuring 3 m × 3 m, with 3 m plant spacing. Prior to transplanting, each plot received 10 tonnes/ha of barnyard manure. Seedlings were propagated, and healthy sprouts were transplanted to the field after 30 to 37 days. Vertical trellises, built using 1.5 m cement pillars spaced 3 m apart, supported vine training. Irrigation was installed, and watering was conducted daily.

2.3. Fertilizer treatments and application

Four fertilizer treatments, consisting of different combinations of Urea (N), Triple Superphosphate (TSP), and Muriate of Potash (MOP), were applied monthly. Fertilizers were applied manually using the pocket method, whereby small holes were made beside the plant root zone; the measured fertilizer doses were placed into the holes, covered with soil, and followed by irrigation to facilitate nutrient dissolution and uptake. The fertilizer combinations were designed based on standard recommendations (Parks et al., 2013) with modifications, allowing evaluation of both low- and high-input systems to reflect a range of nutrient availability and potential responses in Gac plants. The fertilizer combinations were applied monthly, starting two weeks after transplanting and continuing until the fruiting stage. Fertilizer rates used in each treatment are summarized in Table 1. The N application rate differed between the vegetative (planting to flowering) and reproductive (flowering to fruiting) stages to match the physiological nutrient demand of Gac plants. Higher nitrogen rates were applied during the vegetative stage to support vine elongation, leaf development, and branching, while reduced nitrogen rates after flowering were used to minimize excessive vegetative growth and to favor flower development, fruit set, and fruit quality.

Table 1: Four different rates of single fertilizer application, including Urea (N), Triple Super Phosphate (TSP), and Muriate of Potash (MOP), were applied during two growth stages.

Treatments	Rates (kg/ha)					
	From planting to flowering			From flowering to fruiting		
	N	TSP	MOP	N	TSP	MOP
1 (control)	100	20	72	48	20	72
2	80	16	58	38	16	58
3	120	24	86	58	24	86
4	140	28	101	67	28	101

2.4. Growth and yield measurements

Four growth parameters were measured biweekly: vine length, number of leaves, number of nodes, and number of branches. Vine length was measured from the soil base to the apex of the tallest shoot using a measuring tape, selecting the main vine originating near the base. The number of branches, leaves, and nodes on the main vine was manually counted. Data collection continued until the first fruit harvest,

which occurred approximately 14 weeks after transplanting. Fruits were harvested at maturity stage four (bright red pericarp), and the number of fruits per plant was recorded. Samples were then transported to the Crop Science Laboratory at Universiti Malaysia Terengganu for further analysis. Fruits were halved horizontally, and arils were separated from the seeds. The aril weight was then recorded.

2.5. Carotenoid extraction and analysis

Carotenoid levels were determined following the method of Barba et al. (2006). Aril samples were wrapped in aluminum foil and stored at -20°C in the dark until analysis. For extraction, samples were mixed with hexane:acetone:ethanol (50:25:25, v/v/v) and subjected to ultrasonic agitation (Fisherbrand FB15055, UK) for 30 minutes. Afterward, 15 mL of distilled water was added to separate the phases. Carotenoids were recovered from the upper hexane layer.

Approximately 10 mL of the hexane extract was evaporated using a rotary evaporator (NVC-2200, Eyela, Japan). The residue was re-dissolved twice in tetrahydrofuran (THF):acetonitrile:methanol (50:25:25, v/v/v) to a final volume of 4 mL. The extract was filtered through a $0.45\text{ }\mu\text{m}$ Polytetrafluoroethylene (PTFE) membrane (Labquip Australia) prior to High-Performance Liquid Chromatography (HPLC) analysis. HPLC was performed using an isocratic method (Barba et al., 2006) with an Alltech Alltima HP C18 column ($250 \times 4.6\text{ mm}$, $5\text{ }\mu\text{m}$), a flow rate of 1.0 mL/min , and UV detection at 465 nm . The column temperature was maintained at 30°C . Regression equations used to calculate carotenoid concentrations were:

$$\text{Lycopene: } y = 0.0000000526x + 0.0018 \quad (R^2 = 0.98)$$

$$\beta\text{-carotene: } y = 0.0000000314x + 0.009 \quad (R^2 = 0.98)$$

All samples were analyzed in triplicate, and results were expressed as mg/g fresh weight (FW). Growth data were modeled using the logistic growth equation: $y = A / (1 + be^{-cx})$, with the derivative used to estimate growth rate.

2.6. Experimental design and statistical analysis

A factorial randomized complete block design (RCBD) with six replications were used to evaluate treatment effects across seven observation time points, at 14, 28, 42, 56, 70, 84, and 98 days after transplanting. Data were analyzed by two-way Analysis of Variance (ANOVA), and means were compared using Duncan's Multiple Range Test (DMRT) at $P < 0.05$ (SAS 9.3).

3. RESULT AND DISCUSSION

3.1. Pre-harvest growth responses

Figure 1 illustrates the gradual rise in vine length over time. This growth trend was found to follow the equation $y =$

$A/(1+be^{-cx})$, where y denotes vine length and x represent DAT. In this context, the variables A , B , and C are constants determined through regression analysis (Table 2). In the early phase, the increase in plant height was similar across all fertilizer combination treatments. This steady increase remained consistent until 29 days after transplanting, then rose sharply to 74 days for Treatments 1 and 4 and to 84 days for Treatments 2 and 3 (see Figure 1).

In the later growth stage, vine length under all fertilizer treatments approached a plateau (Figure 1), indicating a reduction in vegetative growth rate as plants reached physiological maturity. This suggests a decline in growth, possibly attributed to dormancy following the flowering phase. Additionally, the data indicates that fertilizer Treatments 1 and 4 resulted in greater and more rapid increases in vine length than Treatments 2 and 3.

There were no significant differences in vine length among fertilizer treatments throughout most of the planting period (Table 3). At 98 days after transplanting, vine length in Treatment 2 was significantly higher than in Treatment 3 based on DMRT analysis ($P < 0.05$), representing an approximate 11.3% increase calculated from mean values. The maximum length increment or growth rate for each fertilizer combination of Treatments 1, 2, 3, and 4 was at days 44, 51, 46, and 42 after transplanting, respectively.

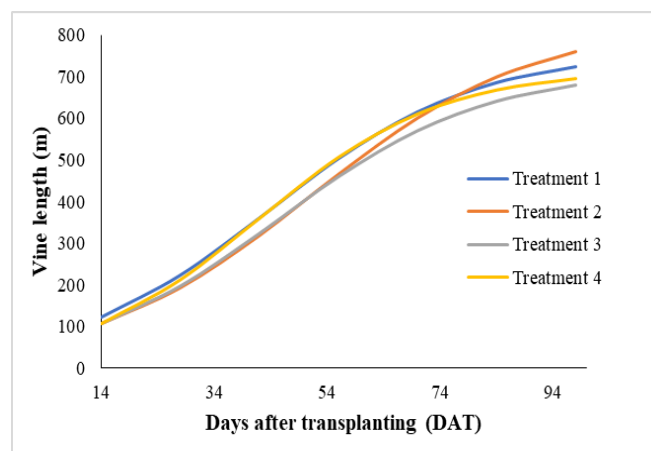


Figure 1: Vine length as a function of four different fertilizer combination treatments, in the form of $y=A/(1+be^{-cx})$ of Gac fruit. $n = 6$

Note: T1 = Control ($100\text{--}20\text{--}72\text{ kg ha}^{-1}$ N-TSP-MOP during vegetative stage; $48\text{--}20\text{--}72\text{ kg ha}^{-1}$ during reproductive stage); T2 = $80\text{--}16\text{--}58$ and $38\text{--}16\text{--}58\text{ kg ha}^{-1}$; T3 = $120\text{--}24\text{--}86$ and $58\text{--}24\text{--}86\text{ kg ha}^{-1}$; T4 = $140\text{--}28\text{--}101$ and $67\text{--}28\text{--}101\text{ kg ha}^{-1}$ applied during vegetative and reproductive stages, respectively.

The growth rate of vine length decreased progressively over time after transplanting, as displayed in Figure 2. Based on the growth rate of vine length, fertilizer used in Treatment 2 indicated a slower growth increment, around 5 to 7 days later than that of the Gac fruit plant in other treatments, which may be attributed to its lower NPK input. A similar enhancement in vine length and vegetative growth

under integrated organic and mineral fertilization was reported in greenhouse-grown cucumber, where combined poultry manure and mineral fertilizer significantly improved plant vigor and yield compared with the control (Sallam et al., 2021). Likewise, higher nitrogen availability has been associated with improved chlorophyll synthesis and photosynthetic efficiency, leading to enhanced biomass accumulation and vine elongation (Bhunia et al., 2021).

Table 2: Constants of plant height of Gac fruit applied with four different combination fertilizer treatments using function $y = A/(1+be^{-cx})$.

Treatment	Constant			F value	Approx. Pr > F	Approx. R ²
	A	B	C			
1 (control)	760.7	11.342	0.0554	662.99	<.0001	0.974
2	829.1	13.8346	0.0514	422.17	<.0001	0.989
3	716.4	12.5822	0.0556	618.05	<.0001	0.978
4	715.5	13.4617	0.0622	557.86	<.0001	0.959

Note: A, B, and C are constants derived from the logistic growth model $y = A / (1 + be^{-cx})$, where y represents vine length and x represent days after transplanting (DAT). A denotes the estimated asymptotic maximum vine length, B is a scaling constant related to the initial growth condition, and C represents the relative growth rate constant. All parameters were estimated using nonlinear regression analysis. T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

Table 3: Main and interaction effects of fertilizer combination treatments and days after transplanting (14, 28, 42, 56, 70, 84, 98 days) on the number of leaves, nodes, and branches of Gac fruit plants.

Factor	Number of leaves	Number of nodes	Number of branches
Fertilizer treatments (FT)			
1 (control)	105.26 b ^z	45.97 ab	14.54 a
2	85.31 c	46.80 a	10.66 d
3	93.51 bc	43.29 c	12.74 c
4	123.74 a	44.23 bc	13.74 b
Days after transplanting (DAT)			
(day)			
14	11.40 g	6.10 g	2.45 g
28	19.90 f	21.40 f	4.50 f
42	63.80 e	36.60 e	8.10 e
56	107.70 d	46.95 d	12.70 d
70	141.10 c	59.35 c	17.55 c
84	165.15 b	67.65 b	21.20 b
98	204.65 a	77.45 a	23.95 a
FT x DAT	ns	ns	*

^zAt a significant level of P=0.05, the same letter is shared within a column, and the factor indicates no significant difference, as determined by the DMRT. *, ns Significant and not significant at P ≤ 0.05, respectively. Note: T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

In the present study, higher fertilizer rates promoted earlier attainment of maximum vine length without negatively affecting reproductive development. Although excessive nitrogen has been reported to prolong vegetative growth at the expense of fruiting in some cucurbit crops, such negative effects were not observed under the current field conditions. This suggests that balanced nutrient application under tropical cultivation conditions can accelerate vegetative growth while maintaining optimal source-sink balance and fruit development.

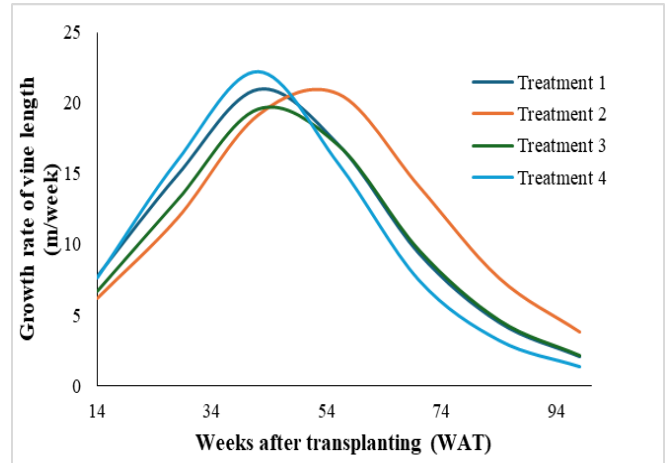


Figure 2: The growth rate of vine length as a function of four different fertilizer combination treatments, in the form of $dy/dx = (Abce^{-cx}) / (1 + be^{-cx})^2$ of Gac fruit. Note: T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

3.2. Leaf and node development

The interaction between fertilizer treatments and days after transplanting did not significantly affect the number of Gac leaves (Table 3). However, plants in Treatment 4 recorded the highest leaf number, indicating an increase of approximately 16.14% to 36.77% compared to other treatments, calculated from mean leaf number values at the final observation time point (Table 3). This result aligns with the higher nutrient input in Treatment 4, supporting the idea that increased nutrient availability enhances photosynthate production and promotes leaf development (Abd El-Hafeez & Ali, 2013).

Similar findings have been reported in okra (Khandaker et al., 2017), ridge gourd (Patil et al., 2024), maize (Chaudhary et al., 2022), cucumber (Abd El-Hafeez & Ali, 2013), and watermelon (Sabo et al., 2013). Node numbers were also unaffected by the interaction between treatment and planting days. Treatment 2 produced 7.8% and 5.6% more nodes than Treatments 3 and 4, respectively, and was similar to Treatment 1. Although Treatments 1 and 2 used lower fertilizer rates, they produced more nodes and longer vines by the end of the experiment. Node counts were taken from the main vine and did not necessarily correlate with leaf number due to Gac's alternate leaf arrangement (Osman et al., 2017). Both leaf and node numbers increased over time, peaking on day 98. This trend agrees with previous studies (Sun et al., 2021; Kumar & Kumar, 2013), where increased photosynthesis and light capture supported vegetative growth. However, excessive fertilizer may reduce plant performance (Dwivedi et al., 2017; Liu et al., 2017).

3.3. Branching and vegetative response

The number of branches in Gac plants exhibited significant interaction between fertilizer treatments and days after transplanting, as detailed in Table 3. This finding suggests that branching patterns were shaped by differences in fertilizer type and concentration, as well as by changes in plant development over time. Understanding this interaction is crucial as it highlights how nutrient availability dynamically interacts with plant growth phases to determine vegetative architecture. Consequently, this section focuses on exploring the detailed relationship between branch development and the progression of time for each fertilizer treatment.

According to Figure 3, the number of branches in Gac plants increased in an almost linear fashion as the days after transplanting advanced. The number of days post-transplanting accounted for a substantial proportion of the variability in branch number, ranging between 94% and 97%, which illustrates a strong temporal effect on branching dynamics regardless of fertilizer treatment. During the initial growth period, spanning up to 28 days after transplanting, branch counts across all fertilizer treatments were very similar. This suggests that early branching is relatively less sensitive to nutrient differences or that baseline nutrient availability was sufficient for initial shoot development.

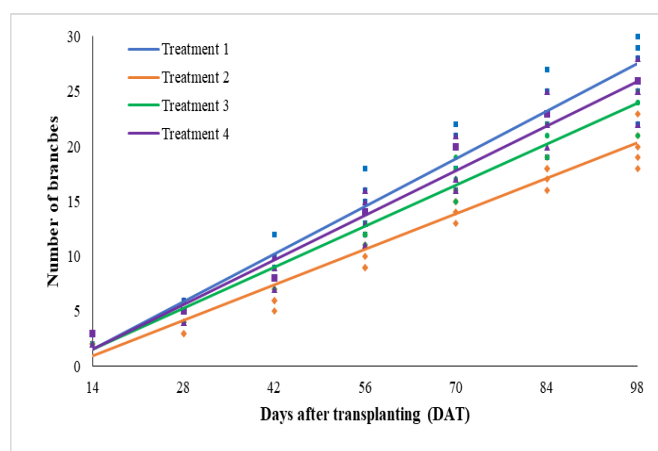


Figure 3: Relationships between the number of branches and DAT of Gac fruit planted under different fertilizer combination treatments; y (Treatment 1) = $-2.743 + 0.309x$ ($R^2=0.94$); y (Treatment 2) = $-2.257 + 0.231x$ ($R^2=0.96$); y (Treatment 3) = $-2.143 + 0.266x$ ($R^2=0.97$); y (Treatment 4) = $-2.514 + 0.290x$ ($R^2=0.96$). The solid line represents a statistically significant linear relationship at the level of significance $P \leq 0.05$. Note: T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

However, by day 42 post-transplant, clear differences began to emerge among the treatments. Plants subjected to Treatment 2 recorded 31.6% fewer branches than in Treatment 1 and 26% fewer than in Treatment 4, although their branch numbers remained comparable to those

in Treatment 3. From day 56 onward, Treatment 2 consistently produced the lowest branch numbers through day 98, likely due to its lower fertilizer application rate. Reduced nutrient availability, particularly nitrogen, may have limited chlorophyll synthesis and photosynthetic capacity, thereby decreasing carbohydrate production required for axillary bud activation and shoot branching.

Nitrogen plays a crucial role in cytokinin synthesis, a hormone involved in stimulating lateral bud growth; thus, an insufficient nitrogen supply may suppress branching by reducing cytokinin-mediated bud outgrowth. Additionally, lower nutrient input may have constrained assimilate partitioning to developing shoots, resulting in reduced vegetative expansion. These findings suggest that adequate nutrient availability enhances branching in Gac plants by supporting photosynthetic efficiency, hormonal regulation, and improved source-sink dynamics. Such results are consistent with earlier studies on similar cucurbit crops, such as bitter melon (Johnson & Sureshkumar, 2015) and muskmelon (Aluko et al., 2021), both of which reported increased branching and more vigorous vegetative growth under higher nutrient regimes. Taken together, these insights underscore the importance of optimizing fertilizer management strategies to stimulate desirable branching patterns and overall plant architecture, which could ultimately have positive effects on yield and fruit quality.

3.4. Fruit yield components and pre-harvest physical characteristics

Based on Table 4, there were no significant differences among fertilizer treatments in average fruit weight, total weight, fruit length, fruit diameter, or aril weight. However, the number of fruits per plant differed significantly across treatments. Treatment 4 produced 38.8% more fruits than Treatment 2, though fruit count was comparable to Treatments 1 and 3. This difference in fruit number may be attributed to the higher fertilizer input in Treatment 4, which received approximately 54.5% higher rates of urea, TSP, and MOP than Treatment 2 during both vegetative and reproductive growth stages (Table 1).

Previous studies have highlighted the importance of nitrogen and potassium in enhancing fruit set in crops like bitter melon and cucumber (Maluki et al., 2016; Dhillon et al., 2017; Ashraf et al., 2019). In addition to supporting photosynthesis, nitrogen and phosphorus enhance potassium and calcium uptake, facilitating the efficient transfer of photosynthates from the source (leaves) to the sink (fruits). Thus, greater nutrient availability, particularly nitrogen and phosphorus, contributed to the increased fruit number observed in Treatment 4.

Table 4: Total weight, number of fruits, fruit length, and fruit diameter of Gac fruit planted at Bukit Kor using four different rates of fertilizers.

Treatment	Average weight (g)	Total weight (g)	Number of fruits /plants	Fruit length (cm)	Fruit diameter (cm)	Weight of aril (g)
1 (control)	790.9 a ²	10827 a	13.8 ab	15.76 a	34.04 a	149.40 a
2	648.5 a	6575 a	10.4 c	14.60 a	34.33 a	132.20 a
3	719.3 a	7835 a	11.0 bc	14.86 a	35.29 a	166.40 a
4	688.8 a	10920 a	15.4 a	15.40 a	35.40 a	161.12 a

²At a significant level of $P=0.05$, the same letter is shared within a column, and the factor indicates no significant difference, as determined by the DMRT. Note: T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

Despite differences in fertilizer rates, no significant effects were observed on average fruit weight, fruit length, fruit diameter, or aril weight among treatments (Table 4). These fruit physical characteristics are influenced by nutrient availability, plant physiological processes, and assimilate partitioning rather than fertilizer rate alone (Zhu et al., 2010). This suggests that increasing fertilizer input beyond a certain level does not necessarily enhance fruit size or aril development in Gac. Nutrient efficiency can be described as “flux density,” where the availability of nutrients per unit of time and area depends on fertilizer rate and water supply, since optimal water enhances nutrient flux and uptake while water stress limits nutrient movement and reduces yield (Ali et al., 2017). A recent study revealed that nitrogen use efficiency (NUE) in watermelon was influenced more by water availability than by fertilizer rate, with the highest efficiency achieved under optimal water supply (around 232 mm) combined with 50 kg/ha nitrogen, whereas water stress reduced yields despite similar nitrogen application rates. Consistently, Hong et al. (2021) and Pereira et al. (2019) reported that nitrogen efficiency is more sensitive to water availability than to fertilizer rate, as water stress lowered melon yield even when fertilization remained constant.

Excessive nutrient allocation, particularly nitrogen, does not always translate into improved fruit size or weight, especially when vegetative growth dominates over reproductive development. Fruit growth and quality are more closely linked to assimilate partitioning and the maintenance of an adequate and healthy leaf area rather than leaf number alone (Van Der Ploeg & Heuvelink, 2015). Therefore, although nitrogen plays a fundamental role in plant metabolism and photosynthetic capacity, its effects on vegetative traits, such as leaf development, may not always be reflected in statistically significant differences under field conditions. Hence, maintaining nitrogen levels within an optimal range throughout the crop growth cycle is crucial. Nitrogen is essential for plant growth, as it supports the formation of amino acids, proteins, nucleic acids, and chlorophyll. Amino acid metabolism is the key process linking nitrogen

assimilation to overall plant productivity (Dellero, 2020). Proper management directly affects the growth and biochemical composition of fruits, including phytonutrient content, such as carotenoids.

3.5. Influence of fertilizer rates on carotenoid accumulation

The chromatographic analysis using High-Performance Liquid Chromatography (HPLC) confirmed the identification of β -carotene and lycopene based on their characteristic retention times, observed at approximately 19.37 and 23.22 minutes, respectively, in the HPLC chromatograms (Figure 4).

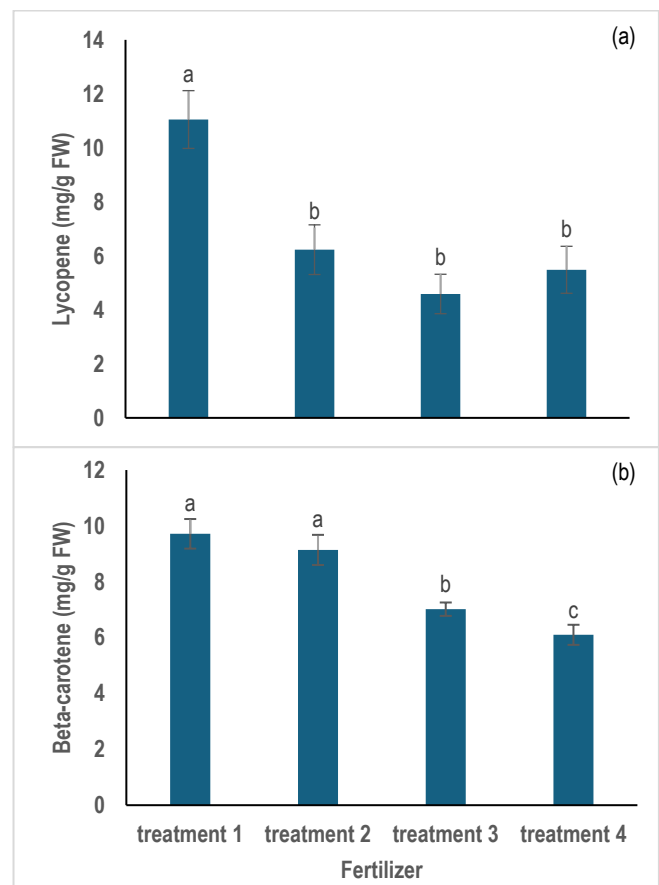


Figure 4: (a) Lycopene and (b) Beta-Carotene of Gac fruit under different fertilizer treatments. Data are presented as mean $\pm$ standard error (SE), $n = 6$. Different letters above the bars indicate significant differences at $p < 0.05$ according to Duncan's Multiple Range Test (DMRT). Note: T1 = Control (100-20-72 kg ha⁻¹ N-TSP-MOP during vegetative stage; 48-20-72 kg ha⁻¹ during reproductive stage); T2 = 80-16-58 and 38-16-58 kg ha⁻¹; T3 = 120-24-86 and 58-24-86 kg ha⁻¹; T4 = 140-28-101 and 67-28-101 kg ha⁻¹ applied during vegetative and reproductive stages, respectively.

Results indicated that Treatment 1 exhibited the highest lycopene concentration (Figure 4a). Moreover, β -carotene content was significantly higher in Treatments 1, 2, and 3 compared to Treatment 4 (Figure 4b), suggesting that moderate nitrogen application promotes carotenoid biosynthesis. These findings suggest that moderate nitrogen supply promotes carotenoid accumulation by maintaining a

balanced carbon-nitrogen metabolism and supporting efficient photosynthesis. In contrast, excessive nitrogen may redirect assimilates toward vegetative growth and protein synthesis at the expense of secondary metabolites. Similar trends have been reported in cucurbit crops, where optimized nutrient management improved physiological performance and yield without compromising fruit quality (Sallam et al., 2021).

Recent studies further demonstrate that nitrogen status alters plant metabolic pathways, affecting pigment accumulation and antioxidant compounds through changes in carbon allocation and enzymatic regulation (Hao et al., 2020; Lu et al., 2017). In cucumber, nitrogen deficiency or excess has been demonstrated to alter nitrogen metabolism and photosynthetic efficiency, thereby affecting pigment composition and fruit biochemical traits. This supports the present findings that balanced fertilizer application is critical for optimizing carotenoid accumulation in Gac fruit. Moreover, excessive nitrogen fertilization may dilute phytochemical concentration due to rapid biomass expansion and altered source-sink relationships (Lee et al., 2024; Zhang et al., 2021). Therefore, precise nutrient management strategies are essential to maintain both fruit yield and nutritional quality while minimizing environmental risks associated with nitrogen overuse.

4. CONCLUSION

Gac growth and yield responses varied under different fertilizer rates. Among the treatments, Treatment 1 demonstrated the most favorable overall performance, providing a balanced combination of vegetative growth, fruit production, and carotenoid accumulation. Although most fruit physical quality parameters were not significantly affected by fertilizer rate, the number of fruits per plant differed among treatments, with Treatment 4 producing significantly more fruits than Treatment 2. In terms of nutritional quality, Treatment 1 produced fruits with significantly higher lycopene content, while β -carotene levels were significantly higher in Treatments 1, 2, and 3 compared to Treatment 4. Overall, Treatment 1 is identified as the most suitable fertilizer regime for Gac cultivation under the conditions of Bukit Kor, Universiti Malaysia Terengganu. Further studies incorporating micronutrients and refined nutrient management strategies are recommended to enhance phytonutrient accumulation, particularly carotenoids.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the Crop Science Program, Faculty of Food Science and Agrotechnology, Universiti Malaysia Terengganu, for providing research facilities. Special thanks to Dr. Munirah Mohamed for her

support and material contributions, and to the Malaysian Meteorological Department for their kind cooperation.

REFERENCES

- Abd El-Hafeez, A.M. & R.M. Ali. (2013). Influence of inorganic nitrogen, phosphorus and bio-fertilizers on growth, yield and yield components and nutrient uptake of cucumber (*Cucumis sativus* L.). *Journal of Soil Sciences and Agricultural Engineering*, 4(11), 1329–1346.
https://jssae.journals.ekb.eg/article_52905.html
- Ali, A., Naeem, M., Ahmad Dar, T., Idrees, M., Khan, M. A., Uddin, M., & Singh, T. (2017). Nutrient uptake, removal, and cycling in Eucalyptus species. In M. Naeem, A. Ansari, & S. Gill (Eds.), *Essential plant nutrients: Uptake, use efficiency and management* (pp. 37–46). Springer, Cham.
https://doi.org/10.1007/978-3-319-58841-4_2
- Aluko, M., Olajide, O. O., & Kehinde-Fadare, A. F. (2021). The effects of single and split NPK fertilizer application on growth and yield of muskmelon (*Cucumis melo* L.). *Annual Research & Review in Biology*, (August), 90–97.
<https://doi.org/10.9734/arrb/2021/v36i830414>
- Ariyaratna, P. M., & Gamage, H. S. D. (2024). Gac (*Momordica cochinchinensis* Spreng) fruit as a promising functional food: A comprehensive review. *International Journal of Science and Research Archive*, 11(01), 2227–2236.
<https://doi.org/10.30574/ijrsra.2024.11.1.0299>
- Ashraf, I., Zain, M., Sarwar, M., Abbasi, K. Y., & Amin, M. (2019). Role of different levels of nitrogen, phosphorus and potassium on growth, yield and quality attributes of bitter melon (*Momordica charantia* L.). *Food Science & Technology*, 7(2), 16–21. <https://doi.org/10.13189/fst.2019.070202>
- Barba, A. O., Hurtado, M. C., Mata, M. S., Ruiz, V. F., & De Tejada, M. L. S. (2006). Application of a UV-Vis detection-HPLC method for rapid determination of lycopene and β -carotene in vegetables. *Food Chemistry*, 95(2), 328–336.
<https://doi.org/10.1016/j.foodchem.2005.02.028>
- Barua, S., Molla, A. H., Haque, M. M., & Alam, M. S. (2018). Performance of Trichoderma-enriched bio-organic fertilizer in N supplementation and bottle gourd production in field condition. *Horticulture International Journal*, 2(3), 106–114. <https://doi.org/10.15406/hij.2018.02.00036>
- Bharathi, L.K. and K.J. John. (2013). *Momordica* genus in Asia-An overview. Springer, New Delhi, Vol. 9788132210. (pp. 147). <https://doi.org/10.1007/978-81-322-1032-0>
- Bhunja, S., Bhowmik, A., Mallick, R., & Mukherjee, J. (2021). Agronomic efficiency of animal-derived organic fertilizers and their effects on biology and fertility of soil: A review. *Agronomy*, 11(5), 823. <https://doi.org/10.3390/agronomy11050823>
- Chaudhary, S., Devi, P., HanumanthaRao, B., Jha, U. C., Sharma, K. D., Prasad, P. V., & Nayyar, H. (2022). Physiological and molecular approaches for developing thermotolerance in vegetable crops: a growth, yield and sustenance perspective. *Frontiers in Plant Science*, 13, 878498.
<https://doi.org/10.3389/fpls.2022.878498>
- Dellero, Y. (2020). Manipulating amino acid metabolism to improve crop nitrogen use efficiency for a sustainable agriculture. *Frontiers in Plant Science*, 11, 602548.
<https://doi.org/10.3389/fpls.2020.602548>
- Dhillon, N. P. S., Hanson, P., Chen, W., Srinivasan, R., Kenyon, L., Yang, R.-Y., Luoh, J. W., & Mecozzi, M. (2017). Suggested cultural practices for bitter melon. World Vegetable Center. <https://growables.com/informationVeg/documents/BitterGourdCulturalAVRDC.pdf>
- Dwivedi, B. S., Singh, V. K., & Meena, M. C. (2017). Efficient nitrogen management under predominant cropping systems of India. In *The Indian nitrogen assessment: Sources of reactive nitrogen, environmental and climate effects, management options, and policies* (pp. 95–115). Elsevier.
<https://doi.org/10.1016/b978-0-12-811836-8.00007-0>
- Hao, J., Li, Q., Yu, H., Wang, H., Chai, L., Miao, T., & Jiang, W. (2020). Comparative proteomic analysis of cucumber fruits under nitrogen deficiency at the fruiting stage. *Horticultural Plant Journal*, 7(1), 59–72.
<https://doi.org/10.1016/j.hpj.2020.12.002>
- Hong, T., Cai, Z., Zhao, R., He, Z., Ding, M., & Zhang, Z. (2021). Effects of water and nitrogen coupling on the yield, quality, and water and nitrogen utilization of watermelon under CO₂ enrichment. *Scientia Horticulturae*, 286, 110213.
<https://doi.org/10.1016/j.scienta.2021.110213>
- Ilupeju, E. A. O., Akanbi, W. B., Olaniji, J. O., Lawal, B. A., Ojo, M. A., & Akintokun, P. O. (2015). Impact of organic and inorganic fertilizers on growth, fruit yield, nutritional and lycopene contents of three varieties of tomato (*Lycopersicon*

- esculentum (L.) Mill.) in Ogbomoso, Nigeria. *African Journal of Biotechnology*, 14(31), 2424–2433. <https://doi.org/10.5897/ajb10.1902>
- Johnson, N., & Sureshkumar, R. (2015). Effect of phosphorus and potassium on growth and yield characters of bitter melon (*Momordica charantia* L.) ecotype 'Mithipagal'. *Asian Journal of Horticulture*, 10(2), 207–211. <https://doi.org/10.15740/HAS/TAJH/10.2/207-211>
- Khandaker, M. M., Fadhliah Nor, M., Dalorima, T., Sajili, M. H., & Mat, N. (2017). Effect of different rates of inorganic fertilizer on physiology, growth and yield of okra (*Abelmoschus esculentus*) cultivated on BRIS soil of Terengganu, Malaysia. *Australian Journal of Crop Science*, 11(7), 880–887. <https://doi.org/10.21475/ajcs.17.11.07.pne552>
- Kubola, J., & Siriamompun, S. (2011). Phytochemicals and antioxidant activity of different fruit fractions (peel, pulp, aril and seed) of Thai Gac (*Momordica cochinchinensis* Spreng). *Food Chemistry*, 127(3), 1138–1145. <https://doi.org/10.1016/j.foodchem.2011.01.115>
- Kumar, S., & Kumar, A. (2013). Spatial and harvesting influence on growth, yield, quality and economic potential of Kalmegh (*Andrographis paniculata* Wall. ex Nees). *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, 114(1), 69–76. <http://nbn-resolving.de/urn:nbn:de:hebis:34-2013030542629>
- Lee, N. R., Kim, Y. X., Lee, Y., Lee, C., Song, Y., Park, H., ... & Lee, Y. (2024). Metabolomics reveals the effects of nitrogen/phosphorus/potassium (NPK) fertilizer levels on cucumber fruit raised in different nutrient soils. *Metabolites*, 14(2), 102. <https://doi.org/10.3390/metabo14020102>
- Liu, C., Liu, Y., Li, Z., Zhang, G., & Chen, F. (2017). A novel way to establish fertilization recommendations based on agronomic efficiency and a sustainable yield index for rice crops. *Scientific Reports*, 7(1), 1–8. <https://doi.org/10.1038/s41598-017-01143-2>
- Lu, J., Yang, R., Wang, H., & Huang, X. (2017). Stress effects of chlorate on longan (*Dimocarpus longan* Lour.) trees: Changes in nitrogen and carbon nutrition. *Horticultural Plant Journal*, 3(6), 237–246. <https://doi.org/10.1016/j.hpi.2017.12.003>
- Maluki, M., Ogwen, J., & Gesimba, R. (2016). Evaluation of nitrogen effects on yield and quality of watermelon (*Citrullus lanatus* (Thunb.) Matsumura and Nakai) grown in the coastal regions of Kenya. *International Journal of Plant Sciences*, 9(2), 1–8. <https://doi.org/10.9734/ijps/2016/18821>
- Muchajib, S., & Muchajib, U. (2015). The development of a production system and postharvest handling for Gac fruit (*Momordica cochinchinensis*): Knowledge transfer to a community enterprise in Thailand. *Acta Horticulturae*, 1091, 63–66. <https://doi.org/10.17660/ActaHortic.2015.1091.6>
- Müller-Maatsch, J., Sprenger, J., Hempel, J., Kreiser, F., Carle, R., & Schweiggert, R. M. (2017). Carotenoids from Gac fruit aril (*Momordica cochinchinensis* [Lour.] Spreng.) are more bioaccessible than those from carrot root and tomato fruit. *Food Research International*, 99, 928–935. <https://doi.org/10.1016/j.foodres.2016.10.053>
- Osman, M., Sulaiman, Z., Saleh, G., Rahman, M.S.A., Zainuddin, Z. M., Sin, M. A., & Hamidon, A. (2017). Gac fruit, a plant genetic resource with high potential. *Transactions of the Persatuan Genetik Malaysia*, 7, 125–128.
- Parks, S. E., Nguyen, M. H., Gale D., & Murray, C. (2013). Assessing the potential for a Gac (Cochinchin gourd) industry in Australia. <https://researchers.westernsydney.edu.au/en/publications/assessing-the-potential-for-a-gac-cochinchin-gourd-industry-in-au/>
- Patil, H. P., Kale, K. D., Mane, M. S., Khedkar, D. D., & Danawale, N. J. (2024). Nutrient availability, nutrient uptake and economics of ridge gourd (*Luffa acutangula* L.) under drip fertigation in summer season. *Journal of Agriculture Research and Technology*, 49(2), 324–328. <https://doi.org/10.56228/JART.2024.49215>
- Pereira, L. D. S., Silva, E. M. D., Ferreira, J. O. P., Santos, V. L. G., Lima, C. J. G. D. S., & Silva, G. B. D. (2019). Watermelon yield and efficiency of use of water and nitrogen. *Revista Caatinga*, 32(3), 769–777. <https://doi.org/10.1590/1983-21252019v32n321rc>
- Rahman, M. N. A., Ismail, A., Azlan, A., Aziz, A. A., Hassim, M. D., & Muhammad, N. H. (2024). Physicochemical properties, proximate composition, and carotenoid content of *Momordica cochinchinensis* L. Spreng (Gac) fruit. *Pertanika Journal of Tropical Agricultural Science*, 47(2), 461–479. <https://doi.org/10.47836/pjtas.47.2.09>
- Revathi, B., Saren, S., Dash, P. K., Mishra, A., Sethy, S. K., Pattnaik, T., & Dey, P. (2024). Optimizing nutrient recommendations for Bottle Gourd Crop by formulation of targeted yield equations in an Inceptisol of Odisha, India. *Asian Journal of Soil Science and Plant Nutrition*, 10(2), 223–235. <https://doi.org/10.9734/ajsspn/2024/v10i2279>
- Sabo, M. U., Wailare, M. A., Aliyu, M., Jari, S., & Shuaibu, Y. M. (2013). Effect of NPK fertilizer and spacing on growth and yield of watermelon (*Citrullus lanatus* L.) in Kaltungo Local Government Area of Gombe State, Nigeria. *Scholarly Journal of Agricultural Science*, 3(8), 325–330. <https://scispace.com/pdf/effect-of-npk-fertilizer-and-spacing-on-growth-and-yield-of-4uzep44q8t.pdf>
- Sallam, B. N., Lu, T., Yu, H., Li, Q., Sarfraz, Z., Iqbal, M. S., Khan, S., Wang, H., Liu, P., & Jiang, W. (2021). Productivity enhancement of cucumber (*Cucumis sativus* L.) through optimized use of poultry manure and mineral fertilizers under greenhouse cultivation. *Horticulturae*, 7(8), 256. <https://doi.org/10.3390/horticulturae7080256>
- Sun, W., Ma, N., Huang, H., Wei, J., Ma, S., Liu, H., & Li, X. (2021). Photosynthetic contribution and characteristics of cucumber stems and petioles. *BMC Plant Biology*, 21(1), 454. <https://doi.org/10.1186/s12870-021-03233-w>
- Van Der Ploeg, A., & Heuvelink, E. (2015). The influence of temperature on growth and development of chrysanthemum cultivars. *The Journal of Horticultural Science and Biotechnology*, 81(2), 174–182. <https://doi.org/10.1080/14620316.2006.11512047>
- Vanessa, B. G., Alice, T. I., William, D. A., Adelaide, D. M., Gisèle, L. E., Condurache, N. N., & Iordachescu, G. (2024). Effect of fertilizers on yield, phytochemical, and antioxidant properties of *Cucurbita moschata* fruits. *Food Science & Nutrition*, 12(9), 6742–6751. <https://doi.org/10.1002/fsn3.4294>
- Zhang, J., Feng, S., Yuan, J., Wang, C., Lu, T., Wang, H., & Yu, C. (2021). The formation of fruit quality in *Cucumis sativus* L. *Frontiers in Plant Science*, 12, 729448. <https://doi.org/10.3389/fpls.2021.729448>
- Zheng, L., Zhang, Y., Liu, Y., Yang, X. O., & Zhan, Y. (2015). *Momordica cochinchinensis* Spreng. seed extract suppresses breast cancer growth by inducing cell cycle arrest and apoptosis. *Molecular Medicine Reports*, 12(4), 6300–6310. <https://doi.org/10.3892/mmr.2015.4186>
- Zhu, X.-G., Long, S. P., & Ort, D. R. (2010). Improving photosynthetic efficiency for greater yield. *Annual Review of Plant Biology*, 61, 235–261. <https://doi.org/10.1146/annurev-arplant-042809-112206>