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Flowering response of torch ginger (*Etlingera elatior*) to PK fertilization

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Abstract. *Hidayat R, Nugrahani P, Maghfiroh RN. 2025. Flowering response of torch ginger (*Etlingera elatior*) to PK fertilization. Biodiversitas 26: 6305-6315.* Demand for the flowers of *Etlingera elatior* has increased, but predictable and timely flowering is constrained by its naturally long vegetative phase. This research aimed to determine the combined effect of dosage and frequency of PK compound fertilizer in inducing flowering in torch ginger. The field trial was carried out at Dapoer Ketjombrang Garden, Giripurno Village, Bumiaji District, Batu City, East Java, Indonesia, from December 2023 to April 2024. A factorial experiment was conducted using a randomized complete block design (two factors: dosage (D): 50, 100, 150, 200 g/clump; frequency (F): 1, 2, 3 applications at 30, 30+45, and 30+45+60 DAT, respectively) with three replicates (36 plots, 3 plants/plot, total 108 plants) was used. Data were analyzed using a two-way ANOVA (dosage, frequency, dosage×frequency), and means were compared using Tukey's HSD (α: 0.05). The combination D4F2 (200 g, 2x at 30 and 45 DAT) produced the earliest flowering (mean 21.89 DAT). The dosage D3 (150 g) produced the best vegetative growth and, when combined with F2, gave the highest number of flowers (23.78 flowers/clump). Dosage effects were significant ($p<0.05$) for several traits; frequency had limited main effects, but dosage×frequency interactions were observed. The highest C:N ratio, antioxidant level, and vitamin C were observed at D4; regression between C:N and flowering age showed R^2: 0.92 (p: 0.041). Overall, applying 150-200 g PK fertilizer per clump in two applications (30 and 45 DAT) provides an effective strategy to induce earlier flowering and increase flower productivity under the conditions tested. Multi-season and multi-site validation is recommended before making broad recommendations.

Keywords: Antioxidant, C:N ratio, fertilizer application, flowering time, torch ginger

INTRODUCTION

Torch ginger (*Etlingera elatior*) is a perennial species belonging to the Zingiberaceae family. It is indigenous to Indonesia and Malaysia and widely cultivated across Southeast Asia for its edible inflorescences, ornamental value, and diverse bioactive compounds that underpin its uses in food, traditional medicine and health care, floriculture market, and aesthetic purposes (Chan et al. 2011a, 2011b; Wijekoon et al. 2013; Choon and Ding 2017; Sabilu et al. 2017; Araújo et al. 2018; Whangsomnuek et al. 2019; Cordeiro et al. 2023). Its economic and cultural significance has been highlighted in recent reviews in botany and phytochemistry. These reviews also note a growing interest in enhancing its agronomic performance for commercial production (Ismail 2023; Prayoga 2025).

Despite its potential benefits, the commercial cultivation of *E. elatior* is hindered by its prolonged juvenile or vegetative phase and delayed flowering under non-treated conditions, resulting in reduced flower yield and farm profitability. The growth and development period until flowering and fruiting takes 2 years (Juwita et al. 2018). Phenological studies and agronomic surveys indicate that, in the absence of specific management interventions, the development of inflorescences in torch ginger frequently requires an extended period before visible floral initiation occurs, thereby creating a production bottleneck for growers who depend on predictable and timely flowering (Yunus et al. 2012; Choon et al. 2016).

The nutritional status of plants, particularly the availability of phosphorus (P) and potassium (K), has been identified as a pivotal factor in the transition from vegetative growth to reproductive development. A series of experimental studies on ornamental and perennial species has demonstrated that ensuring adequate levels of P and K can modify carbohydrate allocation and nutrient partitioning within plants. Phosphorus (P) plays a role in the formation of cell membranes and in various metabolic processes, promotes growth and physiological metabolism (Maathuis 2009). As an activator of various enzymes, potassium is involved in intracellular osmotic regulation and membrane protein transport. In addition, K plays an important role in carbohydrate transport in several plants and is beneficial for plant metabolism and stress resistance (Wang and Wu 2013; Nieves-Cordones et al. 2019). These nutrients optimized the growth and flowering of Chinese carnation (*Dianthus chinensis*) (Owain 2024). This, in turn, has been shown to increase the carbon-to-nitrogen (C:N) ratio, a critical factor in the process of floral induction. Recent controlled studies demonstrate that optimized N:P:K management alters tissue nutrient contents and accelerates reproductive development in horticultural crops. These findings suggest that targeted PK fertilization may be an effective tool for accelerating flowering in species with long natural flowering times (Fang et al. 2023; Weinstein et al. 2024). However, despite the agronomic importance of torch ginger, no empirical studies have evaluated how PK fertilization affects its flowering behavior, C:N ratio dynamics, or yield attributes. Existing research on *E. elatior* focuses largely on phytochemistry, propagation, and phenology, leaving a critical gap in nutrient-based reproductive regulation. The lack of controlled field data on PK-driven floral induction limits growers' ability to implement nutrient strategies that reliably accelerate flowering and improve productivity. Consequently, a systematic examination of PK dosage and application frequency is urgently needed to provide evidence-based recommendations for enhancing floral initiation in torch ginger.

Mechanistically, an increased C:N ratio (reflecting greater carbohydrate availability relative to nitrogen) has indeed been implicated in promoting the floral transition across diverse plant systems. Classical and recent physiological studies indicate that a high C:N environment favors the expression of floral-promoting signals and the mobilization of carbohydrates to developing meristems (Lin and Chang 2017; Tsai and Chang 2022). In light of the prolonged duration required for flowering in untreated torch ginger (*E. elatior*), the recognized impact of phosphorus (P) and potassium (K) on photosynthate production and translocation, and the pivotal role of the carbon-to-nitrogen (C:N) ratio in floral induction, this study aims to test the hypothesis that P fertilization enhances the C:N ratio, thereby expediting flowering in *E. elatior*. The outcomes of this study will address a significant knowledge gap in the species pheno-physiology and provide practical guidance for growers seeking to reduce the time to flower and enhance floral output (Corbesier et al. 2002; Huang et al. 2021). Efforts to enhance and multiply flower induction through fertilization can be optimized by adjusting the frequency of fertilizer application, as nutrient requirements vary throughout growth and development. The absorption of each nutrient varies, requiring different application timings and quantities. In practice, the dosage and application frequency must be considered to increase efficiency. Based on the description above, this research aimed to determine the combined effect of dosage and frequency of PK compound fertilizer in inducing flowering in torch ginger

MATERIALS AND METHODS

Study area

The trial was carried out from December 2023 to April 2024 at torch ginger farm, Giripurno Village, Bumiaji Subdistrict, Batu, East Java, Indonesia. The research area was located at ±1.150 m above sea level with an average daily temperature range from 20ºC to 27ºC. The hilly rural terrain stretching from the slopes of Mount Arjuno in the north to the Brantas River in the south featured fertile soil, springs, natural rivers, and irrigation canals.

Experimental design

The trial was a factorial experiment using a randomized complete block design with two factors. The first factor was the dosage of the compound phosphorus-potassium fertilizer (D), with levels D1: 50 g/clump, D2: 100 g/clump, D3: 150 g/clump, and D4: 200 g/clump. The second factor was the frequency of fertilizer application (F), consisting of F1: 1x application frequency (30 DAP), F2: 2x application frequency (30 and 45 DAP), and F3: 3x application frequency (30, 45, and 60 DAP). It is imperative to verify the validity of the assumption that fertilization occurs once, twice, or three times, with the aggregate of these frequencies constituting 100% of the dosage. To illustrate, when the frequency is set to "once", the entire fertilizer dosage is applied 30 days after preparation (DAP). For a frequency of twice, 50% of the dosage is applied at 30 DAP, with the remaining 50% applied at 45 DAP. Then, a frequency of three times, the application is as follows: one-third is applied at 30 DAP, the second one-third at 45 DAP, and the final third at 60 DAP. The combination of these two factors resulted in 12 treatments combination, each repeated three times, yielding 36 experimental units. The topography of the research site, characterized by an approximate slope of 5%, acted as a confounding factor in the experimental process. The experimental design comprised three blocks, with each block separated by a ditch. The blocks were positioned at varying heights, necessitating three replicates to ensure robustness. Each block contained 72 clumps (6 per row, 12 between rows), for a total of 216 clumps used in this study. Each experimental unit comprised three clump samples from six clumps planted, bringing the total number of research units to 108 clumps. Experimental units are assigned by randomization according to the terms of the RCBD. Observation and measurement were used with a tape measure and a caliper. The materials used were one-year-old torch ginger plants (criteria: 12-15 buds per clump. The uniformity test results indicate that the planting materials meet the standard criteria for homogeneity (*p*-value >0.05), MKP fertilizer (Phosphate (P2O5): 52% and Potassium (K2O): 34%), urea, manure, insecticides, and fungicides. At the beginning of the study, urea (N fertilizer) at a dosage of 15 g/clump, along with organic manure, was applied 30 days before the PK fertilizer treatment. This was carried out to standardize the N nutrient content and enhance plant vigor prior to treatment.

Observation and data analysis

Observation and measurements were recorded for the following quantitative traits: plant height (cm), number of stem shoots per clump (stems), time for flower emergence (DAT), number of flower per clump, length of flower crown, diameter of flower crown, length of flower stalk (cm), fresh weight of fresh flower per clump, and dry flower weight per clump, C:N ratio, antioxidant content (IC_{50}), and vitamin C (mg 100 g^{-1} FW), The carbon-nitrogen ratio (C:N ratio) analysis was performed three times 1) before flowering at the beginning of the research, 2) before flowering two weeks after treatment, and 3) at the time of flowering induction. Nitrogen content analysis was conducted using the Kjeldahl method, and organic carbon content analysis was performed through the Walkley and Black method. The C:N ratio was obtained by comparing the values of organic carbon and nitrogen.

Table 1. Soil characteristics of the experimental field before and after treatment

Type of analysis	Unit	Before treatment		After treatment	
		Value	Criteria	Value	Criteria
pH H_2O	-	6.1	Neutral	6.00	Neutral
N-total	%	0.13	Low	0.18	Low
C-Org	%	1.6	Low	2.30	Low
P-available	ppm	46.32	Very high	355.50	Very high
K-dd	me/100g	1.5	Very high	0.26	Low

The antioxidant activity of the dried flower material was measured using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay, as described by Shahidi and Zhong (2015), with minor modifications. Dried flower extracts were prepared in ethanol and tested in a concentration series to obtain the percent inhibition at each concentration. The dissolved sample was placed into a cuvette containing 33 µL, followed by the addition of 467 µL of adjusted ethanol/solvent and 500 µL of DPPH. Mixing was completed when the total sample volume reached 1000 µL (1 mL). The sample was incubated for 20 minutes in a low-light room at 24-27°C. Antioxidant activity was determined by measuring the decolorization of DPPH at 514-517 nm using a spectrophotometer. The IC_{50} values were calculated by plotting percent inhibition versus log concentration when appropriate.

The quantification of vitamin C (ascorbic acid) was performed by High Performance Liquid Chromatography (HPLC), and the concentration was determined by comparison with a standard of ascorbic acid. The final concentrations were expressed as mg per 100 g of fresh weight (mg 100 g^{-1} FW). Each sample was assayed in triplicate. Data were analyzed using a two-way ANOVA with D, F, and their interaction (DxF) as fixed effects and block as a random effect. The statistical model was as follows:

Y_{ijk}: $\mu + D_i + F_j + (D\times F)_{ij} + B_k + \varepsilon_{ijk}$.

The means were compared using the Tukey test at α: 0.05. All analyses were performed in Microsoft Office Excel and R 4.2.1.

RESULTS AND DISCUSSION

Plant growth and yield characters of torch ginger

Plant height (cm)

The summary of ANOVA is presented in Table 2. Plant height was measured from weeks 1 to 8, and the results indicated that applying PK fertilizer as a single factor had a significant effect from the third to the fifth week. In enhancing the number of stem buds per clump, the dosage as a single factor was significant at the second to the fifth week, while the frequency of application had a significant effect at week 4 to 5. Notably, a significant dosage×frequency interaction was detected for age of flowering (F: 2.67, p<0.05), number of flowers per clump (F: 16.06, p<0.01), weight of fresh flower per clump (F: 21.25, p<0.01), and weight of dry flower per clump (F: 5.8, p<0.01). Additionally, the dosage of application of PK fertilizer significantly increased the C:N ratio after fertilization (C:N ratio 2; F: 4.18, p<0.05). Furthermore, the dosage and frequency of PK fertilizer application as a single factor exhibited a significant enhancement in the C:N ratio in torch ginger plants prior to flowering (dosage: F: 42.45, p<0.01; frequency: F: 9.07, p<0.01).

Plant morphology related to plant growth and production variables was observed. Figure 1 shows that the treatment with a PK compound fertilizer dosage of 150-200 g/clump produced the highest torch ginger plant height during weeks 3 to 5. This was significantly different from the treatment of PK compound fertilizer at 50 g/clump (D1).

Number of stem (buds/clump)

Table 4 shows that the treatment of PK fertilizer dosage of 150 g/clump (D3) gives the best results on the number of buds/clump of torch ginger plant in weeks 2 to 5. This is because the P and K nutrients in fertilizers, which plants need in sufficient amounts, positively affected the growth and development of new shoots.

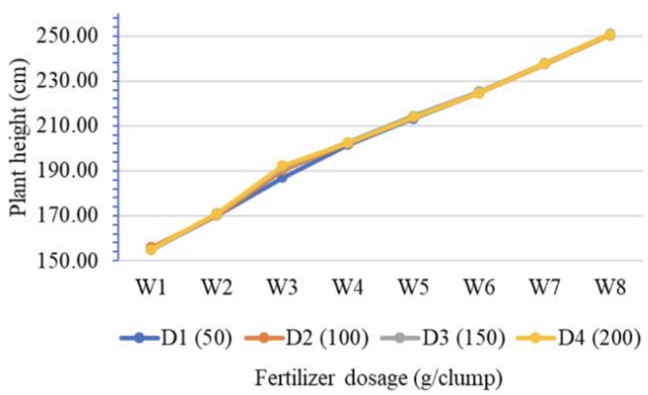
Flower size

Flower size was observed by measuring crown length, crown diameter, stalk length, and stalk diameter. Table 4 shows that there is a tendency to increase the length of the flower crowns of the torch ginger plant by the treatment of compound PK fertilizer dosages up to 150 g/clump. The frequency of fertilizer application (1, 2, or 3 times) did not show significant differences in the length of the flower crowns. In addition, the single-factor compound PK fertilizer dosage treatment of 200 g/clump (D4) produced the largest crown diameter of 16.06 mm and was significantly different from the treatment of 50 g/shrub (D1) and 100 g/shrub (D2). The treatment of fertilizer application frequency (1, 2, or 3 times) did not show significant differences in the diameter of the torch ginger plant crown. However, there was a tendency to increase the length of the flower stalks by the treatment of PK fertilizer dosages up to 150 g/clump. The treatment of the frequency of fertilizer application did not show significant differences in the length of the flower at all ages of observation. The single-factor treatment with PK compound fertilizer at 200 g/clump (D4) produced the largest stalk diameter of 6.20 cm, compared to the others. The treatment of fertilizer application frequency did not show a significant difference in the diameter. There was an increase in the diameter of the stalks due to the dosage of PK compound fertilizer 200 g/clump of plant by 29.44 percent compared to D1.

Table 2. Summary of two-way ANOVA

Character	Dosage (D)		Frequency (F)		D×F	
	MS	F	MS	F	MS	F
Plant height (cm)						
M1	2.28	1.46ns	0.06	0.04ns	1.46	0.93ns
M2	1.43	2.63ns	0.25	0.46ns	0.53	0.98ns
M3	48.81	25.15**	9.06	4.67*	2.43	1.25ns
M4	2.00	3.88*	1.78	3.45*	1.05	2.03ns
M5	2.08	3.31*	3.25	5.18*	1.55	2.47ns
M6	0.76	2.11ns	0.34	0.95ns	0.26	0.72ns
M7	0.22	1.00ns	0.24	1.10ns	0.32	1.44ns
M8	0.51	1.44ns	0.18	0.50ns	0.75	2.12ns
Number of stem buds/clump						
M1	0.78	2.47ns	0.11	0.36	0.33	1.06
M2	23.58	25.72**	0.52	0.57ns	0.73	0.79ns
M3	88.65	217.60**	0.36	0.89ns	0.89	2.18ns
M4	82.14	225.55**	1.58	4.33**	0.17	0.48ns
M5	112.12	104.39**	12.70	11.83**	1.85	1.72ns
Age of flowering (DAT)	112.78	79.26**	29.08	20.44**	3.80	2.67*
Number of flowers per clump	177.49	344.36**	37.27	72.31**	8.28	16.06**
Length of flower (cm)	0.05	2.99ns	0.01	0.46ns	0.02	1.01ns
Diameter of flower (cm)	0.67	10.48**	0.11	1.72ns	0.15	2.31ns
Stalk length (cm)	1.09	0.92ns	0.20	0.17ns	0.92	0.77ns
Stalk diameter (cm)	3.59	55.45**	0.06	0.92ns	0.08	1.31ns
Weight of fresh flower per clump (g)	24269.89	509.85**	3680.43	77.32**	1011.57	21.25**
Weight of dry flower per clump (g)	2329.17	235.54**	131.55	13.30**	57.33	5.80**
C:N ratio 1	2.28	1.46ns	0.06	0.04ns	1.46	0.93ns
C:N ratio 2	27.36	4.18*	1.33	0.20ns	0.43	0.07ns
C:N ratio 3	250.79	42.45**	53.57	9.07**	14.38	2.43ns
Antioxidant activity (IC_{50})	52.75	172.01**	0.08	0.25ns	0.40	1.31ns
Vitamin C content (mg 100 g^{-1} FW)	2.28	1.46ns	0.06	0.04ns	1.46	0.93ns

Note: MS: mean square, F: F-value at α: 0.05, *significant at α: 0.05, **significant at α: 0.05, ns: not significant at α: 0.05



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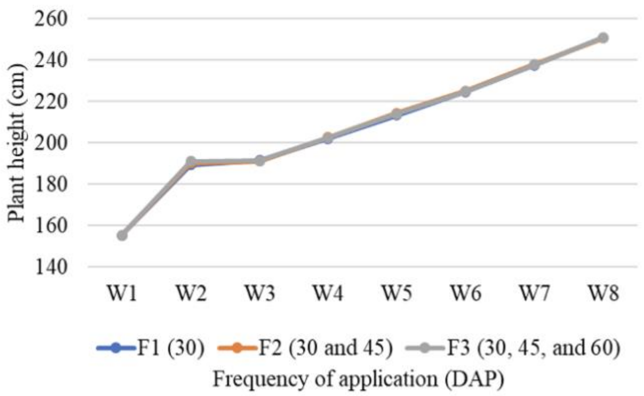

B

Figure 1. Effect of dosage (A) and frequency (B) of P and K nutrient application on plant height

Flower yield characters

The part of the torch ginger plant with economic value is the flower. In this context, flower yield characters were observed by counting and weighing harvested and dry flowers/clump. Based on Table 5, the highest average number formed was in the D3F2 treatment of 23.78 flowers and was significantly different from other combinations, except for D4F2. The number of flowers increased by 57% under the combined treatment of 150 g/clump applied twice (D3F2) compared to 50 g/clump with a single application (D1F1). Furthermore, the average weight of the fresh flowers/clump was the largest in the D4F2 combination treatment at 340.46 g and significantly different from others, except D3F2 and D4F3. The flower weight increased by 55.72% under the combined treatment of 200 g/clump of compound PK fertilizer applied twice (D4F2), compared to 218.54 g observed with 50 g/clump applied once (D1F1). The average results of the largest dry flower weight/clump were in the treatment of compound PK fertilizer dosage of 150 g/clump and the frequency of fertilization 3 times the application (D3F3) of 63.75 g. This was significantly different from all other combination treatments, except for D3F2, D4F2, and D4F3. The dry flower weight increased by 118.77% under the combined treatment of 150 g/clump of compound PK fertilizer applied three times (D3F3), compared to 50 g/clump applied three times (D1F3) (from 29.14 g to 63.75 g).

Table 3. Growth of torch ginger based on the number of stem buds per clump due to the dosage treatment and frequency of application of PK compound fertilizer

Treatment	Number of stem buds per clump				
	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**
Fertilizer dosage (g/clump)					
D1 (50)	14.3	17.15 a	18.59 a	23.78 a	29.11 a
D2 (100)	14.59	20.30 b	23.96 b	28.81 b	33.74 b
D3 (150)	14.89	20.44 b	25.22 c	30.11 c	36.85 d
D4 (200)	14.93	20.41 b	25.11 c	30.15 c	36.30 c
Tukey (α: 0.05)	ns	0.41	0.28	0.26	0.45
Frequency of application (DAP)					
F1 (30)	14.58	19.58	23.17	27.83 a	33.22 a
F2 (30 and 45)	14.78	19.36	23.42	28.56 c	35.17 c
F3 (30, 45, and 60)	14.67	19.78	23.08	28.25 b	33.61 b
Tukey (α: 0.05)	ns	ns	ns	0.18	0.3

Note: ns: not significant at α: 0.05. Means followed by the same letter in the same column are not significantly different by Tukey HSD at α: 0.05

Table 4. The size of the flower (flower crown length, flower crown diameter, flower stalk length, and flower stalk diameter) is due to the dosage treatment and frequency of application of phosphorus-potassium compound fertilizer

Treatment	FCL	FCD	FSL	FSD
Fertilizer dosage (g/clump)				
D1 (50)	10.16	15.46 a	89.63	4.79 a
D2 (100)	10.19	15.54 a	90.38	5.46 b
D3 (150)	10.31	15.82 b	90.34	6.01 c
D4 (200)	10.27	16.06 c	90.21	6.20 d
Tukey (α: 0.05)	ns	0.11	ns	0.11
Frequency of application (DAP)				
F1 (30)	10.24	15.63	90.27	5.56
F2 (30 and 45)	10.26	15.82	90.01	5.69
F3 (30, 45, and 60)	10.21	15.71	90.14	5.59
Tukey (α: 0.05)	ns	ns	ns	ns

Note: DAP: day after preparation, FCL: crown length (cm), FCD: crown diameter (cm), FSL: flower stalk length (cm), FSD: flower stalk diameter (cm). ns: not significant at α: 0.05. Means followed by the same letter in the same column are not significantly different by Tukey HSD at α: 0.05

Table 5. Means of the number of flowers, weight of fresh flowers, and weight of dry flowers due to dosage treatment and frequency of application of phosphorus-potassium compound fertilizer

Treatment (g/clump)	NF			WHF			WFF		
	F1	**F2**	**F3**	**F1**	**F2**	**F3**	**F1**	**F2**	**F3**
D1 (50)	10.33 a	12.00 b	11.56 b	218.64 a	223.58 ab	223.69 ab	30.09 a	29.87 a	29.14 a
D2 (100)	14.89 c	15.44 c	15.78 cd	228.30 ab	230.45 abc	230.16 abc	31.33 a	34.00 a	32.61 a
D3 (150)	18.00 e	23.78 h	19.22 f	281.43 d	335.54 ef	325.00 e	57.61 c	61.85 cd	63.75 d
D4 (200)	16.89 de	22.89 gh	22.00 g	273.88 d	340.46 f	337.04 f	45.56 b	61.74 cd	62.11 cd
Tukey (α: 0.05)		1.21			11.73			5.35	

Note: NF: number of flowers per clump, WDF: weight of dry flower per clump (g), WHF: weight of fresh flower per clump (g). Means followed by the same letter within a column are not significantly different by Tukey HSD at α: 0.05. F1: 30 DAP, F2: 30 and 45 DAP, F3: 30, 45, and 60 DAP

Age of flowering (DAT)

The shortest average time to flower appearance was observed in the treatment combination of a fertilizer dosage of 200 g/clump and a frequency of two times (D4F2), at 21.89 DAT (Figure 2). The onset of flowering was increased by 12 days under the combined treatment of 200 g/clump of compound PK fertilizer applied twice (D4F2), compared to 50 g/clump applied three times (D1F3).

C:N ratio

Based on Figure 3, the C:N ratio of the sparrow plant was low and was not significantly different when the plants were not treated with compound PK fertilizer. After the initial treatment, the C:N ratio increased and was the highest under the D4 (200 g/clump) treatment of flowering (from 23.19 to 37.77). Two-way ANOVA showed a significant effect of dosage on C:N ratio at flowering ($p<0.05$). Meanwhile, the treatment of fertilizer application frequency did not show a significant effect on the C:N ratio ($p>0.05$). A linear regression analysis was conducted to determine the relationship between the C:N ratio and flowering age of torch ginger (Figure 4). C:N ratio was analyzed when the plants were at the flowering stage. The coefficient of determination (R^2) is 0.92 with significance (p)<0.05 (p: 0.041). It indicated that a higher C:N ratio is associated with earlier flowering.

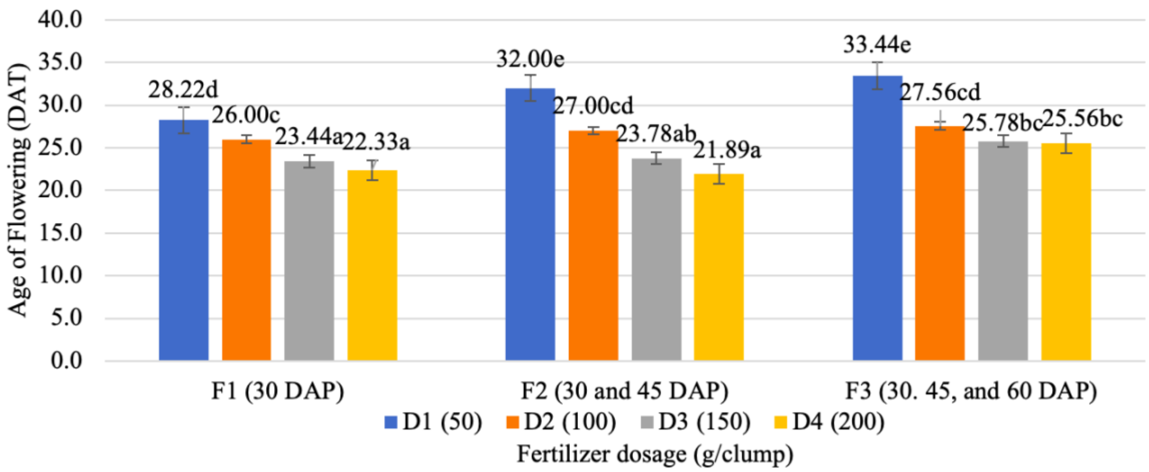

Figure 2. Effect of dosage treatment and frequency of application of phosphorus-potassium compound fertilizer on the age of flowering. DAP: day after preparation, DAT: day after treatment. Means followed by the same letter within the same fertilization frequency are not significantly different by Tukey HSD (α: 0.05)

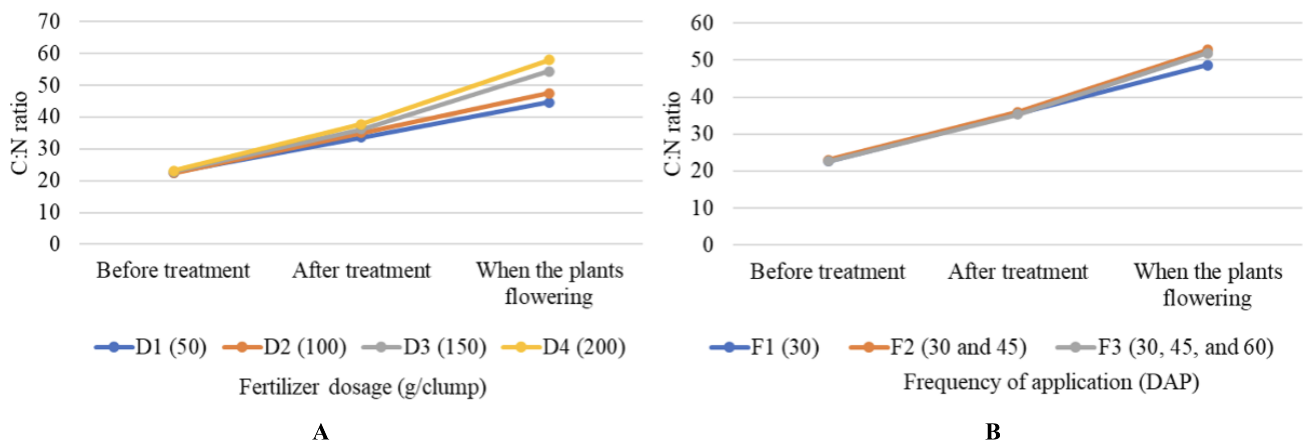

Figure 3. A. Effect of fertilizer dosage on C:N ratio, B. Effect of frequency of application of PK compound fertilizer in terms of flowering induction

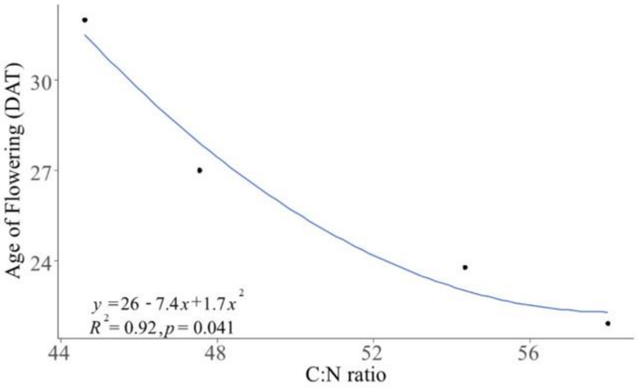

Figure 4. Linear relationship between C:N ratio at flowering and age of flowering (DAT) in torch ginger in the presence of compound PK fertilizer treatment

Antioxidant content

Antioxidant content was analyzed in this research. The single-factor treatment with PK compound fertilizer at 200 g/clump (D4) produced the highest antioxidant content and was significantly different from the other treatments. The treatment of fertilizer application frequency did not show significant differences in the antioxidant levels of the torch ginger plant (Figure 5).

Vitamin C content

Vitamin C content was analyzed in this research. The single-factor treatment with a compound PK fertilizer dosage of 200 g/clump (D4) produced the highest vitamin C content of 12.31 mg 100 g^{-1} FW and was significantly higher than the others (Figure 6). There was a 33.66% increase in vitamin C content with the PK fertilizer dosage of 200 g/clump compared to 50 g/clump. However, the frequency of application, whether once, twice, or three times, did not demonstrate significant differences in the vitamin C levels of the torch ginger plant. Notably, plants receiving two applications manifested the highest vitamin C content (1138 mg 100 g^{-1} FW).

Discussion

Plant growth and yield characters of the torch ginger plant were observed in morphology, including plant height, number of stem buds/clump, flower size (crown length, crown diameter, stalk length, and stalk diameter), and yield characters (number of harvested flower per clump, weight of harvested flower/clump, and weight of dried flower/clump). This research showed that the addition of phosphorus and potassium fertilizers significantly influenced the plant height and number of stem buds/clump. Furthermore, 150-200 g/clump of PK fertilizer resulted in the highest plant height, which was significantly different from the 50 g/clump dosage. The number of stem buds per clump was relatively higher, with 150 g/clump, which led to a higher number of stem buds with twice the frequency. The addition of higher dosages of phosphorus and potassium fertilizers increased the availability of nutrients used in plant physiological processes, including plant height. In another research, P and K fertilizers significantly influenced the pods per plant and yield of mungbean (Yin et al. 2018), production of cayenne pepper fruits (Wirajaya et al. 2022), and the growth and yield of melon (Rohcahyani et al. 2025). In Warnita et al. (2019), these fertilizers enhanced the number of fruit bunches of Salak.

The best results of PK fertilizer for the number of stem buds per clump were obtained by the dosage of 150 g/clump. The frequency of treatment was not significantly different from week 1 to 3. Application of two treatments (30 DAP and 45 DAP) provided the best results for the number of stem buds per clump between weeks 4 to 5. Furthermore, P promotes the growth and development of shoots/buds and activates enzymes involved in photosynthesis (Warnita et al. 2019; Khan et al. 2023).

Several related characters, including crown length, crown diameter, flower stalk length, and flower stalk diameter, were observed in the flower size of the torch ginger plant. The treatment with PK compound fertilizer at different frequencies did not affect flower size. The dosage of 150-200 g/clump provided the best result since a once-time application (30 DAP) was efficient. The combination of a 150 g/clump dosage with twice-applied treatments (at 30 and 45 DAP) resulted in the highest flower yield, including the number of flowers per clump, the weight of fresh flowers per clump, and the dry flower weight per clump.

Frequent fertilization can increase the nutrient levels required by the plant. The right time of application determines the plant's growth and development. The timing of application affects plant growth and development differently. Fertilization should be repeated due to limited nutrient uptake (Nkebiwe 2016). The number of flowers produced depends on several factors, including individual plant characteristics (Anton and Denisow 2014). The weight of a flower/plant is influenced by the number of flowers and the diameter. A large number of flowers per plant accompanies the high weight of flowers/clump; the diameter influences the increased in flower weight. In addition, P plays a role in plant development processes at the cellular and whole-plant levels, including seed germination, seedling formation, root, shoot, flower, and seed development, photosynthesis, respiration, and nitrogen fixation (Malhotra et al. 2018; Muhammad et al. 2021).

The treatment combination of fertilizer dosage of 200 g/clump and fertilization frequency of 2 times (D4F2) produced the fastest flowering time and was significantly different from D1F2 and D2F2 (21.89 DAT). Different environmental factors can influence flowering time, including drought stress and by girdling and defoliation, ambient temperature, gibberellic acid (GA), vernalization, salinity, exogenously applied hormones and chemicals, and pathogenic microbes (Albrigo and Saúco 2004; Chen et al. 2015; Cho et al. 2017; Sharma et al. 2017). Girdling, drought stress, photoperiod, and applied hormones were used to induce flowering. Limited research on torch ginger focused on optimizing crop cultivation, specifically the effects of nutrients. In this study, researchers emphasized that P and K compound fertilizers were applied at various dosages and frequencies to determine the most effective combination for inducing flowering. An impactful discovery was made to induce flowering of torch ginger: a combination of 200 g per clump, applied twice, yielding the earliest flowering (less than 22 DAT). Application of N, P, and K fertilizers affected rice growth and development through physiological and metabolic processes. Rice flowering time was delayed by 1-4 days after N application. Application of P led to flowering 1 day earlier, but there was no significant difference between different P levels. K fertilization promoted flowering 1-3 days earlier, and higher application rates enhanced early flowering (Ye et al. 2019). Moreover, in rose plants, sufficient P and K fertilizers (MKP fertilizer) were positively associated with increased flowering, including growth, flower production, and nutrient uptake through enhanced root growth (Kumar et al. 2017; Ma et al. 2021). In plant breeding, regulating flowering time represents an important scientific advancement. This is because early flowering increases breeding programs and facilitates the development of new plant varieties (Hong and Jackson 2015).

The phenology of torch ginger is as follows. The growth phases and periodization of torch ginger plant growth and development are divided into two main periods: the first year as the vegetative phase and the second year as the flowering and fruiting phase. The following year, torch ginger plants will continue to flower and bear fruit. However, flowering can be induced earlier, within 6-8 months, when growth is vigorous. In the second year, vegetative and generative growth are conducted simultaneously due to clumping growth (Hidayat et al. 2023). Vegetative growth is associated with cell division and elongation, as well as the enlargement of meristem tissue at the stem tip (Setiawati et al. 2017). During the vegetative phase, the shoot apical meristem forms an architectural framework of primordia that develop into leaves or shoots (Sulistiawati et al. 2017). Water-stressed plants will suffer from drought, resulting in loss of turgor, reduced photo-assimilation, and reduced levels of metabolites required for cell division. Therefore, mitosis is impaired, leading to decreased cell elongation and enlargement (Farooq et al. 2009). Under drought stress, endogenous auxin and cytokinin levels decrease, while cell division and elongation are inhibited (Setiawati et al. 2017).

The reproductive phase of the plant is initiated after the inflorescence buds are developed from the rhizome. The success of a plant in transitioning from the vegetative to the reproductive phase depends on the ability to induce flowers. Flowering induction is the process by which external stimuli reach the growing point and induce flower primordia (Sulistiawati et al. 2017). Flowering induction is also influenced by the endogenous ratio of carbohydrates to nitrogen (C:N ratio). The addition of PK compound fertilizer increased the C:N ratio in the plant tissue. At a certain minimum limit, the plant was induced to flower. A high C:N ratio promoted flowering, while increased nitrogen availability promoted vegetative growth (Klebs 1913).

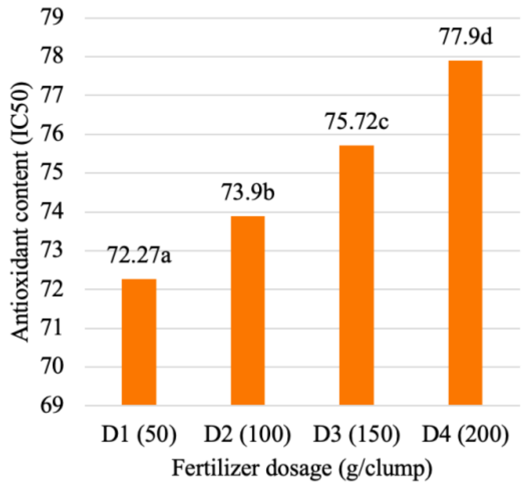

Figure 5. Antioxidant content of torch ginger due to dosage treatment and frequency of application of phosphorus-potassium compound fertilizer

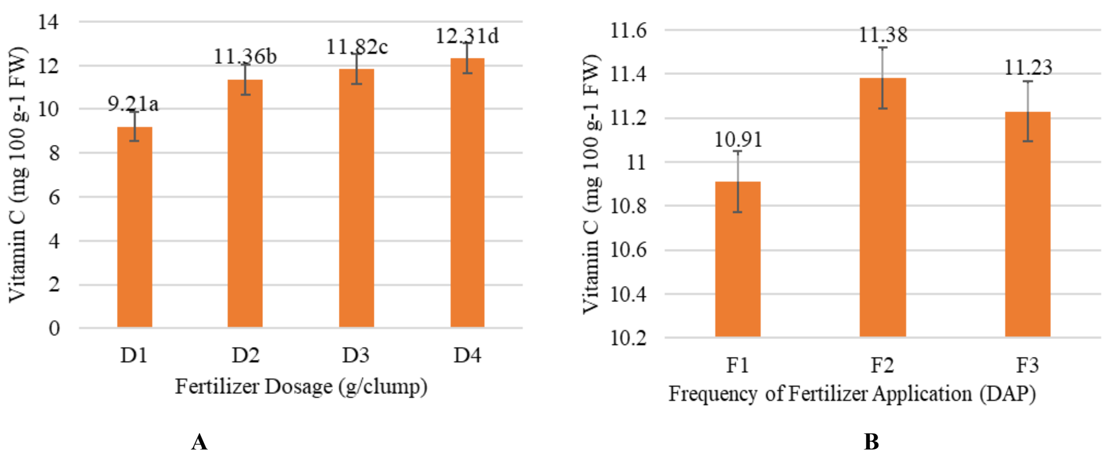

Figure 6. Vitamin C content of torch ginger flower due to dosage treatment (A) and frequency of application (B) of PK compound fertilizer. Different letters indicate significant differences by Tukey's HSD at α: 0.05

These fruiting stages are divided into initiation, flower bud, before bloom, bloom, and anthesis (Lestari et al. 2023). The main phases of *E. elatior* development are peduncle elongation, inflorescence, flowering, and senescence. In early growth, the peduncle elongation stage takes 20 days. However, the process slows down when flower buds are formed during the blooming stage. Inflorescence buds form after 30 days of shoot development. The inflorescence of *E. elatior* consists of floral and involucral bracts. At full bloom, the floral bracts can comprise up to 20-25 layers, while the involucral bracts are only 3-4 layers. A total of seven growth stages of inflorescence bracts development are observed across the innermost to the outermost layer. In this context, floral bracts are softer and smaller than involucral bracts. The purpose of involucral bracts is primarily for defense mechanisms. The inflorescence indicates a flowering phase after 40-52 days of development (Sabu and Smisha 2013). During this phase, the first ring of each flower opens gradually. From the first to the fifth stage, the actual flowers are developing. Meanwhile, the yellow fringe of the labellum appeared through the 6th stage. In the seventh stage, the fully bloomed flower will enter the senescent stage, and the labellum will close. The involucral bracts dry up slowly and turn brown as the actual flower opens (Juwita et al. 2018). The reproductive stages often increase respiration rate, indicating that the plant needs more photosynthate. Application of P and K with N led to optimal nutrient uptake, as photosynthesis was enhanced (Warnita et al. 2019).

Oxidation is a natural consequence of metabolism in biological organisms. The result is the formation of noxious reactive oxygen species (ROS) and reactive nitrogen species (RNS), such as superoxide, hydrogen peroxide, singlet oxygen, and nitric oxide radicals (Xu et al. 2017). In this research, an antioxidant assay used free radical diphenilpicrylhydrazyl (DPPH). The activity of the compound was expressed as the amounts of antioxidants required to reduce the initial concentration of DPPH free radicals by 50% (Lu et al. 2019). Free radical and oxidation reactions were inhibited and neutralized by natural compounds named antioxidants (Shahidi and Zhong 2015; Ulewicz-Magulska and Wesolowski 2019). The daily utilization in relation to health benefits played a prominent role. A typical example is antioxidant therapy in diabetic wound healing (Zhang et al. 2021). Other clinical uses include anti-aging, anti-cancer, anticarcinoma, antidiabetic, anti-inflammatory, antimicrobial, defense against cardiovascular disease, hepatoprotective, nephroprotective, and neuroprotective (Neha et al. 2019; Prastowo et al. 2023). Therefore, the presence of antioxidant content has the potential to be used for health purposes.

After the initial treatment and the C:N ratio increases, and at the time of flowering, the treatment of compound PK fertilizer dosage of 200 g/clump produced the highest ratio and was significantly different from others. The treatment of fertilizer application frequency did not show significant differences in the C:N ratio. Figure 4 shows the relationship between the C:N ratio in the condition of the plant after fertilization and the age of flowering. Figure 4 reports the relationship of C:N ratio in the condition of the plant with R^2: 0.92 and $p<0.05$ (p: 0.041). The processes of flowering and fertilization are related to the ratio of carbon (C) to nitrogen (N). The C:N ratio determines the balance of vegetative and generative phases. A higher nitrogen level or a low C:N ratio kept the plant in the vegetative phase. Plants in the vegetative phase certainly experience problems in the process of flowering and fertilization. This is because the condition for the flowering process is the achievement of the generative phase. Plants with a high C:N ratio are stimulated to immediately enter the generative phase, allowing the flowering and fruiting process to occur immediately. A high C value without sufficient nitrogen can cause plant death (Lin et al. 2019), while low N levels accelerate floral transition (Sanagi et al. 2021).

Vitamin C is a water-soluble micronutrient required for a variety of biological functions. This micronutrient is an essential cofactor for several enzymes in post-transplantation collagen hydroxylation, carnitine biosynthesis, conversion of the neurotransmitter dopamine to norepinephrine, and peptide and tyrosine metabolism. The enzymatic roles are associated with dioxygenases (collagen and carnitine synthesis, involvement in gene transcription, and translation regulation through different mechanisms and tyrosine elimination) or monooxygenases (hormone synthesis). It is also an antioxidant and pro-oxidant agent, an iron absorption agent, and anti-viral (Carr and Maggini 2017; Pehlivan 2017; Bae and Kim 2020; Barańska et al. 2020; Doseděl et al. 2021).

In conclusion, PK fertilization significantly accelerated flowering and improved yield in torch ginger. The most effective treatments were 150-200 g/clump applied twice (30 and 45 DAP), where 200 g/clump (D4F2) produced the earliest flowering and 150 g/clump (D3F2) generated the highest flower yield. PK application also increased the C:N ratio prior to flowering, with a strong negative correlation to flowering age (R^2: 0.92), confirming its physiological role in floral induction. PK treatments further enhanced antioxidant activity and vitamin C content. These findings highlight that targeted PK management can effectively promote both productivity and quality under the tested conditions. However, the study was conducted in a single season and location, used uniform plant material, and measured biochemical traits only at flowering. Soil P status was unusually high, and results may differ under nutrient-poor conditions. Multi-season, multi-location trials; evaluation of different cultivars; expanded N:P:K optimization; mechanistic physiological analyses; longitudinal quality assessments; and cost-benefit evaluations are recommended to refine and validate PK-based flowering strategies for commercial production.

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