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Growth and Flowering Characteristics of *Oncidium* Gower Ramsey Varieties under Various Fertilizer Management Treatments in Response to Light Intensities

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Abstract: Oncidium are grown worldwide and play important economic roles. The objective of this study was to investigate the pseudobulb growth and flowering characteristics of the two *Oncidesa* Gower Ramsey cultivars, 'Honey Angel (HA)' and 'Golden Star (GS)', cultivated under 3 kinds of fertilizer treatments in response to 40% light intensity (LI-40) and 30% light intensity (LI-30, as control) photosynthetic photon flux density over a 5-month period. The conventional-fertilizer (CF) treatment, as a control, consisted of a liquid manure solution of N:K = 1:1.12, mixed with 7.8% N, 0.8% P_2O_5, 0.3% K_2O, and 57.3% of organic matter that was foliage-applied to plants twice weekly. The stage-fertilizer (SF) treatment consisted of N:P:K = 1:1:5 foliage-applied to plants in an unsheathing pseudobulb stage until reaching inflorescence, followed by N:P:K = 1:1:1 application until the end of the experiment. The fortnight-fertilizer (FF) treatment consisted of N:P:K = 1:1:5 and N:P:K = 1:1:1 with interval-rotate foliage-application to plants weekly until the end of the experiment. Pseudobulb length (PL), pseudobulb major axis (PW), and pseudobulb minor axis (PT), and inflorescence length (FL), number of pedicel (FB), and floret numbers (FN) per plant were recorded and calculated from two months after pseudobulb maturity until the end of the five-month experimental period. The GS variety significantly increased PL when treated with CF and FF compared to HA, and GS treated with CF under LI-30 exhibited the longest PL at 81.65 mm. PW increased as LI increased under FF treatment, and the largest PW was observed in GS treated with FF under LI-40. A maximal and significant increase in PT occurred in LI-40 compared to LI-30 under the CF treatment. GS had a significantly higher FL compared to HA treated with CF, and the longest FL was detected in GS under LI-30. HA had a significantly higher FB and FN under LI-40 than under LI-30, and the highest number of FB and FN in HA occurred when it was treated with CF and SF, respectively. Precision management of fertilization treatments in response to LI can maximize pseudobulb growth, development, and flowering quality in *Oncidesa* species.

Keywords: fertilizer; flowering *Oncidium*; Orchidaceae; light intensity; photosynthetic photon flux density

1. Introduction

Orchids are among the most prized ornamental plants due to the variety of their flower size, shape, fragrance, and color combinations, which attract consumers and give them higher global commercial values. The family Orchidaceae is divided into five subfamilies, including *Apostasioideae*, *Cypripedioideae*, *Vanilloideae*, *Orchidoideae*, and *Epidendroideae* [1,2]. There are 374 accepted names of Oncidium (Orchidaceae) species, with more than 90% of them allocated in South America and the remainder in North America [3]. In addition to the species, thousands more interspecific and intergeneric hybrids have been registered with the Royal Horticultural Society and are used in the commercial production of cut and pot flowers worldwide [4]. Orchids are great ornamental potential for use in interiorscaping or landscaping projects due to their longer shelf-life and flowering characteristics. Orchid cultivation has evolved in recent decades to become an economically important activity, especially Oncidium genres, which stand out in internal and export markets and production trades. Recently, the Taiwan cut flower market of *Oncidesa* species has expanded worldwide, especially in exports to Japan, and in 2019, the total export value reached 20 million U.S. dollars, an increase of 33.9% compared to 2018 [5]. In addition, the family Orchidaceae of phytochemical and pharmacological potential were the antioxidant [6], antimicrobial effects, and the inhibitory effect against diabetes related enzymes [6]. They had a great potential for use in food and drug industries as a source of bioactive compounds [7].

Ornamental floriculture, such as any agricultural activity, requires the rational use of chemical fertilizers and alternative sources of organic fertilizer to make it more environmentally friendly and produce quality flowers [8]. Research on fertilizer application and management of *Oncidesa* species is scarce. It is important to understand the different stages of the *Oncidesa* plant development cycle in order to define which manure to employ to optimize fertilization form and timing that is more efficient and at a lower cost on a commercial scale. During the vegetative growth period, a high dose of N relative to P and K is recommended for most orchid plants. Before flowering, P and K application rates need to be increased relative to N, and during flowering the frequency of fertilizer applications should be reduced [9]. In addition, foliar feeding is found to be ideal, and frequent applications of fertilizer in low concentrations is the best way to feed orchids. A concentration of 0.2 to 0.3% of 30:10:10 (N:P:K) at the vegetative stage and 10:20:20 (N:P:K) at the blooming stage are applied for quality flower production, and one spray a week with organic manure is enough [10]. Barman and Naik [11] studied *Cymbidium* 'Baltic Glacier Mint Ice' and applied NPK fertilizers by mixing ammonium nitrate (NH_4NO_3), ammonium dihydrogen orthophosphate ($NH_4H_2PO_4$), and potassium nitrate (KNO_3) in appropriate quantities as per the plant's requirements and sprayed at 1 g L^{-1} once a week.

Light is an important environmental signal and induces chlorophyll biosynthesis [12]. Changes in light irradiance evoke variable morphogenetic and photosynthetic responses that vary among different plant species. Such photo-responses are of practical importance in modern plant cultivation technologies, since the feasibility of purposefully tailoring light intensities (LI) enables one to control plant growth, development, and nutritional quality [13]. Eco-physiological studies require the knowledge of the photosynthetic rates of plants under different environmental conditions and broad ranges in LI. Orchid plants respond to sudden and sustained fluctuations in LI, which affect plant growth and flowering characteristics. De [10] reported that *Cattleya* orchids need medium to bright light exposure of 2000 to 3000 foot-candle power (f.c.), and thrive well under a 40% shade cloth. Most Oncidium orchids thrive with one to several hours of sun a day and a LI of 2500 f.c. A bright dappled afternoon shade during summer and full sun in winter is ideal for *Cymbidium*, but mature plants need 50–55% shade during hot weather. During the growing season, they require up to 5000–6000 f.c. of light, whereas in the flowering season they need up to 2000–3000 f.c. of light. In our study, *Oncidesa* Gower Ramsey species in a greenhouse are best grown under 30% shade in temperatures of 25–30 °C during the daytime and 20 °C during the night [14,15].

The study of photosynthesis irradiance and fertilizer relationships is a basic aspect of plant physiological research and is important for managing *Oncidesa* species. Photosynthetic light responses can be used to assess the ability to capture light and understand the optimal light intensity habitat conditions of plants [16]. Although several studies have been conducted on fertilization or LI of Oncidesa, no study has reported the interaction of different illuminations and fertilizations for the growth and development of *Oncidesa* Gower Ramsey species. Therefore, the aim of our study was to investigate the stem growth and flowering characteristics of two *Oncidesa* Gower Ramsey cultivars cultivated with three kinds of fertilizer treatments in response to two LI conditions. Understanding the relationships between various fertilizations and LI is of great importance to the cut flower marketing of these plants, and Oncidium cultivated under selective fertilization can also be optimized for commercial production via lighting control technologies to produce a stable industrial supply of high yield and quality.

2. Materials and Methods

2.1. Plant Materials and Cultural Practices

Oncidium species, *Oncidesa* Gower Ramsey 'Honey Angel (HA)' and 'Golden Star (GS)' (Figure 1) are highly valued for genetic their resources, the most popular in Taiwan being Golden Shower types (i.e., HA). Their standard and novelty hybrids are commercially used as cut flowers, cultivated on a large scale, and commercially and widely used in the export industry. These plants have been grown in the nursery over the long term and maintained in our nurseries for Sheng Yang Orchid Garden at Da-Lin Farm (DLF) at the National Chia-YiStation, Chia-Yi City, Taiwan (23°35′51.7″ N 120°30′13.7″). When plants are 2 years old and 10~20 cm tall with 4 to 5 leaves, they are transplanted into 16 cm plastic free-draining pots (1.6 L, one plant per pot) containing commercial potting soil with a substrate mixture of crushed stone: charcoal = 3:1, and placed in an environmentally controlled greenhouse at DLF under an 8 h photoperiod at 30/25 °C day/night temperatures, relative humidity of 80%, and 320 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density (PPFD). They are evenly spaced to promote similar growth rates and sizes during April to September in the greenhouse. Plants are watered once a week, and an optimal amount of a compound water-soluble fertilizer solution ($N{:}P_2O_5{:}K_2O$, 20:20:20; Scott, Marysville, OH, USA) applied weekly at 1 g L^{-1}. For this study, uniformly sized plants of each variety were selected and randomly separated into six different groups for subsequent light-intensity and fertilization experiments. Microclimate stations were centrally located within each study plot where PPFD values were recorded. Culture conditions for each group were the same as mentioned above for the environmentally controlled greenhouse, where the average temperature was 26.8 °C and photoperiod was 12 h during the 5-month LI and fertilization experiment period.

2.2. Light-Intensity (LI) and Fertilizertreatments

Plants were divided into 3 groups for each of two LI treatments, 11 replicates of each treatment being arranged in a completely randomized design, for a total of 66 pots of each variety. Two LI levels were created by blocking light penetration using black shading nets stretched over a rigidframe. The LI groups were 40% light intensity (60% shaded, LI-40) and 30% light intensity (70% shaded, LI-30, as the control). The incidence of photosynthetically active irradiation in microeinsteins per square meter per second ($\mu E\ m^{-2}\ s^{-1}$) was measured with an LI-250 portable Light Meter System equipped with a Linear Quantum Sensor LI-191SA (LI-COR Bioscience, Lincoln, NE, USA). The average LI in the 2 treatments was 645 and 470$\mu mol\ m^{-2}\ s^{-1}$ PPFD at noontime (April to September 2020) for the LI-40 and LI-30 treatments, respectively.

A total of 3 kinds of fertilizer treatments (CF, SF, and WF) were applied to different batches of eleven plants of each light treatment of each variety at a rate of 30 mL of liquid manure solutions twice weekly for five months. The conventional-fertilization (CF) treatment, as the control, comprised of a liquid manure solution of N:K = 1:1.12, that mixed FERTIPLANT® 30 + 10 + 10 (PLANTA, Germany) and 7.8% total nitrogen, 0.8% P_2O_5, 0.3% K_2O, and 57.3% of organic matter (a certified organic product from Taiwan Fertilizer Co., Taichung, Taiwan, was used as a source of micronutrients applied together with CF). The liquid manure solutions used in (SF) and (FF) with NH_4NO_3, $Ca(NO_3)_2$, P_2O_5, K_2SO_4 to adjust the N:P:K concentration to = 1:1:5, 1:1:1, the pH value of the nutrient solution is adjusted to 6.0, and the frequency of watering and medium changes was also controlled so that the EC value was controlled at 0.8–1 mmho. The stage-fertilization (SF) technique consisted of a second batch of eleven plants in the vegetative pseudobulb (enlarged stems) stage being given N:P:K = 1:1:5 until they reached the reproductive flowering stage, followed by N:P:K = 1:1:1 applications being given until the end of the experiment. The fortnightly fertilization (FF) treatment consisted of a third batch of eleven plants being given N:P:K = 1:1:5 and N:P:K = 1:1:1 with interval-rotate application conducted weekly until the end of the experiment. Leaves were sprayed until saturated with solutions of different concentrations of N, K, and other nutrients, and the concentrations and volumes of these solutions selected based on data from our previous work in which the accumulation of dry matter was related to nitrogen [15,17,18].

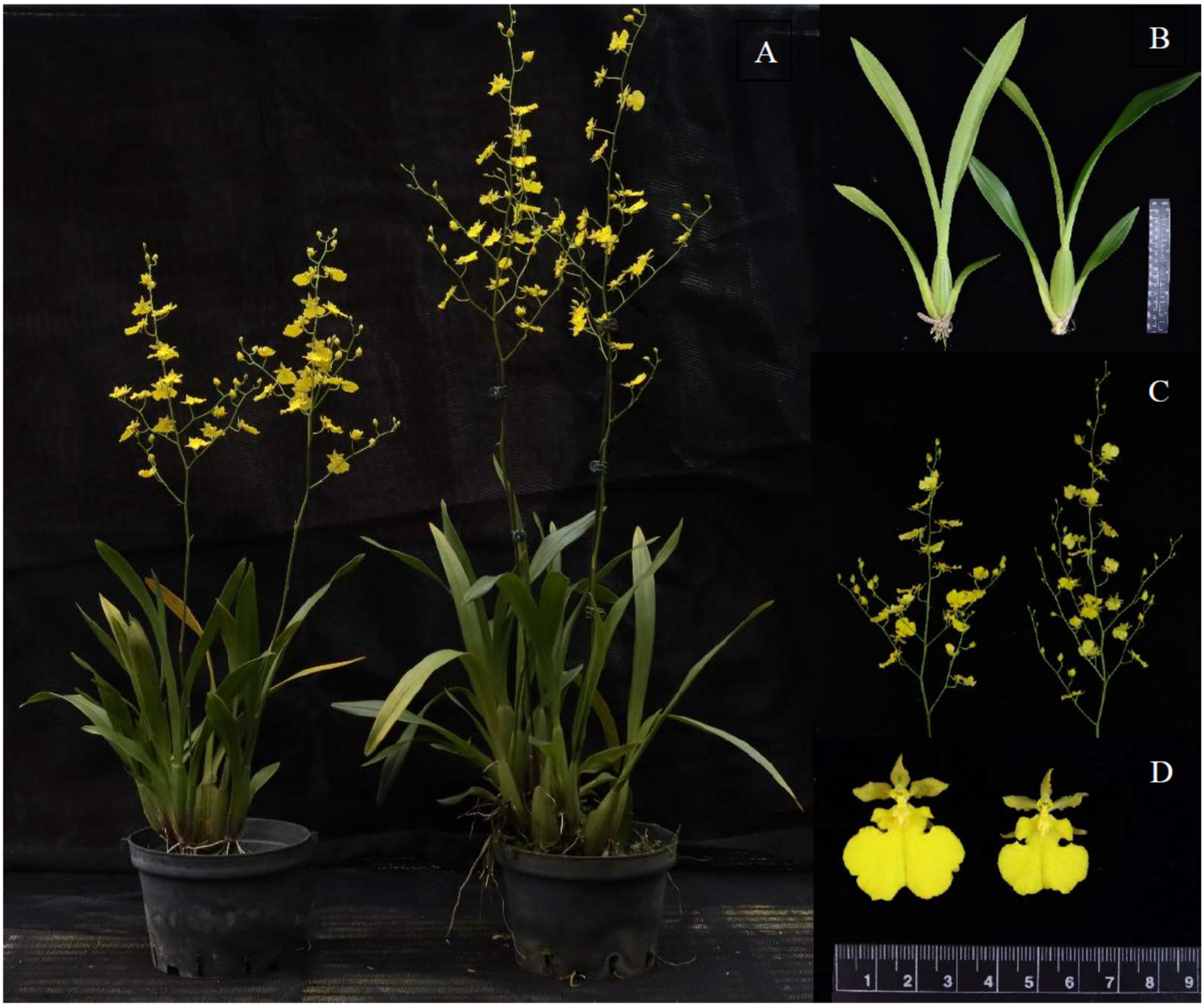

Figure 1. Plant morphology (**A**) between *Oncidesa* Gower Ramsey 'Honey Angel' (HA, left) and 'Golden Star' (GS, right). The comparisons between HA (left) and GS (right) in (**B**) pseudobulb, (**C**) pedicel, and (**D**) floret of pedicel.

2.3. Plant Growth and Flowering Quality Assessments

In general, the bud stage and plantlet are vegetative stages that last for 3~4 months, followed by the unsheathing phase for one more month, and the further stage of pseudobulb with florescence for 1.5~2 months. Observations of pseudobulb length, major axis, and minor axis per plant were recorded after pseudobulb maturity was established, and pseudobulb diameter (represented by the major axis and the minor axis according to its oval-shape cross section), followed by the pseudobulb with florescence stage in which both branch and floret numbers and flower stalk length were measured. All of the analyses were performed at the end of the five-month experimental period (Figure 2):

1. Pseudobulb length (PL), measured as the length (mm) between the base and the top of a pseudobulb with a Vernier caliper;
2. Pseudobulb major axis (PW), measured as the major axis (width, mm) of a pseudobulb with a Vernier caliper;
3. Pseudobulb minor axis (PT), measured as the maximum (thickness, mm) of a pseudobulb with a Vernier caliper;
4. Inflorescence length (FL), measured as the length (mm) between the base to the top of a flower stalk with a Vernier caliper;
5. Number of pedicel (FB), recorded as all the branches of a flower-stalk;
6. Number of florets (FN), recorded as all the florets of a flower-stalk.

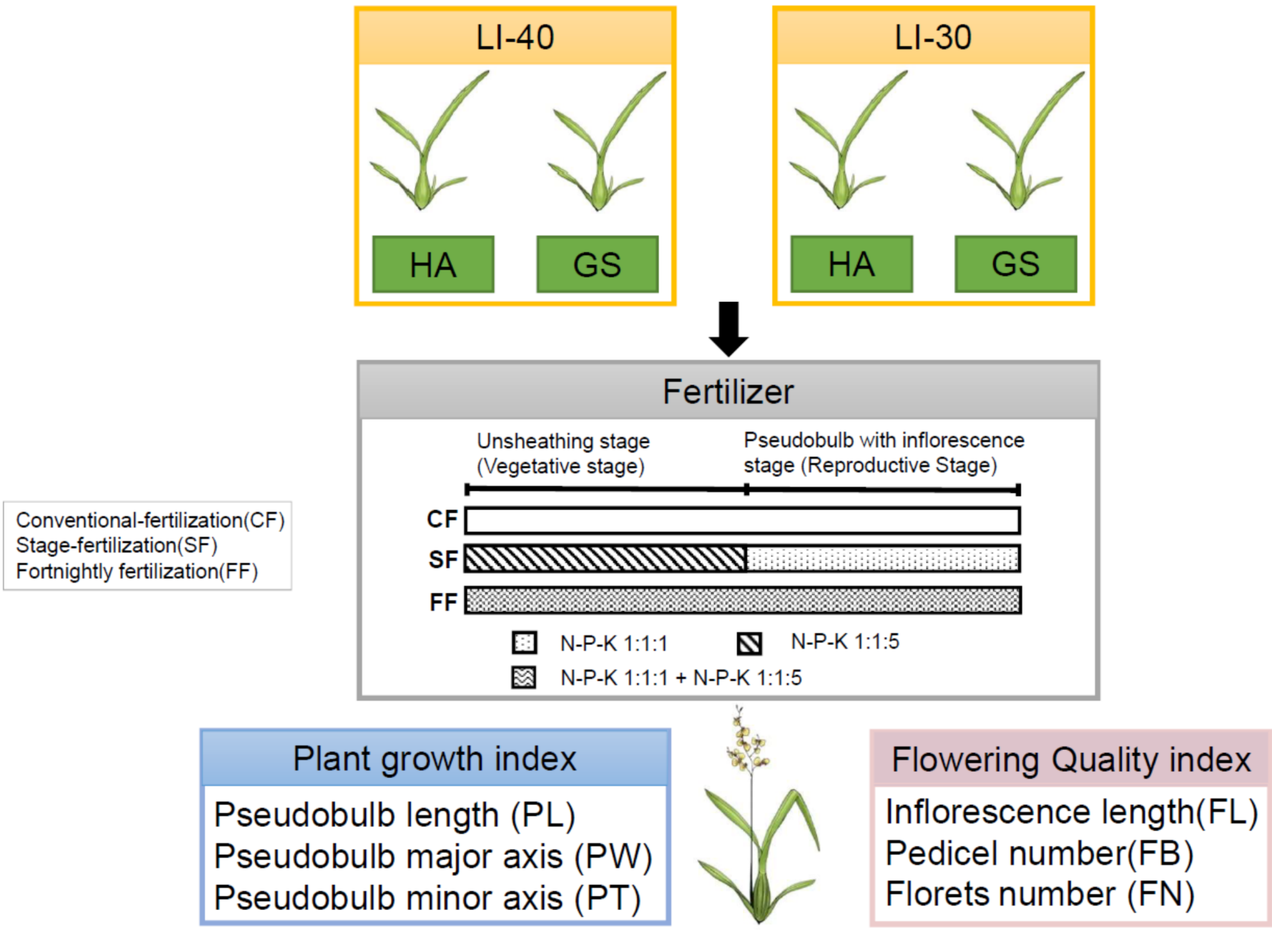

Figure 2. The experimental design and process of this research. The data of pseudobulb length (PL), pseudobulb major axis (PW), pseudobulb minor axis (PT), inflorescence length (FL), number of pedicel (FB), and floret numbers (FN) under LI—40% and LI—30% photosynthetic photon flux density (PPFD) in 'Honey Angel' (HA) and 'Golden Star' (GS) cultivars of *Oncidesa* cultivated under conventional-fertilizer (CF), stage-fertilizer (SF), and fortnight-fertilizer (FF) treatments.

2.4. Statistical Analysis

A total of 2 varieties (HA and GS), two LIs (30% and 40%), and 3 different fertilization treatments (CF, SF, and FF) were selected as the experimental variables. The analysis was carried out according to a completely randomized design with 66, 66, and 44 plants (replicates) for variety, LI, and fertilization, respectively. The treatment combinations were 2 × 3 × 2 with 11 replications, and total number of 132 pots. Measurements of the 6 horticultural traits were evaluated for significance using analysis of variance (ANOVA), and treatment means were separated by Tukey's HSD test and Student's *t*-test at $p \leq 0.05$ using CoStat 6.4 (CoHort Software, Monterey, CA, USA).

3. Results

3.1. Plant Growth and Flower Quality Traits

The effects of LI on the *Oncidesa* varieties cultivated with different fertilization treatments were recorded by measuring changes in PL, PW, PT, FL, FB, and FN, and each treatment was assumed to be dependent on the others in the experiment. Table 1 indicates that PW and FN were significantly different at the levels of 1% or 5% for all main effects, whereas PL, PT, and FB only showed significant differences in light (L), variety (V), and fertilizer (F), respectively, at the 5% level. Moreover, when the V × L interaction was examined for significance, all flower quality components significantly differed at the 0.1%, 1%, or 5% levels, suggesting that the effects of LI treatments on FL, FB, and FN differed with variety. PT, FL, and FN appeared to significantly differ in the interactive effect L × F. All measurements were significant at the levels of 1% or 5% for V × F interaction effects.

Table 1. Analysis of variance of the effects of variety (V), light intensity (L), and fertilizer (F), and their interactions (V × L, V × F, L × F, and V × L × F), including 3-way interaction effect, on the pseudobulb length (PL), pseudobulb major axis (PW), and pseudobulb minor axis (PT), and inflorescence length (FL), number of pedicel (FB), and floret numbers (FN) of per plant.

Trait	Main Effect					
	Variety (V)		Light Intensity (L)		Fertilizer (F)	
	F and *p* Value with Significance					
	F	*p*	F	*p*	F	*p*
PL (mm)	1.06	0.306 NS	4.54	0.035 *	0.85	0.430 NS
PW (mm)	4.70	0.032 *	10.96	0.001 **	3.39	0.037 *
PT (mm)	4.71	0.032 *	3.05	0.083 NS	0.09	0.918 NS
FL (mm)	0.04	0.847 NS	0.54	0.466 NS	4.13	0.018 *
FB	0.78	0.379 NS	3.10	0.080 NS	0.02	0.977 NS
FN	10.00	0.002 **	9.59	0.002 **	4.88	0.009 **
Trait	Interaction Effect					
	V × L		L × F		V × F	
	F and *p* Value with Significance					
	F	*p*	F	*p*	F	*p*
PL (mm)	3.31	0.071 NS	0.69	0.505 NS	7.84	0.0006 ***
PW (mm)	0.06	0.802 NS	2.46	0.089 NS	13.53	0.0000 ***
PT (mm)	0.03	0.855 NS	3.76	0.026 *	5.34	0.0059 **
FL (mm)	6.76	0.010 *	5.72	0.004 **	14.07	0.0000 ***
FB	29.03	0.0000 ***	1.39	0.252 NS	5.08	0.0075 **
FN	7.13	0.009 **	8.48	0.0003 ***	8.98	0.0002 ***

Table 1. *Cont.*

Trait	Interaction Effect	
	V × L × F	
	F and p Value with Significance	
	F	p
PL (mm)	2.67	0.073 ^{NS}
PW (mm)	1.79	0.170 ^{NS}
PT (mm)	7.65	0.0007 ***
FL (mm)	4.06	0.019 *
FB	2.46	0.090 ^{NS}
FN	1.71	0.184 ^{NS}

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, ^{NS} Non-significant difference; n = 66, 66, and 44 plants (replicates) for variety, LI, and fertilizer, respectively, and n = 132 for all interaction effects (V × L, L × F, V × F, V × L × F).

Results of the horticultural evaluation of the 6 treatments derived from LI and fertilization cultures of HA and GS varieties are presented in Tables 2–4, and phenotypic variations among treatments are apparent. The mean values of PW, PT, and FL in the GS variety were significantly higher (respectively, 34.12 mm, 23.52 mm, and 101.88 mm) than in the HA variety (respectively, 32.75 mm, 23.04 mm, and 95.48 mm), but significantly lower FN (73.96) occurred in the GS variety compared to the HA variety (87.89) in all treatments (Table 2). In addition, no significant differences were exhibited in the specific characteristics of PL and FB between varieties, suggestive of varietal variations in the Oncidesa. Table 3 illustrates that all light treatments did not seem to strongly affect PT and FB, but compared to the LI-30 treatment, LI 40-treated plants had significant higher PW and FN values (respectively 33.78 mm and 86.77), whereas there were significantly higher PL (77.39 mm) and FL (101.22 mm) when treated with LI-30 compared to LI-40 (76.14 mm PL and 96.14 mm FL). Table 4 shows that the SF treatment had an augmented effect on PW and FN (respectively 34.07 mm and 85.08) compared to other treatments, whereas fortnightly FF had a prominent role by increasing the FL (101.43 mm) compared to other treatments (96.32 mm and 98.28 mm). Moreover, PL, PT, and FB were not affected by fertilization treatments.

Table 2. Means of six traits (PL, PW, PT, FL, FB, and FN) per plant in each variety HA and GS over a five-month period after two months of pseudobulb maturity cultivation was established.

Trait	Honey Angel (HA)	Golden Star (GS)
PL (mm)	73.91 a	79.63 a
PW (mm)	32.75 b	34.12 a
PT (mm)	23.04 b	23.52 a
FL (mm)	95.48 b	101.88 a
FB	7.58 a	7.74 a
FN	87.89 a	73.96 b

Means in the same row within varieties followed by different letters are significantly different at $p \leq 0.05$ by Student's t-test. Each treatment is assumed to be dependent on the other. n = 66.

Table 3. Means of six traits (PL, PW, PT, FL, FB, and FN) per plant exposed to different light intensity (LI) treatments over a five-month period after two months of pseudobulb maturity cultivation was established.

Trait	40% LI (60% Shade)	30% LI (70% Shade)
PL (mm)	76.14 b	77.39 a
PW (mm)	33.78 a	33.10 b
PT (mm)	23.49 a	21.07 a
FL (mm)	96.14 b	101.22 a
FB	7.92a	7.10a
FN	86.77a	75.08b

Means in the same row within varieties followed by different letters are significantly different at $p \leq 0.05$ by Student's *t*-test. Each treatment is assumed to be dependent on the other. n = 66.

Table 4. Means of six traits (PL, PW, PT, FL, FB, and FN) per plant treated with three different fertilizer methods over a five-month period after two months of pseudobulb maturity cultivation was established.

Trait	CF	SF	FF
PL (mm)	76.06 a	77.04 a	77.20 a
PW (mm)	32.71 b	34.07 a	33.54 a
PT (mm)	23.21 a	23.23 a	23.40 a
FL (mm)	96.32 b	98.28 a	101.43 a
FB	7.64 a	7.65 a	7.69 a
FN	74.34 b	85.08 a	83.36 a

Means in the same row within fertilizer treatments followed by different letters are significantly different at $p \leq 0.05$ by Tukey's HSD. Each treatment is assumed to be dependent on the other. n = 44; CF, conventional-fertilizer treatment comprised of a liquid manure solution of N:K = 1:1.12 mixed with 7.8% N, 0.8% P_2O_5, 0.3% K_2O, and 57.3% of organic matter; SF, stage-fertilizer treatment consisted of N:P:K = 1:1:5 foliage-applied to the plants in a unsheathing stage of pseudobulb until inflorescence period, followed by N:P:K = 1:1:1 application to the end of the experiment; FF, fortnight-fertilizer treatment consisted of N:P:K = 1:1:5 and N:P:K = 1:1:1 with interval-rotate foliage-application to plants weekly until the end of the experiment.

3.2. Plant Growth and Flower Quality Traits of Oncidesa Species Illuminated under Different LIs under Fertilizer Treatments

When varieties were compared across LI and fertilization treatments, the GS variety significantly increased its PL when treated with CF and FF compared to the HA variety, and the GS variety treated with CF under LI-30 exhibited the highest PL at 81.65 mm (Figure 3A), indicating that different fertilization treatments affected PL differently. In addition, the PL of the GS variety from the CF treatment under LI-30 was significantly longer than the other LI treatments in all plants. Figure 3B demonstrates that PW increased as LI increased under SF treatment, and the highest PW (35.11 mm) was observed in the HA variety treated with FF under LI-40. However, HA plants treated with SF and GS plants treated with CF under LI-40 had significant longer PWs (35.11 and 34.98 mm, respectively) than the other LI treatment in all plants. Figure 3C shows that a maximal and significant increase in PT occurred in the LI-40 treatment at 24.89 mm, compared to LI-30 treatment under the CF condition. Moreover, under SF and FF conditions, HA plants subjected to LI-40 treatment significantly increased their PT compared to LI-30. Figure 3D illustrates that the GS variety had a significantly higher FL compared to the HA variety treated with CF, and the longest FL was 110.09 mm in the GS variety under LI-30. Moreover, under SF and FF conditions, HA plants subjected to LI-30 treatment significantly increased their FL compared to LI-30. Interestingly, the HA variety had a significantly higher FB and FN under LI-40 than under LI-30 treatment regardless fertilization conditions, and the highest numbers of FB (8.82) and FN (115.55) of the HA variety were those treated with CF and SF, respectively (Figure 3E,F). Thus, both FB and FN were affected by both LI and fertilization.

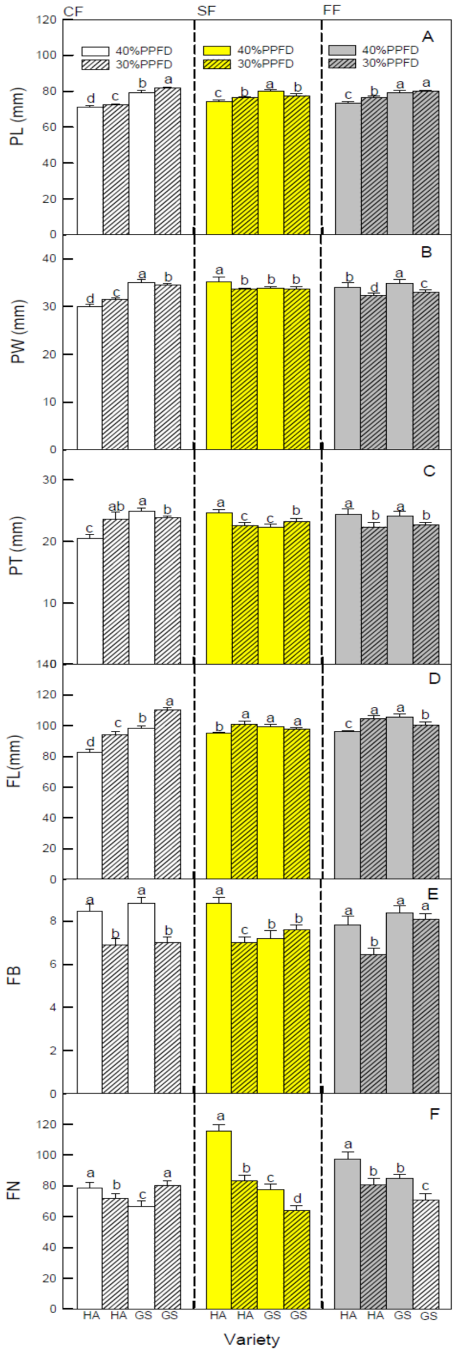

Figure 3. The responses of pseudobulb length (PL) (**A**), pseudobulb major axis (PW) (**B**), pseudobulb minor axis (PT) (**C**), inflorescence length (FL) (**D**), number of pedicel (FB) (**E**), and floret numbers (FN) (**F**) to LI—40% and LI—30% photosynthetic photon flux density (PPFD) in 'Honey Angel' (HA, ▭) and 'Golden Star' (GS, ▨) varieties of *Oncidesa* cultivated under conventional-fertilizer (CF, white), stage-fertilizer (SF, yellow), and fortnight-fertilizer (FF, gray) treatments. Data were recorded and calculated after two months of pseudobulb maturity cultivation until the end of the experimental period. Means within the same fertilization treatment of all LI treatments in the two varieties followed by different lowercase letters significantly differ at $p \leq 0.05$ by Tukey's HSD test. Each treatment was assumed to be dependent on the other. Vertical bars represent the mean ± standard errors (n = 11).

4. Discussion

4.1. Light Intensity Effects on Plant Growth and Flower Quality Traits of Oncidesa Species

The determination of an observed phenotypic trait during a plant's development in response to complex environments is one of the most challenging issues in the differentiation of plant tissues and organs. In addition to their unquestionable botanical and ecological importance, Oncidium participate in current cultivation systems using high-tech horticulture and are grown in environments with good climate control. This allows the induction of inflorescence length and pedicel regardless of the time of year, especially when aiming for a scheduled supply of potted and cut flowers in the competitive world flower market. In this study, the growth, morphology, and differentiation of Oncidium are all affected by LI, and all plants had their maximal PL and FL values when subjected to LI-30 irradiance under the CF treatment (Figure 3A,D), indicating that a low LI induced an increase in both pseudobulb and flower length of the plants. However, HA plants had higher PW and PT values than GS plants and GS plants had more FN than HA plants when exposed to LI-30 irradiance under CF treatment (Figure 3B,C,F). Therefore, the large differences in traits and varieties exposed to different LIs also demonstrated their ability to respond to the selected LI. Under low irradiance, plants compensated for the decrease in light, making better use of this resource by increasing PL and FL and efficiently utilizing photoassimilates, as a larger photosynthetic area is produced per unit of accumulated PL and FL [19]. Many types of morphologic traits occur when plants encounter low-light irradiance, and the tested plants' visual appearances showed obvious changes after five months of LI-30 treatments. Visual observations indicated that the optimal growth and development producing acceptable leaves occurred at LI-30, and most of the leaves in the plants appeared healthy and green when they were grown under LI-30 and CF conditions compared to the LI-40 condition (photos not shown), so all plants tended to be unaffected and exhibited adaptive morphologic plasticity. This is possibly due to the effect of LI-30 on minimizing photorespiration but enhancing/or maintaining carbon assimilation to maintain photosynthetic integrity during adaptation [20]. These findings enable us to use LI as a selection tool for improving morphology in Oncidium and are also informative for germplasm conservation propagation and the production of Oncidium.

Conversely, as LI increased, the PW of GS plants with FF treatment and the FN of HA plants with SF treatment increased (Figure 3B,F). Thus, the increase in pseudobulb major axis and floret numbers was caused by changes in fertilization management in response to decreased shading, and plant growth tended to be more sensitive to LI-40 (40% light intensity, 60% shaded) than to LI-30 (30% light intensity, 70% shaded). Furthermore, when GS plants were subjected to LI-40 irradiance, we also detected longer PL under SF treatment and greater PT and more FB under CF treatment compared to LI-30 irradiance (Figure 3A,C,E), indicating that a high LI induced an increase in pseudobulb length and minor axis and flower branching traits in GS plants. As LI increased from LI-30 to LI-40, the PW, PT, FB, and FN of all plants treated with FF were elevated. Perhaps, under LI-40, the light reaction absorbed more photons than could be used for carbon fixation reactions, affording strong photoprotection under LI-40 treatments [21]. Since *Oncidesa* species are sold on a flower quality basis, plants could specifically increase their FL, FB, and FN in response to selected LI treatments, which would effectively help increase their market quality by increasing flower quality. The effectiveness of a simple and inexpensive method that utilizes shade could help increase plant growth and flower quality in greenhouses. More studies on a wider range of LI for any relationship between photo-physiology and staged-development of *Oncidesa* species are needed to elucidate the observed differences among LI variations during plant culture.

4.2. Influences of Fertilization Technique on Plantgrowth and Flower Quality in Oncidesa Species

Optimizing the fertilization strategy is critical for meeting the temporal and spatial N-P-K requirements of plants while protecting the environment and maintaining farm profitability. Recently, Schnitzer et al. [22] reported that the application of nitrogen between

3.20 and 4.33 mg/pot resulted in the highest values for the length of pseudobulbs and roots, numbers of roots and leaves, and plant height for *Oncidium baueri* (Lindl.) orchid. In addition, plant height and leaf area increased significantly with increasing doses of nitrogen regardless of the source used, but the pseudobulb length, root number, and dry matter production of plants only increased when urea was used as a nitrogen source. Tejeda-Sartorius et al. [23] demonstrated that the use of commercial biofertilizers in combination with mineral fertilizers (30N-10P-10K) is recommended in order to increase the availability and uptake of Ca, Mg, and Cu nutrients in young *Laelia anceps* (Lindl.) plants. In our study, to produce *Oncidesa* efficiently in industrial applications, we undertook to determine the optimum N-P-K fertilizer application for maximizing plant growth and development, and PL, PW, PT, and FL in GS plants under CF treatment were improved compared to HA plants (Figure 3A–D). Nevertheless, SF treatment resulted in greater values of PW, PT, FB, and FN in HA plants compared to GB plants (Figure 3B,C,E,F). Both PL and FL were based on variety differences; in GS, SF-treated plants under LI 40 condition had significantly greater PL and FL values compared to HA plants. These results suggest that SF treatment has the potential to become a maturity fertilizing guideline. Having a unique fertilizer cultivation method is also sometimes a marketing strategy. Indeed, the orchid industry desperately needs a quality management program. Future study is needed to construct a statistical prediction model based on precision fertilization management.

To ensure an accurate production plan, it is important for commercial growers to judge the maturity of Oncidium to determine the appropriate fertilizing schedule [10,15,18]. HA and GS varieties had significant differences in plant growth and flower quality, and also had different trends in fertilization management or technique. Consequently, a variety of responses to LI correlated with the fertilization method, and plants grown in specific LI and fertilization cultures exhibited various morphological changes due to varietal variation. FF treatment was shown to remarkably enhance all of the measured traits of GS plants subjected to LI-40, except for reducing FN, where the highest FN was observed in HA plants under LI-40 in FF treatment (Figure 3F), suggesting that fortnightly fertilizer treatment might interact with luminosity. In addition, the management and application of chemical fertilizers resulted in an increase in nutrient availability and ultimately increased plant growth and flower quality traits, and leaf-spraying with chemicals and nutrients improved these traits and caused a more efficient uptake by leaves. It is possible that interactions between fertilizer components can increase some nutrient concentrations. For instance, organic matter significantly increased macro- and micro-nutrient concentrations in leaves, stems, and pseudobulbs. Photosynthetic characteristics might also be affected by changes in nutrient demands when fertilizers containing N, P, K, and organic matter are supplied at regular intervals (conventional nutrient supply), resulting in plant growth and flower quality changes. More work is required to study the physiological and photosynthetic responses of Oncidium under differing nutrient supply treatments. In addition, it would also be interesting to manipulate plant growth and flower quality when illuminated by specific LI percentages under additional fertilizer treatments and management actions. Finally, the technology provided in this experiment is compared with the traditional technology. The cost of materials and equipment is almost the same. The only difference is that the manual operation is more frequent, which affects the final cost by about 6–10%.

5. Conclusions

A factorial experiment consisting of variety, LI, and fertilizer treatments in completely randomized blocks with eleven replications (plants) was conducted and showed varietal differences in changes in pseudobulb and flower quality traits. An understanding of these changes enables the development of models to plan optimum processing times for different genotypes to match specific industry needs. Precise management of fertilization treatments in response to varying LI levels can maximize the growth, development, and flowering characteristics of Oncidium. In addition, understanding the adaptive mechanisms of these plants to various fertilization treatments under varying LI levels would aid in the selection process for developing high quality flowering *Oncidesa* breeding programs in the future.

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