

## Photosynthesis – Light Response of Whole Plants of Wax Begonia Grown Under Different Light Intensities

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**Nature of Work:** Many species have the ability to acclimate to low light intensities, allowing them to more efficiently capture light and maximize photosynthesis under low-light conditions. Acclimation responses to shade include higher shoot to root ratio and increased leaf area per unit dry mass (thinner leaves). Both of these acclimation responses enable plants to produce a larger leaf area and therefore to capture a larger fraction of the available light. At the cellular level, there may be an increase in the chlorophyll concentration and size of the light harvesting complex per reaction center. In contrast, acclimation to high light involves thicker leaves with more chloroplasts (but not necessarily more chlorophyll), smaller light harvesting complexes, more nitrogen per unit leaf area, and increased amounts of Rubisco compared to shade-grown plants. Wax begonias are classified as obligate shade plants (shade 'loving') and listed among the top five bedding plants grown in the South. In the South, wax begonias are grown under various light levels and, interestingly, perform well under a wide range of light intensities. However, there have been no studies examining physiological and/or morphological responses of wax begonias to different light intensities. The objective of this study was to quantify the physiological and morphological responses of wax begonia to varying light intensities and to use that information to provide recommendations on the light requirements for the commercial production of wax begonias.

Seedlings were grown in 36-cell flats filled with a soilless growing medium (Fafard 2P mix, Fafard) inside whole-plant gas exchange chambers (van Iersel and Bugbee, 2000) arranged in growth chambers. Plants were grown under four light levels (here referred to as growth irradiance) for a period of 25 d by covering individual gas exchange chambers with shade cloth. The average daily growth irradiance measured at the top of the canopy in the different treatments was 5.3, 9.5, 14.4, and 19.4 mol/m<sup>2</sup>/d (corresponding to 730, 1300, 1970, and 2660 foot-candles for 14 hours per day). After 25 days, 12 plants from each experimental unit were used to determine whole-plant photosynthesis-light response curves. Plants were initially placed in darkness for 10 h. Then, plants were exposed to increasing levels of photosynthetic photon flux (PPF) up to 700 μmol/m<sup>2</sup>/s (4830 foot-candles) in approximate increments of 50 μmol/m<sup>2</sup>/s (345 foot-candles). Dark respiration (i.e. the CO<sub>2</sub> exchange rate at 0 μmol/m<sup>2</sup>/s) and net photosynthesis were measured, while gross photosynthesis was calculated as the sum of net photosynthesis and dark respiration. The measured CO<sub>2</sub> exchange rates were divided by the total leaf area of plants to estimate net photosynthesis and dark respiration per m<sup>2</sup> leaf area (P<sub>n</sub> and R<sub>d</sub>, respectively, μmol/m<sup>2</sup>/s). The following asymptotic equation was fitted to P<sup>n</sup> data using PROC NLIN of SAS (SAS institute, Cary, NC):  $P_n = P_{max} \times (1 - e^{-\alpha I / P_{max}}) - R_d$  where P<sub>max</sub> is the gross photosynthesis per m<sup>2</sup> leaf area (P<sub>g</sub>) at light saturation, α is

the quantum yield (maximum number of moles of CO<sub>2</sub> fixed per mole of *PPF* incident on the plants, i.e. the slope of the photosynthesis-light response curve at a *PPF* of 0 μmol/m<sup>2</sup>/s), and *I* is the *PPF* incident on top of the plants. The light compensation point (LCP) was determined as the *PPF* at which P<sub>n</sub> was estimated to be 0 μmol/m<sup>2</sup>/s and the light saturation point (LSP) was defined as the *PPF* at which P<sub>g</sub> was 95% of P<sub>max</sub>. The net amount of carbon which the plants would have gained at different *PPF* levels in a day with a 14-h light and 10-h dark period [mol/m<sup>2</sup>/d, the net assimilation rate (NAR), a measure of growth rate per unit leaf area] was estimated as (14 x P<sub>n</sub> - 10 x R<sub>d</sub>) x 0.0036, where 0.0036 converts μmol/m<sup>2</sup>/s to mol/m<sup>2</sup>/hour. Growth measurements included leaf chlorophyll concentration per m<sup>2</sup> leaf area (SPAD-502, Minolta), leaf area (LI-3100, Li-Cor), and total dry weight of plants (including roots). Leaf area ratio (LAR) of plants was estimated as the ratio of leaf area to total dry weight. The experimental layout was a randomized complete block with two replications (growth chambers) each containing four *PPF* treatments (four gas exchange chambers), and each experimental unit (gas exchange chamber) consisted of 12 plants. The photosynthetic parameters were analyzed using PROC GLM (replication as a class variable and *PPF* as continuous variable). The light response curves were fitted using PROC NLIN (nonlinear regression) of SAS. In both cases, *P* < 0.05 was considered to be statistically significant.

**Results and Discussion:** An asymptotic equation accurately described the response of P<sub>n</sub> to increasing *PPF* (*R*<sup>2</sup> = 0.98 - 0.99). Net photosynthesis of plants from all growth irradiances initially increased rapidly as *PPF* was increased from 0 to 200 μmol/m<sup>2</sup>/s, and photosynthesis in all treatments became light saturated at approximately 530 μmol/m<sup>2</sup>/s (Fig. 1). At high light levels, photosynthesis is limited by the ability of plants to utilize the absorbed light to assimilate carbon. At these *PPF* levels, factors such as stomatal conductance, CO<sub>2</sub> concentration inside the leaf, levels of Rubisco, other enzymes, or various substrates involved in the photosynthetic pathway may become rate-limiting. Despite the similar LSP in all treatments, plants grown at 14.4 or 19.4 mol/m<sup>2</sup>/d had higher P<sub>max</sub> rates than plants grown at 5.3 or 9.5 mol/m<sup>2</sup>/d (Table 1). This indicates that wax begonia undergoes a physiological acclimation in response to high growth irradiance, allowing it to use high *PPF* levels more efficiently than plants grown at low irradiance. One likely reason for this acclimation is that plants grown at high light generally contain more Rubisco in their leaves, which increases their photosynthetic capacity. However, other possibilities like more efficient electron transport systems, proteins, or pigments of the light harvesting complexes in plants grown at high growth irradiance cannot be ruled out. The LSP of wax begonia (500 to 550 μmol/m<sup>2</sup>/s, Table 1) was only about 30% of full sunlight in summer, which is low compared to the LSP of other species. This low LSP may limit their photosynthetic capacity, since the plants cannot efficiently utilize high *PPF* levels. When compared to normal P<sub>max</sub> values seen in many other species (15 to 25 μmol/m<sup>2</sup>/s) (Jones, 1992), wax begonias had a low P<sub>max</sub> (3.6 to 4.4 μmol/m<sup>2</sup>/s).

There were no differences in quantum yield among treatments (Table 1). Dark respiration increased linearly with increasing growth irradiance (Table 1), probably because of the increased carbohydrate supply at higher irradiance. Generally, an increase in R<sub>d</sub> also results in an increase in the LCP of plants,

because plants with a high  $R_d$  need to photosynthesize more to offset respiration. However, there were no differences in the LCP among treatments. The LCP is defined as the light level above which there is an instantaneous net gain of carbon in plants. Thus, the LCP does not take into account any loss of carbon from respiration at night. Therefore, plants which are grown at the LCP for part of a day, and in the dark for the rest of the day, will have a net loss of carbon during a 24-h period. The 'true' LCP, which would result in zero carbon gain or loss during a 24-h period, can be determined by estimating the NAR (Fig. 2). To determine the 'true' LCP, we fitted an asymptotic equation [ $NAR = NAR_{min} + (NAR_{max} - NAR_{min}) \times (1 - e^{-b \times PPF})$ ] to the relationship between NAR and *PPF* ( $NAR_{min} = NAR$  at a *PPF* of 0,  $NAR_{max} = NAR$  at light saturation). The 'true' LCP increased linearly with increasing growth irradiance (Table 1). The estimated  $NAR_{max}$  for plants grown at 5.3, 9.5, 14.4, and 19.4 mol/m<sup>2</sup>/d was 0.22, 0.21, 0.26, and 0.27 mol/m<sup>2</sup>/d, respectively.

At low *PPF* levels,  $P_n$  is mostly limited by the amount of light absorbed by the plants. Wax begonia acclimated to low growth irradiance by increasing the chlorophyll concentration in the leaves (Table 1), which helps the plants to capture light more efficiently. Total dry weight and leaf area of plants increased linearly with increasing growth irradiance, while chlorophyll concentration decreased linearly with increasing growth irradiance (Table 1). There were no differences in leaf area ratio and shoot to root ratio among treatments.

**Significance to Industry:** This study has shown that wax begonias have the potential to acclimate to various light levels during their growth. At high growth irradiance, their photosynthetic capacity ( $P_{max}$ ) was increased, which allowed the plants to use high *PPF* more efficiently. At low growth irradiance, wax begonias increased the chlorophyll concentration of the leaves, thus capturing the available *PPF* more efficiently. We did not find any evidence of morphological acclimation to growth irradiance. Acclimation to different light levels allows wax begonias to be grown under a wide range of growth irradiances, although they do grow faster under higher irradiance. Plants grown under 9.5 to 19.4 mol/m<sup>2</sup>/d were of commercially-acceptable quality.

**Literature Cited:**

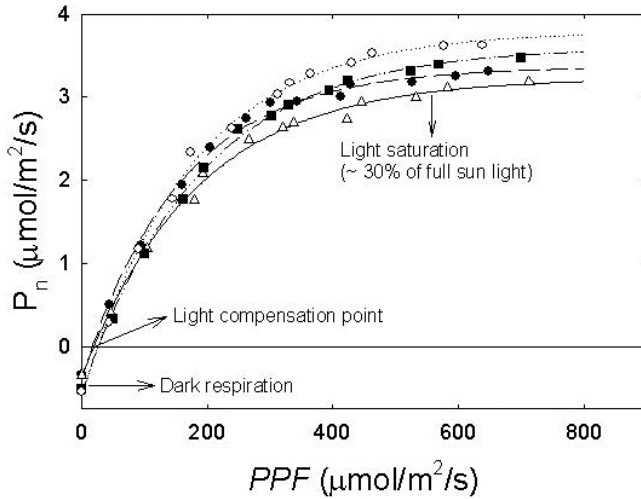
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**Table 1.** The effect of different growth irradiance on photosynthetic and growth parameters of wax begonia.  $P_{max}$  = light saturated gross photosynthesis,  $R_d$  = dark respiration rate, LCP = light compensation point, 'true' LCP = true light compensation point, LSP = light saturation point, chl = leaf chlorophyll concentration, TDW = total dry weight, and LAR = leaf area/total dry weight.

| Growth irradiance     | Quantum yield | $P_{max}$                    | $R_d$                        | LCP                          | 'true' LCP                   | LSP                          | chl        | leaf area      | TDW  | shoot root ratio | LAR <sub>plant</sub> |
|-----------------------|---------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------|----------------|------|------------------|----------------------|
| mol/m <sup>2</sup> /d | mol/mol       | $\mu\text{mol/m}^2/\text{s}$ | $\mu\text{mol/m}^2/\text{s}$ | $\mu\text{mol/m}^2/\text{s}$ | $\mu\text{mol/m}^2/\text{s}$ | $\mu\text{mol/m}^2/\text{s}$ | spad units | m <sup>2</sup> | g    |                  | m <sup>2</sup> /kg   |
| 5.3                   | 0.024         | 3.76                         | 0.39                         | 17.7                         | 29.3                         | 477                          | 30.3       | 0.29           | 9.8  | 2.25             | 29.1                 |
| 9.5                   | 0.020         | 3.61                         | 0.43                         | 24.1                         | 34.9                         | 556                          | 29.3       | 0.38           | 12.5 | 1.88             | 30.5                 |
| 14.4                  | 0.022         | 4.17                         | 0.57                         | 27.1                         | 46.7                         | 596                          | 29.2       | 0.47           | 16.8 | 2.60             | 27.8                 |
| 19.4                  | 0.023         | 4.39                         | 0.54                         | 25.9                         | 45.1                         | 522                          | 28.4       | 0.51           | 16.8 | 2.26             | 30.3                 |
| regression analysis   |               |                              |                              |                              |                              |                              |            |                |      |                  |                      |
| $r^2$                 | - NS          | 0.76                         | 0.67                         | -                            | 0.70                         | -                            | 0.75       | 0.82           | 0.84 | -                | -                    |
| intercept             | 0.023         | 3.37                         | 0.29                         | 23.7                         | 22.7                         | 527                          | 30.9       | 0.23           | 7.4  | 2.25             | 29.4                 |
| slope                 | -             | 0.05                         | 0.015                        | -                            | 1.39                         | -                            | -0.14      | 0.015          | 0.55 | -                | -                    |

<sup>NS</sup> regression not significant at  $P < 0.05$ .

**Figure 1.** Response of net photosynthesis ( $P_n$ ) in wax begonia to increasing photosynthetic photon flux ( $PPF$ ). Photosynthesis is expressed per unit leaf area. Before the light response curves were determined, plants were grown at 5.3 (closed circle), 9.5 (open triangle), 14.4 (closed square), and 19.4 (open circle)  $\text{mol/m}^2/\text{d}$  for a period of 25 days.



**Figure 2.** Effect of increasing photosynthetic photon flux ( $PPF$ ) on the net assimilation rate (NAR) of wax begonias. The arrow points at the true 'light' compensation point at which net carbon uptake during a 24 h period is zero. Plants were grown at 5.3 (closed circle), 9.5 (open triangle), 14.4 (closed square), and 19.4 (open circle)  $\text{mol/m}^2/\text{d}$  for a period of 25 days before determining the light response curves.

