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Physiological and Yield Performance Is Partially Linked to Water Use Efficiency of Eggplant Genotypes in a High-Tech Glasshouse

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Abstract: Eggplant (*Solanum melongena* L.) has become an increasingly common vegetable grown in glasshouses. This study emphasized on the physiological traits and productivity of three eggplant cultivars (Longa, Lydia, and Tracey) in a high-tech glasshouse to determine the genotypic differences of agronomical, morphological, and physiological responses. The physiological parameters as well as the productivity of these eggplant cultivars were evaluated. The results showed that Tracey had significantly higher leaf growth than Longa and Lydia. Longa exhibited significantly higher values of net CO_2 assimilation (A), stomatal conductance (g_s), and transpiration rate (T_r) than Tracey, whereas Tracey showed significantly larger g_s, T_r, and intracellular CO_2 concentration (C_i) than Lydia. Tracey showed a significantly higher number of flowers per node compared to the two other varieties, but the number of fruits did not statistically differ among cultivars. Tracy produced the highest yield (fruit weight and fruit yield per m^2) due to the significantly higher leaf length and leaf expansion rate despite the lowest level of A among the three cultivars. Interestingly, the higher yield of Tracey translated into better water use efficiency (WUE) in the agronomic term, but its intrinsic WUE (A/g_s) was the lowest among the three cultivars. However, significant correlations between photosynthetic parameters and WUE were only found in certain stages of eggplant growth. Therefore, further research work with an emphasis on the source and sink partitioning of a large number of eggplant genotypes is required to investigate the varietal performance of greenhouse eggplants. Then, the information can be translated into protected cropping to set up the growth benchmark for large-scale sustainable production of eggplants with better yield and less water consumption for the horticultural industry.

Keywords: protected cropping; genotypic variation; sustainable production; leaf gas exchange; water use efficiency; *Solanum melongena*

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1. Introduction

Eggplant (*Solanum melongena* L.), also known as aubergine, guinea squash, or brinjal, is an economically valuable crop available worldwide, with a total harvest area of approximately 1.8 million hectares per annum dedicated to their cultivation [1]. Eggplant has become a widely accepted vegetable because of its high dietary value including high levels of antioxidants [2] and phenolic acids that affect eggplant culinary quality and antioxidant content [3]. Due to its versatile usage, eggplant is the 4th most commonly grown greenhouse crop and is mostly grown in greenhouses and foil tunnels [4,5].

Enormous types of eggplants have been produced in Europe, America, Asia, and Africa with the increasing diversity of their habits and fruit shapes, sizes, and colors. Eggplant varietal diversity has been lost/reduced globally [6] along with numerous eggplant varieties no longer cultivated [7], but several varieties in Asia are promising [8]. Cultivars around the world harbor alleles that may be potentially significant in improving stress tolerance, disease resistance, and nutritional quality of eggplants through plant breeding in conjunction with new genetic and genomic tools [9–12]. Low genetic diversity among eggplant germplasm has raised concern hence, preserving eggplant germplasm is vital for future varietal development, resilience to environmental conditions and maintaining global food security [11,13].

Technological advancements and crop improvement are required for higher yields as cultivable agricultural arable lands are decreasing, while food demands are growing [14]. Protected cropping of horticultural vegetables in controlled environments is one potential solution to crop production constraints such as climate change [15]. With the advent of computerized automation, the modern greenhouse has provided sophisticated ways of producing horticultural crops through precise environmental control driven by the constant acquisition and accumulation of information [16]. Dynamic growth and development of crops can be improved by integrating environmental control with the critical assessment of physiological traits to manage the production [3,17].

During the day, plants utilize about 49% of total solar energy within the photosynthetically active spectrum, whereas 51% of total solar energy is not biologically relevant and generates heat inside the glasshouse [18]. Higher greenhouse temperatures often lower the total yield of vegetable production [19,20]. However, a few modern greenhouses have incorporated innovative technologies to sustainably use energy [21–26]. In addition, there may be impacts of altered light environment on plant growth, photosynthesis, biomass partitioning, and yield [16,27,28]. Plants detect the light intensity, light quality, and duration of light in their surroundings with a variety of photoreceptors [29–32] at the whole plant, cellular, biochemical, and molecular levels [16,33–36].

The growth of Solanaceous crops in greenhouses is tightly regulated by the interactions between plant genetic properties and the environmental conditions [3,17]. Greenhouse environmental conditions affect the growth, development, and productivity of crops [37–39], including prolonged photoperiod, supplementary light, and continuous light [35,40,41]. It has been shown that supplementary light may reduce the photosynthetic efficiency of Solanaceous crops by affecting the chloroplast ultrastructure, its function, and photosynthetic pigments, which potentially leads to leaf chlorosis [41–45].

The global production of year-round eggplant in greenhouses may mitigate the calamitous impact of climate change and maintain productivity with a ballooning population [16,38,46–49]. Eggplant genotypes exhibit different responses to greenhouse conditions, thereby affecting the growth, yield and adaption of genotypes to different climate zones and environments [11,46]. Cultivar-dependent eggplant responses to simultaneous stresses include significantly reduced plant growth, photosynthesis rate, leaf gas exchange, and affected gene expression levels to a greater extent than the sole stress [50]. However, research on eggplants has been less extensive in high-tech commercial standard greenhouses compared to other Solanaceous crops, most notably tomato.

This greenhouse trial was conducted on three local eggplant cultivars (*cv*. Longa, Tracey, and Lydia) in the high-tech glasshouse during the long photoperiod summer, with routinely practiced standard management practices. The primary objective of this study was to evaluate the physiological traits and productivity of the three eggplant genotypes in an environmentally controlled high-tech glasshouse, which may provide a standardized benchmark for growing greenhouse eggplant in the Eastern Australian subtropical coastal climate.

2. Materials and Methods

2.1. Glasshouse Facility Descriptions

The trial was carried out in the advanced glasshouse facility at the National Vegetable Protected Cropping Centre of Western Sydney University (WSU), Richmond NSW, Australia. It is state-of-the-art and designed for research and small-scale commercial production of horticultural crops, which is centralized and fully automated with Priva software (Connext 912) and hardware (Priva, The Netherlands) to monitor and regulate temperature, humidity, nutrients, CO_2, and irrigation. Typical high-tech hardware was employed to control glasshouse light, temperature, humidity, and CO_2 level. We used one research bay of 360 m^2 with the precise and independent regulation of greenhouse microclimate with a hydroponic nutrient and water delivery system.

2.2. Plant Growth and Management

Solanum melongena (*cv.* Tracey Longa and Lydia) was tested from August 2018 to February 2019. For the experiment, 6 weeks old nursery-grown seedlings were purchased (Rijk Zwaan Australia PTY Ltd., Musk, VIC) and transplanted to the Rockwool slabs. This bay consisted of 8 gutters (length 32 m, width 25 cm, AIS Greenworks, Castle Hill, AUSTRALIA) with Rockwool slabs (100 cm × 15 cm × 10 cm, Grodan, The Netherlands). Spacing was maintained at 160 cm between the gutters and at 40 cm between the plants within the gutter. Three plants per slab were planted in all the gutters. A total of 96 plants were grown in each gutter, but the measurements were only performed on the selected 10 plants per cultivar around the middle of the gutters to avoid edge effects.

In this trial, three stems were allowed to grow from each plant. Only one stem was considered as an individual plant for replication. Replication refers to the total number of individual plants in the experimental bay per variety per gutter for three varieties. In this trial, 10 plants per gutter were used as replicates number (n = 10) per variety with a total of 30 replicates for each variety (n = 30). Plants were grown and maintained at standard growth conditions under natural light conditions with the Priva automated fertigation system (nutrients and water). Crop management practices with weekly pruning and integrated pest management (IPM) measures according to commercial practices of eggplant production for protected cultivation.

2.3. Plant Growth and Productivity Measurements

Measurements were consistently performed weekly from the newly emerging node of selected stems for a total of 30 plants per cultivar from 9 to 29 weeks old. Plant growth and yield parameters were measured periodically in this trial. Stem diameter, stem length (mm), and stem growth (mm/1 week) were measured from the newly emerging node of the stem (n = 10 shoots per variety per gutter). Leaf length (mm) of an expanded leaf followed by the successive leaf growth (mm/1 week) & (mm/2 weeks), leaf numbers (no. $node^{-1}$); flower numbers (no. $node^{-1}$) and fruit numbers (no. $node^{-1}$) were also determined similarly (n = 10 stems per variety per gutter). Flower and fruit developments were tracked routinely till plants attained full development to the fruiting stage. Fruit size was determined by intensive purple color with a characteristic metallic shine. Seven weeks after transplanting, eggplant fruits were harvested from every plant at their commercial maturity stage (between 350 to 450 g, mean harvest mass) till plants aged 34 weeks. Total fruit weight (kg)/m^2 and total fruit number m^{-2} followed by the measurement of individual fruit length (mm), fruit width (mm), and fruit weight (g) were also recorded.

2.4. Leaf Gas Exchange Measurements

The portable gas exchange system LI-6400XT infrared gas analyzer (Li-Cor Inc., Lincoln, NE, USA) was used to measure Instantaneous steady-state leaf gas exchange from fully expanded top canopy leaves according to [35,51]. Net CO_2 assimilation (A, μmol m^{-2} s^{-1}), stomatal conductance (g_s, mol m^{-2} s^{-1}), intercellular CO_2 concentration (C_i, μmol mol^{-1}), the ratio of leaf intercellular [CO_2] to ambient air [CO_2] (C_i/C_a, μmol mol^{-1}), leaf temperature (T_{leaf}, ^{0}C), transpiration (T_r, mmol m^{-2} s^{-1}), and vapor pressure deficit (*VPD*, KPa) were determined when plants aged 13–21 weeks old. The conditions in the measuring chamber were controlled at a flow rate of 500 mol s^{-1}, at growth PARs and saturating PAR at 1500 µmol m^{-2} s^{-1}, 400 mmol mol^{-1} CO_2, 25 °C leaf temperature and the relative humidity of 60–70%.

Water use efficiency (WUE) is measured as the amount of fruit produced (kg) per unit of water (m^3) consumed by each variety of eggplant during the crop season. An average of 3.24 m^3 water per m^{-2} floor area was used for each eggplant variety. Intrinsic water use efficiency (*iWUE*) was calculated as the ratio of photosynthetic rate to gas exchange.

2.5. Statistical Analysis

All the values were expressed as means ± SE. Statistical significance was examined using descriptive analysis in SPSS. Statistical significance amongst the cultivars was determined by Duncan's multiple range test at $p < 0.05$ employing IBM SPSS Statistics 25 (IBM, Armonk, New York, USA). All data were plotted using Sigma Plot 14 (Syntat, Palo Alto, CA, USA).

3. Results

3.1. Leaf and Stem Growth Parameters

Tracey showed significantly higher leaf growth parameters than Longa and Lydia. This result showed significantly higher leaf length in Tracey (485.1 mm) compared to Longa (458.7 mm) and Lydia (433.6 mm) (Figure 1A), which later is also reflected as increased leaf length growth rate (Figure 1B). Leaf number per node showed differences for Tracey compared to Longa and Lydia. There is a report of a higher number of eggplant leaves in the greenhouse, compared to those plants grown outside the greenhouse [52]. Reports showed high temperatures in the range of 23/29 °C (night/day) stimulate sweet paper plant vigor inside the greenhouse, which encourages plants to grow vertically, leading to improved total fruit yield in most genotypes [20].

Stem parameter results indicated no significant difference in internode length among the genotypes for Longa, Lydia, and Tracey in the greenhouse with 172.2 mm, 160.1 mm, and 150.3 mm, respectively (Figure 1D). Similarly, there was not any significant difference in stem diameter among the genotypes with 8.67, 8.07, and 8.7 mm, respectively for Longa, Lydia, and Tracey (Figure 1E). However, Lydia showed the highest stem growth (135.6 mm) per week compared to Longa (124.1 mm) with the least amount of growth was evident in Tracey (80.7 mm) (Figure 1F).

3.2. Leaf Gas Exchange Parameters

Longa exhibited significantly higher values of net photosynthetic rate (*A*). The average *A* over the eggplant growth season were 24.7, 22.5 and 22 µmol CO_2 m^{-2} s^{-1} for Longa, Lydia, and Tracey. The corresponding values of stomatal conductance (g_s) were 1.13, 0.89 and 1.15 mol H_2O m^{-2} s^{-1}. A negligible difference was found between Longa and Tracey in terms of g_s and transpiration rate (T_r). While Lydia showed 22% and 17% reductions in g_s and T_r, respectively compared to the other two genotypes. Tracey had a higher leaf intercellular CO_2 concentration (C_i) value (293.5 µmol CO_2 mol air^{-1}) in comparison to Longa (311.1 µmol CO_2 mol air^{-1}) and Lydia (277.7 µmol CO_2 mol air^{-1}) (Figure 2D). Lower C_i in Lydia can be attributed to a lower g_s value in this genotype. Gas exchange parameters of three eggplant cultivars measured over 6 different weeks are presented in Supplementary Table S1.

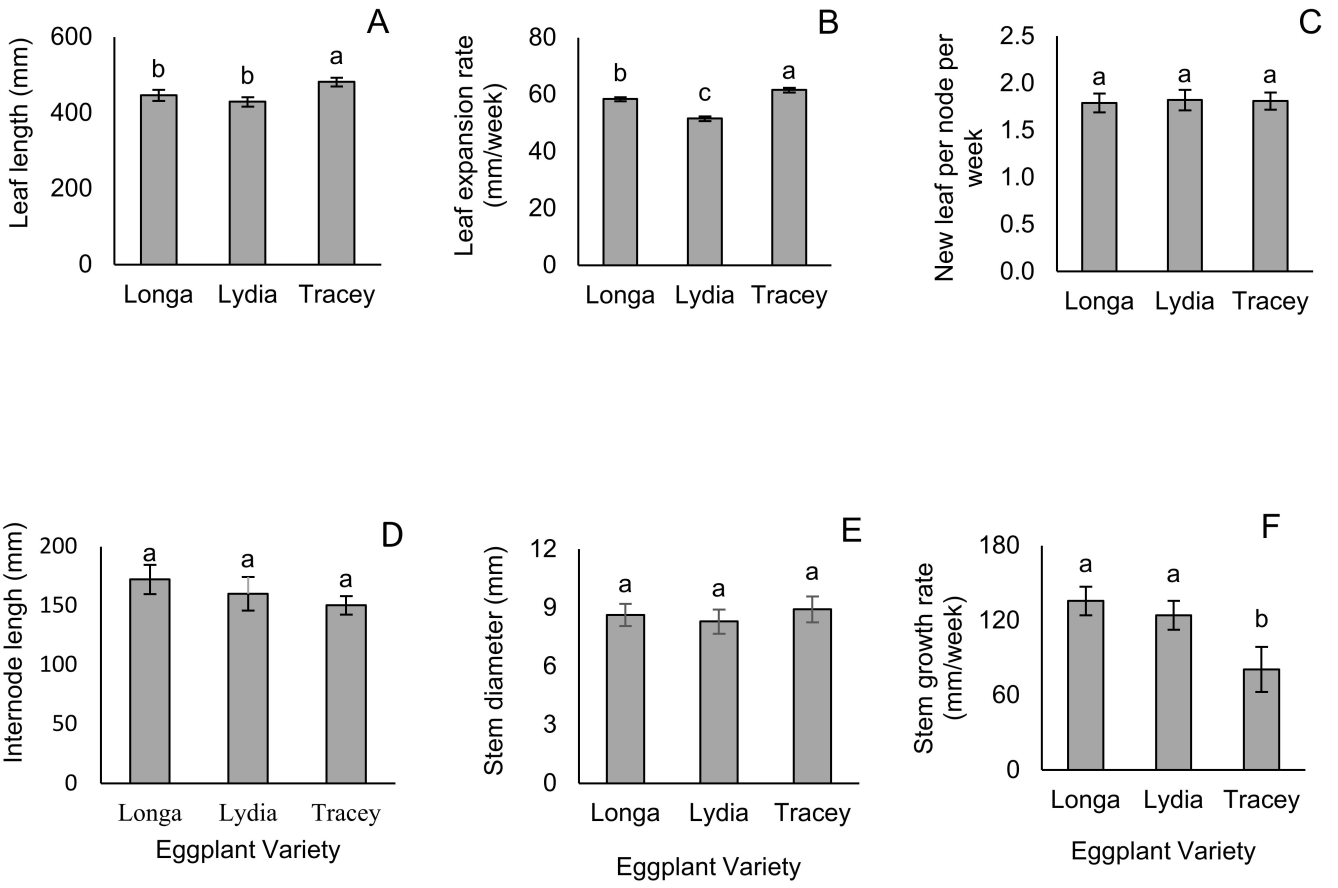

Figure 1. Leaf and stem growth properties of eggplant in the high-tech greenhouse. Leaf length (**A**), Leaf expansion rate (**B**), New leaf per node (**C**) Internode length (**D**) Stem diameter (**E**), and Stem growth rate (**F**). Data are averaged over 21 weeks of measurements with 30 biological replicates for each cultivar per week. Different lowercase letters indicate statistical significance at $p < 0.05$.

3.3. Flower Number and Fruit Growth Parameters

The number of flowers per node showed a significant difference between the genotypes with the highest number reported in Longa (1.49 flowers) followed by Lydia (1.27) and Tracy (1.13) however, differences in the number of flowers between Lydia and Tracy were insignificant (Table 1).

Table 1. Flower and fruit number of Eggplant varieties in a high-tech greenhouse. Data are mean ± SE (n = 30).

Reproductive Growth	Longa	Lydia	Tracey
Weekly new flower per node	1.49 ± 0.12	1.27 ± 0.07	1.13 ± 0.06 *
Average fruit numbers (m^{-2} $week^{-1}$)	2.92 ± 0.36	3.2 ± 0.4	3.55 ± 0.35

* indicated significant statistical difference at $p < 0.05$ using Student *t*-test, compared to Longa.

The number of fruits per week remains unaffected between the genotypes with 2.92, 3.20, and 3.55 (Fruit m^{-2} $week^{-1}$), respectively in Longa, Lydia, and Tracey (Table 1).

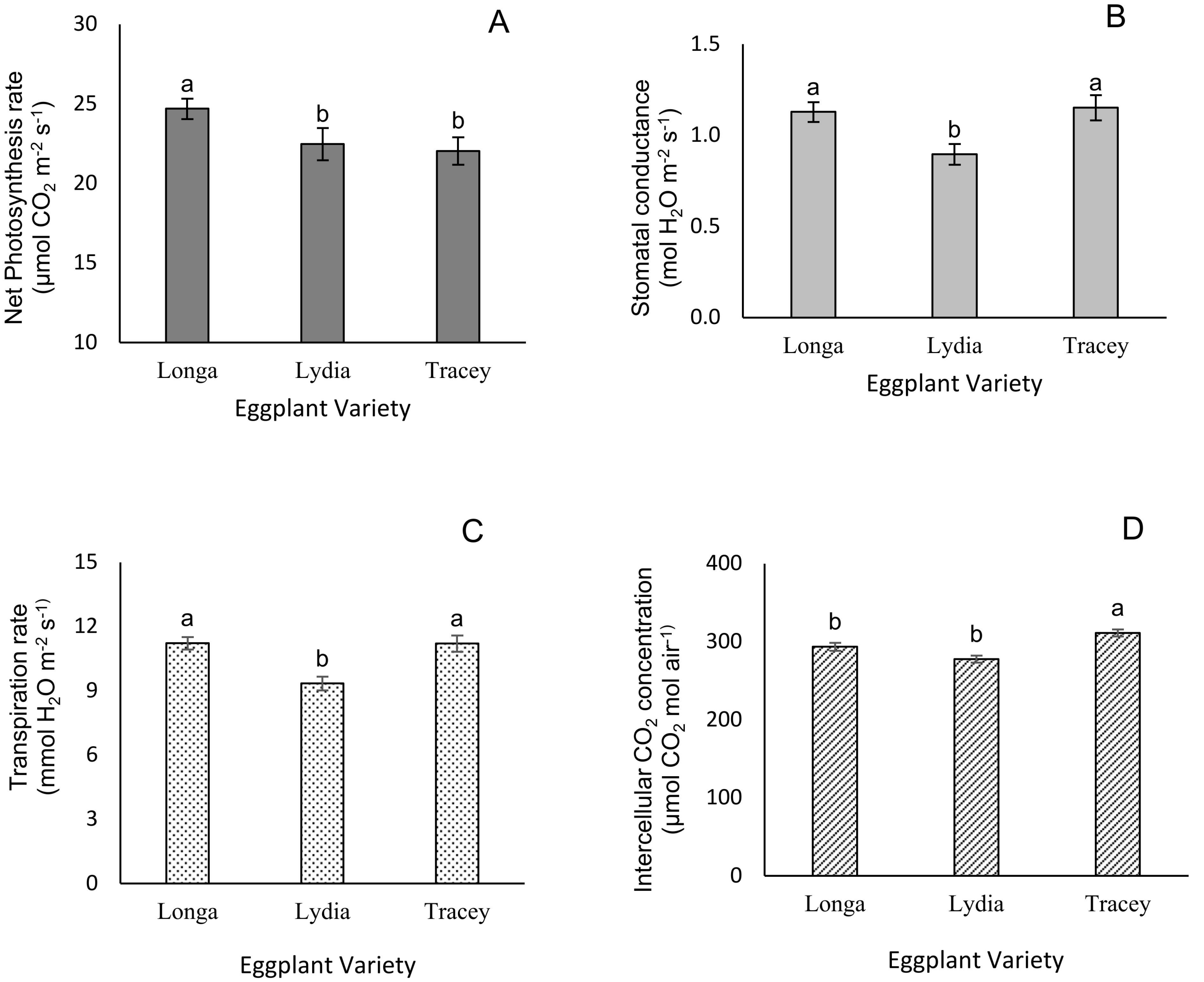

Figure 2. Average of leaf gas exchange parameters of eggplant in the high-tech greenhouse. Net Photosynthesis rate (**A**), stomatal conductance (**B**), Transpiration rate (**C**), and intercellular CO_2 concentration (**D**). Data are averaged over 6 weeks of measurements with 6 biological replicates for each cultivar per week. Different lowercase letters indicate statistical significance at $p < 0.05$.

The individual fruit weight of eggplant was significantly different in the glasshouse trial with the weight of 289.1 g/fruit, 345 g/fruit, and 393.8 g/fruit, respectively for Longa, Lydia, and Tracey (Figure 3A). However, this may not correlate to the fruit length and width. Tracey and Lydia exhibited larger fruit width than Longa but not in terms of fruit length (Figures 3 and 4). Longa showed a significantly higher fruit length 224.6 mm, whereas Lydia and Tracey had fruit lengths of 164 mm and 181.2 mm, respectively (Figures 3C and 4). This is mainly due to the genetic control of Longa of its bigger fruit length. Fruit width significantly varied between the cultivars with the highest significance in Lydia (72.6 mm) and Tracey (75.5 mm) compared to Longa (60.1 mm), which showed the very lowest growth in fruit diameter (Figures 3B and 4A1–C3).

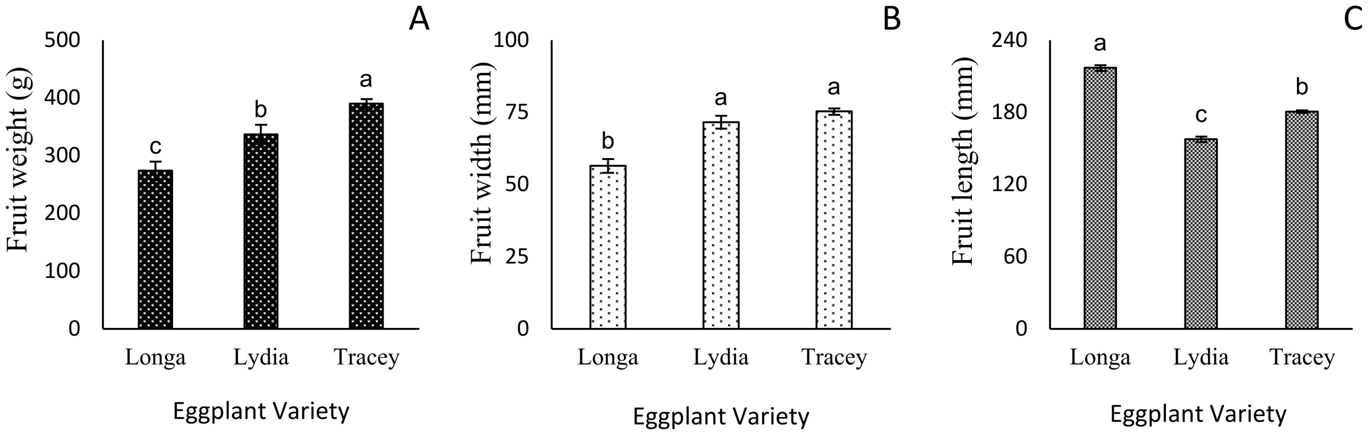

Figure 3. Fruit parameters of eggplant in the high-tech greenhouse. Individual fruit weight (**A**), fruit width (**B**) and fruit length (**C**). Data are averaged over 9 weeks of measurements with 30 biological replicates for each cultivar per week. Different lowercase letters indicate statistical significance at $p < 0.05$.

Figure 4. Eggplant grown in the high-tech greenhouse: Longa (**A1**–**A3**); Lydia (**B1**–**B3**); Tracey (**C1**–**C3**).

3.4. Yield

We found that Tracey shows the highest yield compared to Longa and Lydia throughout the entire lifecycle. For the whole season, the yield of 29.5, 22.9, and 19.7 (kg/m^2 $season^{-1}$) was recorded in Tracey, Longa, and Lydia (Figure 5), which can be estimated as yearly fruit production of 59.0, 45.8, and 39.4 kg/m^2, respectively. The total fruit yield for these cultivars was different because of the fruit number and the individual fruit weight (Table 1 and Figure 3).

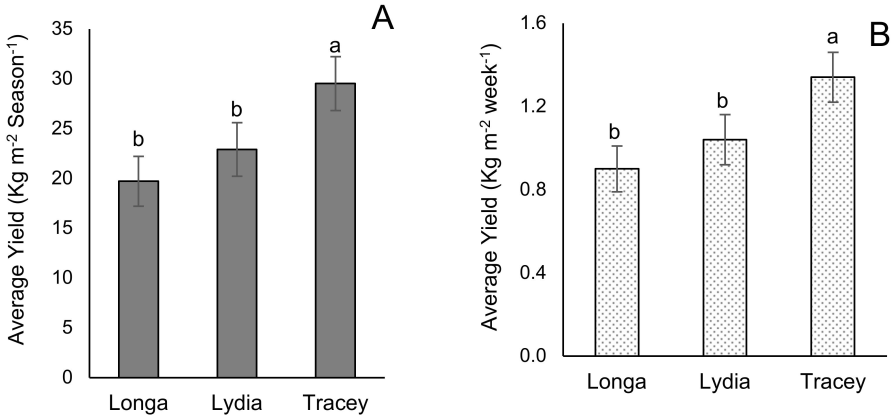

Figure 5. Eggplant fruit yield in the high−tech greenhouse. (**A**) Average fruit yield in kg per square meter over the whole growth season. (**B**) Average weekly fruit yield in kg per square meter. The whole growing season lasted for 6 months. Data are mean ± SE (n = 10). Different lowercase letters indicate statistical significance at $p < 0.05$.

3.5. Water Use Efficiency Only Correlates with Photosynthetic Parameters in Certain Weeks

Water use efficiency (WUE) is a crucial parameter for crops with high water demands, especially in regions where water is scarce. In this study, we calculated WUE based on two approaches. First, WUE was calculated based on the amount of fruit yield produced by each variety of eggplant for a unit of water used during growing season. Intrinsic water use efficiency (WUEi) was defined as the ratio of net photosynthesis rate over stomatal conductance.

WUE based on total fruit yield per water consumption was higher in Tracy as compared to other two cultivars (Figure 6A). As the equal amount of water has been used for each eggplant variety during the growing season, Tracy may be capable of assimilating more carbon for using each unit of water. Moreover, eggplant varieties showed significant differences in WUEi where he highest value of 41.97 was manifested in Lydia (Figure 6B) followed by longa (31.89) and Tracey (23.57) (Figure 6B).

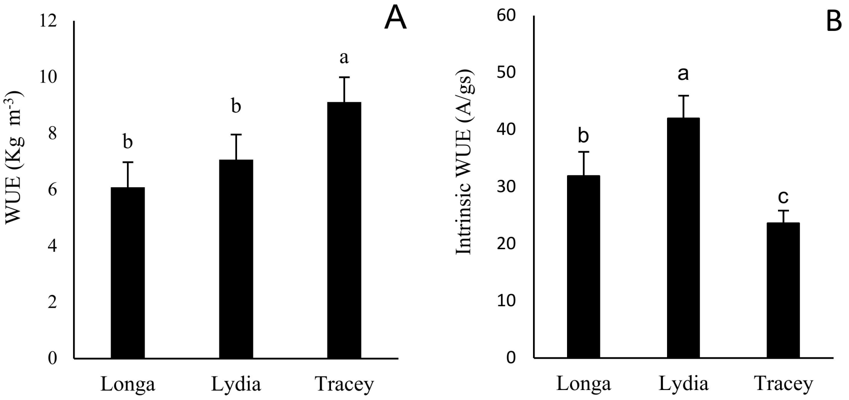

Figure 6. Water use efficiency (WUE) (**A**) and intrinsic WUE (iWUE) (**B**) in the high−tech greenhouse. Data are averaged over 6 weeks of measurements with 6 biological replicates for each cultivar per week. Different lowercase letters indicate statistical significance at $p < 0.05$.

We then conducted a correlation analysis between gas exchange parameters and WUE (Supplementary Figure S2). We found that average gas exchange parameters A, g_s, T_r, or C_i over the whole growth season do not correlate significantly with WUE. This was also the case for A, g_s, T_r, or C_i measurements in majority of the individual gas exchange measurements over the growth period. However, there were some significant correlations between WUE and A (Week 21), g_s (Week 13), T_r (Week 19), or C_i (Week 14), respectively (Supplementary Figure S2).

4. Discussion

4.1. Protected Cropping of Eggplants Cultivars Is Sustainable in High-Tech Greenhouse

Crop production in a greenhouse with optimal environmentally controlled conditions is growing throughout the world. The overall total greenhouse area has been estimated to be 405 thousand hectares around the world with different degrees of technology depending on the socio-economic environment and local weather conditions. Producing crops in a greenhouse plays a significant role as a technique for raising crops sustainably, improving water use and nutrient efficiency and controlling the safety and quality of the products. Greenhouse farming would be essential for food security in the region, where water scarcity and harsh environments are prevalent [53]. In conventional air-open conditions, a huge supply of inputs and resources such as fertilizers and, pesticides are required while crop productivity is always accompanied by substantial losses [54] compared to greenhouse crop production. Open field agriculture is the main user of fresh water worldwide [55], while aquaponic and hydroponic systems in greenhouse and indoor farming are possible solutions to reduce consumption of water [56].

Eggplant is normally cultivated in warm season in air-open farmland conditions with temperature below 10 °C and beyond 30 °C, which affect its productivity [57]. Eggplants are perennial and can produce fruits for couple of seasons under tropical and subtropical conditions, however in temperate climates eggplants are categorized as annual plants as they are not able to withstand cold winter weather [58]. In greenhouse conditions, growing calendars of eggplants could be extended. Hence, a year-round supply of eggplant production is feasible and increasingly profitable. The radiation requirement of eggplants is suggested to be about 6 h per day and the ambient humidity of 70–90% is desirable for eggplant [59].

Due to closed irrigation loop and reusing drained water, 20–30% reduction in irrigation water and fertilizers occurred in greenhouse farming compared to an irrigation system in farmlands [60]. In our recent study on two eggplant trials, Smart Glass (SG) reduced cooling energy use by 4.4% and fertigation demand by 29% in cooler months, and reduced cooling energy use by 4.4% and fertigation demand by 18% in warmer months. SG may be beneficial for reducing nutrient/water use alongside minor energy savings in commercial glasshouses for eggplants [61]. Here, we explored the agronomical traits, yield, photosynthesis, and water use efficiency of three commercial eggplant varieties in a high-tech greenhouse. We recommend the Tracy cultivar for high-tech greenhouses located in regions with climate conditions similar to Richmond, NSW, Australia, due to higher potential for yield production and greater water use efficiency. However, owing to the low intrinsic water use efficiency of this variety, further research work is required to maximize its photosynthetic capacity for greenhouse conditions.

4.2. Genotypic Difference of Growth and Gas Exchange of Eggplants

There is evidence of increased stem diameter in tomato and eggplant as temperature increases the interactive effect of temperature and light intensity on stem diameter [62,63]. The decrease of stem diameter under shade treatments [64,65] and the response of stem diameter to light intensity [66] could be attributed to genetic traits. It was shown that there is an increased plant height accompanied by the increased internode length of the plant and the number of nodes inside the greenhouse compared to the same genotypes in the field [52,67]. Moreover, the number of flowers in eggplants is increased significantly in the greenhouse under shade, which is attributed to the decrease in fruit set, ultimately encouraging the development of new flowers [64]. It was also demonstrated that the fruit length and fruit width of eggplants significantly decrease when plants are grown inside the greenhouse compared to those outside the glasshouse with a positive correlation between fruit length/width and the average fruit weight [64], which is in agreement with [20,48,68].

The genotypic difference was also identified in the leaf gas exchange parameters of eggplants in this study. Longa exhibited much better photosynthetic performances with higher values of A, g_s, and T_r than Tracey, whereas Tracey showed better gas exchange parameters than Lydia. Moreover, there were no significant differences in VPD for the eggplant cultivars grown in the glasshouse (Supplementary Figure S1). The ideal VPD for Solanaceous crops, like tomatoes grown in the greenhouse, is around 1.5 kPa. Our VPD result indicates that all the eggplant cultivars are grown in the glasshouse under the optimum conditions in terms of humidity and temperature. Earlier studies have reported that low VPD may interrupt stomatal function with no response to closing stimuli including darkness, ABA, and elevated Ca^{2+} levels [69,70]. Increasing VPD can maintain normal stomatal responses when plants are grown in the altered light conditions [35,71], whereas tomato plants in blue light showed significantly lower VPD in the CE compared to those plants grown in green and red-light [36]. An earlier study on eggplant has shown that elevated CO_2 in the greenhouse can massively promote C_i and A, whereas stomatal conductance decreased by 26% [72]. It was shown that the decline of photosynthesis rate because of the stomatal closure with the dramatic decrease in A, g_s, T_r, and C_i when plants were subject to combined stress than single stress alone including either severe drought in eggplant or to combined stress [50,73]. The reduction of A and C_i in eggplants have been reported when plants are subject to either severe drought or combined stress [50]. In the future, several eggplant genotypes should be tested in glasshouses over multiple seasons to identify the best-performing one that is suitable for specific regions.

With the growing concerns about the recent genetic variability of many crops including eggplants, the utilization and conservation of germplasm are promising for the enhancement of vegetable diversity in varietal development in future. However, the advent of next-generation sequencing (NGS) technologies and the continuous decrease in sequencing costs may increase our understanding of the molecular genetics of eggplant genotypes [10,12,13,74].

4.3. Yield of Eggplants Is a Combination of Genetic and Environmental Factors That May Not Be Directly Linked to Net Photosynthetic Rate

The yield response of eggplant varieties also showed that higher total production can be achieved from Tracy compared to two other cultivars. Uncoupling the total eggplant production and the rate of photosynthesis could primarily attribute differences in leaf size among the genotypes. Photosynthesizing leaves are the major source of fruit production. Larger leaves in Tracy (Figure 2) may suggest more sugars, amino acids, and organic acids are available for the formation of larger fruits and more fruits per plant. A study of 31 eggplant genotypes showed a highly positive correlation between leaf length and width and the average fruit weight [75]. Surprisingly, in many plant species, including soybean, sorghum, wheat and rice little correlation has been found between the rate of photosynthesis and total yield [76].

It was shown that the by 5% decrease in relative water content in plants leads to a reduced photosynthetic efficiency by 40–60%, resulting in a lower yield [77]. Eggplant requires a considerable amount of water for their growth and development, which makes them very sensitive to water deficit [78]. Leaf water deficit from the reduction of relative water content in the plant due to increasing heat, therefore, leads to the reduction of eggplant yield in the greenhouse [79]. Water use efficiency (WUE) defined as the ratio of fruit yield to the unit of water used showed higher values in Tracy and Lydia. In other words, more carbon has been assimilated in Tracy and Lydia for using the same amount of water in the greenhouse. Hence, Tracy and Lydia could be preferable options for fruit production in the greenhouses. Intrinsic water use efficiency (WUEi), defined as the ratio of photosynthesis rate to stomatal conductance may reflect more accurate plant responses to environmental factors, especially in the open field where plants are exposed to changing environments. In this situation, fast response of stomata is required for assimilating CO_2 efficiently and preventing water loss. Higher WUEi is associated with higher adaptability to changing environments [80]. In our study, WUEi showed a lower value in Tracy, the most productive variety in the greenhouse, suggesting that this variety is ideal for high-tech greenhouses, but may not have the same potential for fruit production in field conditions. Further research work is required to fully investigate and evaluate the optimum performance of this eggplant variety in field conditions. Significant differences between eggplant production under open-air conventional conditions and greenhouse conditions clearly suggest that the greenhouse could be an alternative option in the temperate region of Australia for sustainable production of eggplants.

In summary, due to unprecedented changes in the weather and climate patterns accompanied by the massive decline in cultivable land, it is of the utmost importance to address the issues of climate-resilient vegetable production in protected cropping to feed the growing population. The optimization scheme for the crops can be made in the computer-controlled modern greenhouses to maneuver scientific and quantitative management for sustainable horticultural production.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae9010019/s1, Figure S1: Vapor pressure deficit (VPD) for the eggplant cultivars grown in a high-tech glasshouse, Figure S2: Correlation analysis of overall water use efficiency and photosynthetic parameters in different weeks of gas exchange measurements.

Author Contributions: Z.-H.C., M.B., F.R., L.L. and W.L. conceived and conducted the research including the experimental design, crop maintenance and phenological measurement. M.B., M.-T.Y. and F.R. analyzed the data. M.B., M.-T.Y., T.A., S.H., D.T. and Z.-H.C. wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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