Article

Adding UVA and Far-Red Light to White LED Affects Growth, Morphology, and Phytochemicals of Indoor-Grown Microgreens

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Abstract: White light emitting diodes (LED) have commonly been used as a sole light source for the indoor production of microgreens. However, the response of microgreens to the inclusion of ultraviolet A (UVA) and/or far-red (FR) light to white LED light remains unknown. To investigate the effects of adding UVA and FR light to white LEDs on plant biomass, height, and the concentrations of phytochemicals, four species of microgreens including basil, cabbage, kale, and kohlrabi were grown under six light treatments. The first three treatments were white LED (control) and two UVA treatments (adding UVA to white LED for the whole growth period or for the last 5 days). Another three treatments consisted of adding FR to the first three treatments. The total photon flux density (TPFD) for all six light treatments was the same. The percentages of UVA and FR photons in the TPFD were 23% and 32%, respectively. Compared to white LEDs, adding UVA throughout the growth period did not affect plant height in all the species except for basil, where 9% reduction was observed regardless of the FR light. On the contrary, the addition of FR light increased plant heights by 9–18% for basil, cabbage, and kohlrabi, regardless of the UVA treatment, compared to white LED. Furthermore, regardless of UVA, adding FR to white LEDs reduced the plant biomass, total phenolic contents, and antioxidant concentrations for at least one species. There was no interaction between FR and UVA on all the above growth and quality traits for all the species. In summary, microgreens were more sensitive to the addition of FR light compared to UVA; however, the addition of FR to white LEDs may reduce yields and phytochemicals in some species.

Keywords: anthocyanins; antioxidants; plant height; indoor production; light spectra; total phenolics

1. Introduction

The interest in microgreens as a specialty vegetable has risen in recent years due to their short production cycle and high nutritional value [1]. Light emitting diode (LED) lights have been increasingly used as the sole light source for indoor crop production [2]. For indoor microgreens, the optimization of the light spectra quality is an essential lighting strategy for achieving a desirable morphology, improving yield, and increasing nutritional quality [3]. Tall microgreen plants are more easily harvested by hand or machine, making this a valuable morphological characteristic. Phytonutrients such as the antioxidants in microgreens are greatly influenced by light spectra [4–6]. Antioxidants are phytochemicals such as phenolic acids, flavonoids, anthocyanins, glucosinolates, and carotenoids. These substances can prevent or slow the damage to cells caused by free radicals, unstable molecules that the body produces as a reaction to environmental and other pressures. Due to the difficulties in measuring the individual antioxidant components of a complex mixture such as microgreens, the Trolox equivalent antioxidant capacity (TEAC) is used as a benchmark for the antioxidant capacity.
White (W)-LED light is commonly used for the indoor production of leafy vegetables including microgreens because of its broad-spectrum features that are beneficial to plant growth [7,8]. W-LEDs are primarily made from blue LED with the addition of a phosphor coat that can convert a portion of blue light into longer-wavelength lights [7]. However, the spectral quality of W-LEDs may not be optimal for all types of plant species and production purposes. For example, most W-LEDs lack shorter wavelengths such as ultraviolet A (UVA), despite the important role it plays in plant growth and metabolization [9].

The biosynthesis of secondary metabolites such as anthocyanins and phenolics can be induced by UVA, which increases the antioxidant levels in plants [9]. Supplemental lighting with 12–40 µmol m⁻² s⁻¹ of UVA throughout the production period has been reported to increase antioxidant levels for the indoor production of some microgreen species such as broccoli (Brassica oleracea), mustard (Brassica juncea L), and pak choi (Brassica rapa chinensis) [10–12]. However, in these studies, the background lighting mainly consisted of combinations of red and blue LEDs (RB-LED) rather than W-LEDs. Adding UVA at 10 µmol m⁻² s⁻¹ to W-LEDs throughout the production period increased the antioxidant concentrations for the indoor production of lettuce but reduced plant biomass [13]. In addition, adding UVA (5–7% of photosynthetic photon flux density) to blue-LEDs reduced plant height for some microgreen species [14]. Our recent study found that short-term preharvest lighting treatment with UVA/Blue LEDs (containing both UVA and blue wavelengths) increased the antioxidant concentrations of greenhouse-grown lettuce plants without compromising plant growth and biomass [15,16]. To the best of our knowledge, the effects of adding UVA to W-LEDs on the growth and quality of indoor microgreens, for either the whole production period or at the end, remain unknown.

Under indoor environment conditions, including far-red (FR) at 11–44% total photon flux density (TPFD) to RB-LED lighting has been found to increase plant biomass in seedlings such as basil, mature plants such as lettuce, and several ornamental crops [17–19]. However, there is limited available information analyzing the effects of adding FR light to W-LEDs on the morphology and phytochemicals of indoor microgreens. Ying et al. [20,21] reported that adding high-level FR light (32% TPFD) to RB-LED lighting or nighttime low-level supplemental FR light (20–40 µmol m⁻² s⁻¹) to RB-LED promoted microgreen stem elongation. For the indoor production of lettuce, the inclusion of FR light (17% TPFD) to W-LEDs did not affect the levels of most phytochemicals; however, when FR light was added together with UVA, the phytochemical content was reduced, suggesting an interaction between FR light and UVA towards phytochemicals [13].

Nevertheless, knowledge on the effects of UVA addition to W-LEDs during the entire production period or at its end, with or without adding FR light, on indoor microgreens is still lacking. Thus, the objective of this study was to investigate the effects of adding UVA to W-LED with or without FR light on the plant biomass, height, and phytochemicals of indoor microgreens.

2. Materials and Methods

2.1. Plant Materials and Culture

The experiments were performed in a growth chamber and repeated three times from 2020 to 2021. According to germination speed observed in our preliminary study, seeds of four microgreen species (basil, kale, cabbage, and kohlrabi) were sown sequentially on rockwool sheets (10 cm × 10 cm) placed in square containers (with a top dimension of 12 cm × 12 cm, a bottom of 10 cm × 10 cm, and a height of 6 cm) to synchronize the emergence. Specifically, basil seeds were sown on day 1, kale and cabbage seeds were sown on day 2, and kohlrabi was sown on day 3 in the same growth chamber. On day 5, light treatments were initiated when all species start to emerge. One rockwool sheet was fitted in one square container (same species in the same container and tray), and there were eight containers in one standard nursery tray with 72 cells (25 cm width × 51 cm length × 6.4 cm depth, Figures S1 and S2). Seeding rates were based on the recommendations of the seed company (Table 1). The seeded trays were covered with plastic domes to maintain high humidity until seedling emergence.
Germination was checked daily and misted as needed to prevent seeds from drying out. The growth chamber temperature for germination was maintained at 23 °C.

### Table 1. Plant materials used for the experiment and their management.

| Common Name | Scientific Name             | Variety Name   | Seeding Rate (g m⁻²) |
|-------------|----------------------------|----------------|----------------------|
| Basil       | Ocimum basilicum           | Dark Opal      | 63                   |
| Cabbage     | Brassica oleracea var. capitata | Red Cabbage    | 131                  |
| Kale        | Brassica rapa              | Red Russian    | 125                  |
| Kohlrabi    | Brassica oleracea          | Purple         | 119                  |

During the growth period, microgreens were sub-irrigated by placing the tray in another shallow tank filled with nutrient solution until saturated (it took about 30 to 60 s). For the first four days, a half-strength custom nutrient solution (EC = 1.0 dS m⁻¹, pH = 6.0) was used and then full-strength nutrient solution (EC = 1.5 dS m⁻¹, pH = 6.0) was followed for the rest of the experimental period (10 days). The mineral composition of the full-strength nutrient solution is presented in Table 2. The position and direction of each tray within each shelf were rotated every day to account for any environmental variation. During the whole plant growth period, the average air temperature and relative humidity inside growth room were 21.8 ± 0.2 °C and 63.6 ± 5.2%, respectively. The CO₂ was at ambient level, which was approximately 415 µmol mol⁻¹. When the first true leaves appeared for most plants (i.e., 10 days after start of light treatments), the microgreens were harvested.

### Table 2. Mineral composition of the full-strength, custom nutrient solution used for the experiments.

| Macroelement (mM) | Microelement (µM) |
|-------------------|-------------------|
| N                 | 7.3               |
| P                 | 0.75              |
| K                 | 3.6               |
| Ca                | 2.2               |
| Mg                | 0.96              |
| S                 | 0.96              |
| Fe                | 35.8              |
| B                 | 18.5              |
| Mn                | 4.0               |
| Zn                | 1.2               |
| Cu                | 0.73              |
| Mo                | 0.42              |

#### 2.2. Light Treatments

There were six light treatments: (1) W: white LED (control); (2) W + U-T—adding UVA to W throughout the growth period; (3) W + U-E—adding UVA to W for the last 5 days; and another three treatments performed by adding FR light to the above three treatments throughout the growth period, i.e., (4) W + FR; (5) W + U-T + FR, and (6) W + U-E + FR. The light treatments were created by using the tunable PHYTOFY® RL LED lighting system (OSRAM GmbH, Munich, Germany) through PHYTOFY® RL control software (OSRAM GmbH). For the treatments with UVA and FR light, UVA and FR light accounted for 23% and 32% of TPFD, respectively. The light spectra distributions of all light treatments are presented in Figure 1 and Table 3. The TPFD was 100 µmol m⁻² s⁻¹ for the first 5 days with a photoperiod of 12 h d⁻¹ and then increased to 190 µmol m⁻² s⁻¹ with a photoperiod of 18 h d⁻¹ for the rest of the time. The spectra and TPFD of each treatment were measured using a Blue Wave spectroradiometer (VIS-25; StellarNet, Tampa, FL, USA). The six light treatments were randomly allocated to different shelves of the grow racks in the growth chamber. Reflective insulation materials were used to separate different light treatments to avoid light pollution from neighboring light treatments.

#### 2.3. Measurements

At harvest time, for each replicate and each treatment, 5 of the 8 containers were sampled from each species to measure growth traits. For each of the sampled containers, plant height was measured at three locations and the average used as height data, and five plants were randomly selected for measurements of their hypocotyl lengths. After height was measured, all plants from each sampled container were cut at 1 cm above substrate and collected in a plate to measure the total fresh weight (FW) and were then bagged and put in drying oven at 70 °C until constant weight was reached, to determine dry weight.
Based on seeding area in each container, plant biomass unit area (kg m$^{-2}$ for FW and g m$^{-2}$ for DW) was calculated.

Table 3. Photon proportion (%) of different light wavelengths to total photon flux density.

| Treatment       | UVA (340–399 nm) | Blue (400–499 nm) | Green (500–599 nm) | Red (600–699 nm) | Far-Red (700–799 nm) | PAR (400–700 nm) |
|-----------------|------------------|-------------------|--------------------|-----------------|---------------------|------------------|
| W               | 0                | 8                 | 32                 | 52              | 8                   | 92               |
| W + U-T         | 21               | 7                 | 25                 | 41              | 6                   | 73               |
| W + U-E         | 24               | 7                 | 24                 | 39              | 6                   | 70               |
| W + FR          | 0                | 5                 | 23                 | 39              | 33                  | 67               |
| W + U-T + FR    | 23               | 5                 | 16                 | 26              | 30                  | 47               |
| W + U-E + FR    | 23               | 5                 | 16                 | 27              | 30                  | 48               |

Note: For the six light treatments, W = white LED; W + U-T = adding UVA to W for the whole growth period; W + U-E = adding UVA to W for the last 5 days, W + FR = adding FR to W throughout the growth period; W + U-T + FR = adding FR to W + U-T throughout the growth period; and W + U-E + FR = adding FR to W + U-E throughout the growth period. PAR = photosynthetically active radiation.

Figure 1. Light spectrum distribution for the six light treatments: (1) W (A); (2) W + U-T (B); (3) W + U-E (C); (4) W + FR (D); (5) W + U-T + FR (E); (6) W + U-E + FR (F). For the six light treatments, W = white LED; W + U-T = adding UVA to W throughout the growth period; W + U-E = adding UVA to W for the last 5 days. FR light was added to the other three treatments throughout the growth period. For the above light treatments with added UVA or FR light, proportions of UVA and FR light in total photon flux density were 23% and 32%, respectively, and the rest was white LED light.

For the remaining three containers in each treatment, 1 g of fresh tissue from each container was sampled and was immediately placed in liquid nitrogen and stored in $-80^\circ$C.
freezer. Subsequently, these samples were ground with a mortar and pestle using liquid nitrogen and extracted in methanol. The extracted samples were analyzed for anthocyanins, total phenolic compounds (TPC), and Trolox equivalent antioxidant capacity (TEAC) using the methods by Silva et al. [22], Ainsworth and Gillespie [23], and Arnal et al. [24], respectively. The procedures are briefly described as follows.

For anthocyanin, the absorbance of the extract was measured at 530 nm using a spectrophotometer (Genesys 10S ultraviolet/Vis, Thermo Fisher Scientific, Madison, WI, USA), and anthocyanin concentration was expressed as μg cyanidin-3-glucoside equivalent per g FW of microgreen leaves using a molar extinction coefficient of 29,600.

For TPC, a modified Folin–Ciocalteau reagent method was used to determine TPC of microgreen leaves. A mixture of 100 μL extraction sample, 200 μL 1/10 dilution Folin–Ciocalteau reagent, and 800 μL 7.5% Na₂CO₃ (Sodium Carbonate) was incubated at room temperature for two hours, and absorbance was measured at 725 nm using a microplate reader (EL800, BioTek, Winooski, VT, USA). Results were shown as μg of gallic acid equivalent per g FW of microgreen leaves.

For TEAC, a mixture of 100 μL extracted sample and 1 mL of ABTS+ solution was measured at 734 nm using a spectrophotometer (Genesys 10S ultraviolet/Vis, Thermo Fisher Scientific, Madison, WI, USA). Results were shown as μg of Trolox equivalent antioxidant capacity per g FW of microgreen leaves.

2.4. Experimental Design and Statistical Analysis

The study followed a randomized complete block design with three replications over time (each replication at different time is considered a block). For each species, a two-way analysis of variance (ANOVA) was used to determine the effects of UVA, FR light, and UVA × FR interaction on all growth and quality traits evaluated in this study. When the UVA × FR interaction was not significant, but the UVA (or FR light) treatment effect was significant, the UVA (or FR light) treatment effect was presented independently of FR light (or UVA) treatment. All data were analyzed using JMP 14 (SAS, Cary, NC, USA). Data were presented as means ± standard errors. For each trait, means were separated using Tukey’s honest significant difference (HSD) test for UVA treatments and using Student’s t-test for FR light treatments at α = 0.05.

3. Results

3.1. Plant Biomass

The UVA treatment did not affect the plant biomass for all the species, and neither did FR light treatment for all species except for Kohlrabi (Table 4). There was no UVA × FR interaction on plant biomass for all the species. Only the data for the significant treatment effects are presented in the following graphs. Adding FR light reduced fresh weight by 10% and dry weight by 20% for kohlrabi, respectively, compared to the no-FR light treatment (Figure 2A,B).

![Figure 2](image-url)

**Figure 2.** Responses of plant biomass to light treatments for the indoor-grown microgreens. For the light treatments, −FR and +FR indicates without or with FR for the whole growth period. FW = fresh weight; DW = dry weight. Different letters above bars indicate significant differences tested by t-test at p ≤ 0.05. Vertical bars indicate standard errors. (A) Plant FW for kohlrabi; (B) Plant DW for kohlrabi.
Table 4. Summary results (p value) of the two-way analysis of variance (ANOVA) for the effects of UVA, FR light, and UVA × FR interaction on plants’ fresh weight (FW) and dry weight (DW) of four microgreen species.

| Plant Trait | Treatment | Species       |
|-------------|-----------|---------------|
|             |           | Basil         |
|             |           | Cabbage       |
|             |           | Kale          |
|             |           | Kohlrabi      |
| Plant FW    | UVA       | 0.9911        |
|             | FR        | 0.1829        |
|             | UVA × FR  | 0.4884        |
|             |           | 0.3723        |
|             |           | 0.7935        |
|             |           | 0.5147        |
| Plant DW    | UVA       | 0.8765        |
|             | FR        | 0.1264        |
|             | UVA × FR  | 0.2766        |
|             |           | 0.2128        |
|             |           | 0.1224        |
|             |           | 0.3542        |

Note: The data inside the table are p values from the ANOVA analysis. Numbers highlighted in red represent a p value less than 0.05 and indicate a significant treatment effect.

3.2. Plant Size

The UVA treatment did not affect the plant heights for all species except for basil, and FR light treatment affected the plant heights for all species except for kale (Table 5; Supplemental Figure S1). The hypocotyl length was not affected by UVA or FR light treatments. There was no UVA × FR interaction with plant height and hypocotyl length for all species. The plant height decreased by 9% for basil when UVA was added to W-LED light for the whole period (Figure 3A). Compared with no FR light, the addition of FR light increased plant heights by 18%, 16%, and 9% for basil, cabbage, and kohlrabi, respectively (Figure 3B–D).

Figure 3. Responses of plant height to light treatments for the indoor-grown microgreens. For UVA treatments, W: white-LED; W + U-T: adding UVA to W for the whole growth period; and W + U-E: adding UVA to W only for the last 5 days. For far-red treatments, −FR or +FR indicates without or with FR light for the whole growth period. (A–C) Plant height for Basil, Cabbage, Kohlrabi, and Basil, respectively, in response to addition of FR light. (D) Basil height in response to the addition of UVA to W LED for the whole growth period or at the end. Different letters above bars indicate significant differences according to t-test or Tukey’s HSD at p ≤ 0.05. Vertical bars indicate standard errors.
Table 5. Summary results (p value) of the two-way analysis of variance (ANOVA) for the effects of UVA, FR light, and UVA × FR interaction on plant size traits of four microgreen species grown in indoor environment.

| Plant Trait          | Treatment | Species          | Basil | Cabbage | Kale   | Kohlrabi |
|----------------------|-----------|------------------|-------|---------|--------|----------|
| Plant height         | UVA       | 0.0407           | 0.3223| 0.3937  | 0.3005 |          |
|                      | FR        | 0.0011           | 0.0327| 0.4892  | 0.0104 |          |
|                      | UVA × FR  | 0.2725           | 0.6809| 0.9920  | 0.7790 |          |
| Hypocotyl length     | UVA       | 0.1521           | 0.0551| 0.3060  | 0.7812 |          |
|                      | FR        | 0.0775           | 0.1640| 0.5158  | 0.9428 |          |
|                      | UVA × FR  | 0.6213           | 0.1302| 0.6289  | 0.8476 |          |

Note: The data inside the table are p values from the ANOVA analysis. Numbers highlighted in red represent a p value less than 0.05 and indicate a significant treatment effect.

3.3. Nutritional Traits-Phytochemicals

The UVA treatment had no effect on the three phytochemicals in all species; however, FR light treatment affected the total phenolic content in basil and the antioxidant activity in cabbage (Table 6). There was no UVA × FR interaction with the three phytochemicals for all plant species. Compared with no FR light added, adding FR light reduced the total phenolic content by 12% in basil, and reduced antioxidant activity by 13% in cabbage (Figure 4A,B).

Table 6. Summary results (p value) of the two-way analysis of variance (ANOVA) for the effects of UVA, FR light, and UVA × FR interaction on plant phytochemical traits of four microgreen species grown under indoor environment.

| Plant Trait | Treatment | Species | Basil | Cabbage | Kale | Kohlrabi |
|-------------|-----------|---------|-------|---------|------|----------|
| Anthocyanin | UVA       | 0.9538  | 0.9910| 0.8517  | 0.9071|
|             | FR        | 0.8898  | 0.9911| 0.9053  | 0.6601|
|             | UVA × FR  | 0.9748  | 0.9640| 0.8985  | 0.9016|
| TPC         | UVA       | 0.8070  | 0.7614| 0.6635  | 0.4835|
|             | FR        | 0.0477  | 0.3173| 0.1870  | 0.7896|
|             | UVA × FR  | 0.2315  | 0.8158| 0.4043  | 0.3997|
| TEAC        | UVA       | 0.8419  | 0.2033| 0.5034  | 0.4993|
|             | FR        | 0.1760  | 0.0497| 0.0642  | 0.5622|
|             | UVA × FR  | 0.2354  | 0.1435| 0.7642  | 0.7163|

Note: The data inside the table are p values from the ANOVA analysis. Numbers highlighted in red represent a p value less than 0.05 and indicate a significant treatment effect. TPC = total phenolics content; TEAC = Trolox equivalent antioxidant capacity.

Figure 4. Responses of phytochemical concentrations to light treatments for indoor-grown microgreens. For far-red treatments, −FR or +FR indicates without or with FR light for the whole growth period. TPC = total phenolics content; TEAC = Trolox equivalent antioxidant capacity. (A) TPC of basil with or without the addition of FR light. (B) TEAC of cabbage with or without the addition of FR light. Different letters above bars indicate significant differences tested by t-test at p ≤ 0.05. Vertical bars indicate standard errors.
4. Discussion

4.1. Adding UVA to White LED Has Limited Effects on Microgreens

In the UVA treatments, the photosynthetic photon flux density was reduced to achieve a similar TPFD to that of white-LEDs. However, the UVA treatments did not reduce plant biomass in the present study. It is possible that photosynthesis played a minor role in the microgreens’ plant biomass accumulation since the microgreens’ plant biomass accumulation mainly of the cotyledon emergence stage when seed storage contributes more to plant biomass [1,25]. Nevertheless, our result suggests that adding UVA to white LED would likely not compromise microgreen yield.

Differing from plant biomass, adding UVA to white-LEDs reduced the plant height for basil, but not for the other species. Possibly, the elongation growth response to UVA treatment was more sensitive for basil than other species. It has been confirmed that UVA can activate cryptochrome, a blue light receptor, to mediate the inhibition of plant elongation, but its inhibitory effect varies with the plant genotype [9]. In addition, despite sharing a common photoreceptor with blue light, UVA appears to have a greater inhibitory effect on plant elongation, since adding a low level of UVA to blue light can inhibit plant elongation to some degree [14].

It is worth noting that all the plant traits evaluated in this study under the two UVA treatments showed no differences, indicating that adding UVA (replacing PPFD with UVA) for several days or for the whole production period has similar effects on microgreens. In addition, short-term supplemental UVA at the end of the production period did not reduce plant height for all species in the present study and thus would have few negative effects on microgreen harvesting, since taller plants are easier to harvest, especially by machines [1,26]. The portion of UVA used in this study was 23% of TPFD, which is extremely high. Therefore, we can conclude that adding UVA for the whole production period is not necessary in indoor microgreen production since it would potentially increase the cost for lighting fixtures.

4.2. Adding FR Light to White LED Affects Microgreen Biomass, Height, and Phytochemicals

In the present study, adding FR light to white LED increased the plant heights for most microgreen species. Similar results were observed by Ying et al. [20] in indoor microgreens when high-level FR light was added to RB-LED lighting. The increased FR light level might have reduced phytochrome activity and triggered shade-avoidance responses in these plants, which would then grow taller to compete for the light source through elongated stems and petioles [27]. This could also explain why longer hypocotyls were not observed in the plant species, while the plant height increased after adding FR light to white LED. Possibly, the taller plants in these species resulted from longer petioles, which were not measured in this study. Nevertheless, the increased plant height resulting from the inclusion of FR light would benefit the machine-harvesting of microgreens.

Previous studies have indicated that adding FR light to RB-LED lighting can increase plant biomass, especially in mature plants [17–19]. The FR light-increased plant biomass could result from larger leaves to increase the light capture efficiency [18], as well as an improved photosynthetic efficiency due to the Emerson effect [28]. In the present study, adding FR light to white LED did not increase plant biomass for all species; on the contrary, it reduced plant biomass in kohlrabi. As mentioned before, unlike mature plants, microgreen biomass accumulation is less affected by photosynthesis than photomorphogenesis [26]. Due to the shade-avoidance response triggered by the inclusion of FR light, the kohlrabi microgreens might have reduced their cotyledon sizes, which is a common response to shade signals in microgreens [25]. The smaller cotyledons may contribute to a reduced plant biomass in kohlrabi by adding FR light to white-LED, since the cotyledons’ biomass can affect the total biomass of microgreens to a large degree for some small-seed species [29].

Apart from a decreased plant biomass, adding FR light to white-LED also reduced antioxidant levels for cabbage and basil microgreens. A similar response in the antioxidant level was reported in thornberries (*Rubus hongnoensis* Nakai) after adding FR light
to white-LEDs [30]. Recent studies indicate that activated phytochrome can relieve stress by increasing antioxidant levels [31,32]. Adding FR light to white-LED might have deactivated phytochrome and thus reduced stress tolerance ability associated with decreased antioxidant levels. The speculation was also supported by the enhanced antioxidant level by red light, a phytochrome activator, in thornberry plants [30].

4.3. Interactive Effect of UV A and FR Light on Microgreen Phytochemicals Is Not Significant

As one of the important signal regulatory factors, light, including both UVA and FR light, can regulate anthocyanin biosynthesis [33]. There is a complicated positive and negative regulation pathway in light-dependent anthocyanin biosynthesis [33]. Generally, anthocyanin biosynthesis is promoted by UVA, but inhibited by FR light [13,34]. In the present study, the plants showed a slightly different trend in the anthocyanin concentration response to UVA (or FR light) treatment with and without adding FR light (or UVA) with no statistical significance (Supplemental Figure S3). However, neither UVA nor FR light showed any statistically significant effect on the anthocyanin concentration regardless of the species. Possibly, the intensities of both lights were not strong enough to provoke a difference due to the low sensitivity of the plant species. Consequently, the interaction between UVA and FR light on anthocyanin was not significant in the current study.

Similarly, for the total phenolic content and antioxidant activity, the interaction between UVA and FR light was not significant in the present study. Huché-Thélier et al. [9] indicated that UVA can promote the biosynthesis of phenolics and thus increase antioxidant activity, but its effect varies with the light intensity and plant genotypes. In contrast, He et al. [13] reported that FR light treatment reduced phenolic content and antioxidant activity despite a varying sensitivity among plant species. In the present study, for basil and cabbage, plants responded to FR light rather than UVA in terms of these two traits, as mentioned before. Possibly, unlike FR light, the UVA intensity was not strong enough to affect the total phenolic content and antioxidant activity in the two species due to a relatively lower percentage of UVA than FR light in the current light treatment. In this case, the interaction effects of UVA and FR light on the two traits were covered by the strong effect of FR light in the two species.

5. Conclusions

For indoor microgreens grown under LED lighting, the addition of UVA to white LED light throughout the growth period did not affect plant height except for basil. On the contrary, compared with no FR light, adding FR light throughout the growth period increased plant heights for basil, cabbage, and kohlrabi. Additionally, the inclusion of FR light reduced plant biomass and concentrations of some phytochemicals such as total phenolics and antioxidants in some species. FR light and UVA interactively affected the anthocyanin concentrations in basil, kale, and kohlrabi. Therefore, FR light has greater effects on microgreens than UVA under background white LED lighting, but it may result in some negative effects on the yield and phytochemicals in some species. Considering the small effect and added costs, we conclude that adding UVA and/or FR light is not necessary for indoor microgreen production.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14148552/s1, Figure S1: Side view of the four microgreen species grown indoor under six light treatments. For UVA treatments, W: white-LED; W + U-T: adding UVA to W throughout the whole growth period; W + U-E: adding UVA to W only at the end of production for the last 5 days. For far-red treatments, −FR or +FR indicates without or with FR light. Figure S2: Microgreens (two culture shelves out of 4) right before harvest. From left to right (upper): Kale, Cabbage, Kohlrabi, and basil. Lower: Kohlrabi, cabbage, kale, and basil. Figure S3: Responses of anthocyanin concentrations to UVA and FR light treatments for indoor-grown microgreens. For UVA treatments, W: white-LED; W + U-T: adding UVA to W for the whole growth period; W + U-E: adding UVA to W only for the last 5 days. For far-red treatments, −FR or +FR indicates without or with FR light.
light for the whole growth period. For the above light treatments with UVA or FR light, UVA and FR light photons accounted for 23% and 32% of total photon flux density, respectively. Vertical bars indicate standard errors.

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