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Effects of Light Intensity and Photoperiod on the Fresh Locking and Quality of Hydroponic Arugula in the Harvesting Period

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Abstract: At present, the research on the light environment of arugula mostly stays in its emergence and growth stage and there is a lack of research on the fresh-keeping quality of hydroponic arugula under light treatment during the harvest period. This study takes hydroponic arugula as the research object and explores the influence of light intensity and photoperiod on the fresh-keeping quality of arugula during the harvest period. With light intensity and photoperiod as experimental factors; and fresh weight, water content, chlorophyll, soluble sugar, nitrate, and cellulose content of arugula during harvest as experimental indicators, combined with sensory evaluation methods, a two-factor completely random experiment was completed. The experimental results show that medium and high intensity light treatment effectively enhances the fresh-keeping ability of arugula during the harvest period, which is conducive to reducing the decline in leaf fresh weight and water content caused by aging of arugula and delaying the decline in quality of arugula; 3 h and 6 h photoperiods can significantly delay the decomposition of chlorophyll in hydroponic arugula during harvest, reduce the loss of soluble sugar, inhibit excessive accumulation of nitrate, and slow down the production of leaf cellulose; and LED red-blue composite light irradiation is conducive to maintaining the sensory quality of hydroponic arugula during harvest. Among them, the sensory quality of cabbage leaves under 200 μmol·m^{-2}·s^{-1} light intensity and 6 h photoperiod treatment is the best. This study provides an important theoretical basis for improving the quality and yield of hydroponic arugula and provides a strong basis for setting intelligent environmental lighting in artificial light-type plant factories.

Keywords: arugula; light intensity; photoperiod; fresh locking; harvesting period

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1. Introduction

Light conditions can regulate the morphological formation, metabolism, and gene expression of arugula [1]. The entire life cycle of arugula is accompanied by constantly changing light environments. They not only adjust to changes in the light environment but are also easily affected by the surrounding environment. Light intensity and photoperiod are important factors affecting plant photosynthesis and dry matter accumulation. The daily light integral (DLI) determined by light intensity and photoperiod is also closely related to the electrical energy input of LED light sources [2]. Therefore, it is necessary to determine the optimal combination of light intensity and photoperiod to efficiently produce high-quality hydroponic arugula in plant factories.

Light intensity is an important factor affecting the growth of arugula. Appropriate light intensity can effectively promote plant growth, accelerate plant growth rate, increase dry matter accumulation, etc. [3]. Gao et al. [4] explored the effects of low light intensity on the growth and chemical composition of broccoli microgreens and determined the optimal light intensity for promoting the growth of broccoli microgreens. Wang et al. [5] compared the effects of different LED red–blue combination light intensities on the growth of hydroponic lettuce and found that under the light treatment of 200 μmol·m^{-2}·s^{-1} during the seedling stage, the fresh weight of lettuce above ground was significantly higher than that under the light intensity treatment of 100 μmol·m^{-2}·s^{-1}, while during the growth period, the yield and quality of lettuce under the light intensity treatment of 350 μmol·m^{-2}·s^{-1} were significantly better than those under the light intensity treatment of 200 μmol·m^{-2}·s^{-1}. Liu et al. [6] explored the influence of light intensity on photosynthesis and chlorophyll fluorescence characteristics of hydroponic lettuce and showed that appropriately increasing light intensity can effectively improve the photochemical reaction of hydroponic lettuce, but it will reduce the synthesis of chlorophyll, not only increasing its heat consumption but also reducing the efficiency of light energy utilization.

The photoperiod directly affects the time of the plant's photochemical reaction. If the light exposure time is too long, the plant leaves will show dehydration, yellowing, and other phenomena, and it will also cause energy waste [7]. Liu et al. [8] explored the effects of different photoperiods on the growth, nutritional quality, and antioxidant characteristics of two cruciferous micro-vegetables, providing strong support for the high-quality microgreen production in artificial lighting plant factories. Huang et al. [9] compared the effects of different LED red–blue combination photoperiod changes on spinach and found that under light treatment with a duration of more than 12 h·d^{-1}, the soluble sugar and soluble protein content in spinach were significantly higher than those in other test groups.

With the development of light-emitting diode (LED) technology, researchers have conducted in-depth studies on the application of LEDs in plant factories. The use of different LED light modes can effectively improve the production efficiency of vegetables in plant factories [10]. The light environment not only affects the growth of arugula but also affects its senescence. Because plant cells have an endogenous circadian clock, different light rhythms can affect their growth and metabolism [11]. The light intensity can affect the release of chlorophyll enzymes and chlorophyll degradation in plant leaves, as well as the production and metabolism of soluble sugars [12]. To delay the senescence of arugula in HP and obtain arugula with a longer HP and better quality, it is necessary to optimize the lighting scheme for arugula in HP along with other environmental parameters.

At present, most of the light treatments in China and abroad are applied to the preservation of fruits and vegetables after harvest. Light environment research on arugula mostly focuses on the seedling emergence and growth stages, and the introduction of light environments to regulate the growth of arugula in HP is rare. Lester, G.E. et al. [13] found that continuous light irradiation can significantly increase the content of biologically active substances in hydroponic spinach. Noichinda, S. et al. [14] found that different lighting modes could reduce the loss rate of soluble sugars in hydroponic Chinese kale.

Under non-low-temperature conditions, proper light environment regulation can also delay the senescence of fruits and vegetables in HP, thereby appropriately prolonging HP of fruits and vegetables. Zhou, et al. [15] found that short-term continuous light irradiation of ripe lettuce in HP significantly reduced the nitrate content in the ripe lettuce and reduced the loss rate of soluble sugar.

A previous screening of monochromatic light irradiation showed that both red and blue monochromatic lights could effectively improve the fresh locking effect of arugula and prolong its HP. Therefore, this paper used a LED red and blue (7:1) composite light source to treat ripe arugula in HP. By measuring the changes in quality and color of arugula in HP, we explored the effects of red and blue LED composite light treatments on the fresh locking and quality of arugula in HP. The aim of our work is to improve the harvest quality of arugula and prolong the HP of arugula, thus providing a theoretical basis for the application of LED light sources to regulate the quality of fruits and vegetables in HP.

2. Materials and Methods

2.1. Experimental Site

Taking arugula as the research object, we used intelligent vegetable cultivation boxes and LED light sources for hydroponic cultivation of large-leaf arugula in Northeast China.

In order to explore the influence of light intensity and photoperiod on the growth quality of hydroponic arugula and the fresh-keeping quality during the harvest period, the experiment was conducted indoors in the comprehensive experimental building of the Garden Campus of North China University of Water Resources and Electric Power (113°68′ E, 34°81′ N) from 2021 to 2022, breaking through regional restrictions and providing certain reference values for the intelligent plant factory production of hydroponic arugula.

2.2. Hydroponics Setup and Growing Conditions

A single culture rack contained 4 cultivation beds and a solution tank, and each cultivation bed (1200 mm × 900 mm × 70 mm) had 20 planting holes (Φ = 20 mm). Arugula seedlings were transplanted to the cultivation frame 7 days after germination, with a planting density of 22 plants per square meter.

Under the same growth environment, arugula entered HP at 30 days after seedling emergence. To ensure the accuracy of the experimental results, plants with similar sizes, colors, and weights were selected as the experimental materials.

During the experiment, the temperature of the hydroponic rack was kept at (25 ± 1) °C, the relative humidity of the air was kept at 65–75%, and the CO_2 concentration was kept at (800 ± 50) $\mu mol \cdot mol^{-1}$.

2.3. Experimental Design and Treatments

The test light sources were all tubular red and blue LEDs (7:1, RB-LED7/1^{-1}6 W, Tianjin Guangzhiyun Lighting Appliance Co., Ltd., Tianjin, China), which were installed 35 cm above the cultivation bed. This LED tube covered the full red–blue wavelengths [16] the wavelengths of red light were 610–630 nm and 650–670 nm, and the wavelengths of blue light were 410–430 nm and 430–450 nm.

In the experiment, the hydroponic arugula plants in HP were divided into 13 groups. The control group was always kept in darkness, while the other test groups were treated with intermittent light.

The experiment began on 20 December 2021, and the transplanting of arugula seedlings was completed 10 days later. All indicator measurements were completed on 20 February 2023.

As shown in Table 1, the three light intensities, S1, S2, and S3, were 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$, and 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$, respectively; and the four photoperiods, T1, T2, T3, and T4, were 3 h, 6 h, 12 h, and 24 h. A completely randomized two-way factorial design was used to obtain a total of 12 treatment combinations. Taking the fresh weight, water content, chlorophyll, soluble sugar, nitrate, and cellulose content of arugula during harvest as experimental indicators, combined with sensory evaluation methods, a two-factor completely random experiment was completed to explore the influence of different light intensities and photoperiods on the growth characteristics and nutritional quality of arugula during the harvest period.

During the experiment, each group was subjected to repeated light treatment every day. The fresh weight, water content, chlorophyll content, soluble sugar content, nitrate content, and cellulose content of arugula were measured every 2 days, and the sensory quality of the samples was evaluated every 5 days.

2.4. Nutrient Solution Preparation and Management

The nutrient solution used in the experiment was renewed every 4 days. The nutrient solution was provided by Aoma Agricultural Technology Co., Ltd., (Zhongshan City, Guangdong Province, China) and the Hoagland formula was used [17]. The composition of the nutrient solution is shown in Table 2. The pH of the nutrient solution was always kept at 6.2–6.5, and the electrical conductivity (EC) was kept at 800–1000 $\mu S \cdot cm^{-1}$.

Table 1. Illumination treatments obtained from the combination of three light intensities (S) and four photoperiods (T).

Group	Light Intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	Photoperiod ($h \cdot d^{-1}$)	Daily Light Integral ($mol \cdot m^{-2} \cdot d^{-1}$)	Total Energy Consumption of LEDs for 20 Days ($kW \cdot h$)
S1-T1	100	3	1.08	2.24
S1-T2	100	6	2.16	4.48
S1-T3	100	12	4.32	8.96
S1-T4	100	24	8.64	17.92
S2-T1	200	3	2.16	4.48
S2-T2	200	6	4.32	8.96
S2-T3	200	12	8.64	17.92
S2-T4	200	24	17.28	35.84
S3-T1	350	3	3.78	7.84
S3-T2	350	6	7.56	15.68
S3-T3	350	12	15.12	31.36
S3-T4	350	24	30.34	62.72

Note: Daily light integral ($mol \cdot m^{-2} \cdot d^{-1}$) = light intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$) × daily light duration ($h \cdot d^{-1}$) × 3600 ($s \cdot h^{-1}$) × 10^{-6}.

Table 2. Nutrient solution composition.

Component	Concentration/$mg \cdot L^{-1}$
$MgSO_4 \cdot 7H_2O$	493
$NH_4H_2PO_4$	115
$[\text{-}CH_2N(CH_2COONa)CH_2COO]_2Fe$	35
H_3BO_3	2.86
$ZnSO_4 \cdot 7H_2O$	0.22
$MnSO_4 \cdot 4H_2O$	2.13
$CuSO_4 \cdot 5H_2O$	0.08
$(NH_4)2MoO_4 \cdot 4H_2O$	0.02
$Ca(NO_3)_2 \cdot 4H_2O$	945
KNO_3	607

2.5. Plant Materials

In this study, the emerging commercialized arugula, Eruca sativa Mill., was used as the test material. To ensure the accuracy of the experimental results and minimize error, the seeds of same batch of arugula were soaked for 12 h in a 40 °C water bath and germinated at a constant temperature of 30 °C in a thermostat [17]. When the seedlings grew to have two true leaves, the roots were rinsed three times with ionized water and then transplanted into a vertical rack for hydroponic culture (Figure 1).

2.6. Measurement of Experimental Indicators

2.6.1. Measurement of Sample Fresh Weight and Water Content

After arugula entered HP at 30 d after seedling emergence, the samples were harvested every 2 days, and the fresh weight of the edible part was measured using an electronic balance with an accuracy of 0.001 g (ZG-TP203, Hangzhou Songjing Co., Ltd., Hangzhou, China).

The leaves of hydroponic arugula were dried in an oven at 105 °C for 3 h and then dried at 75 °C until the weight was constant. From this the dry weight of the leaves was determined, and the water content of the leaves of the hydroponic arugula was calculated.

2.6.2. Chlorophyll Fluorescence and Content

Chlorophyll fluorescence was measured using a multifunctional plant efficiency analyzer (M-PEA^{-2}). The chlorophyll content was detected by spectrophotometry [18]. The third unfolded leaf in the central leaves of the plant was selected, the chlorophyll was extracted from the leaves using 80% acetone, the optical density of the solution was measured in a spectrophotometer (UV-3150) at wavelengths of 645 nm and 663 nm, and the chlorophyll content was calculated according to the formula of DANIEL et al. [15].

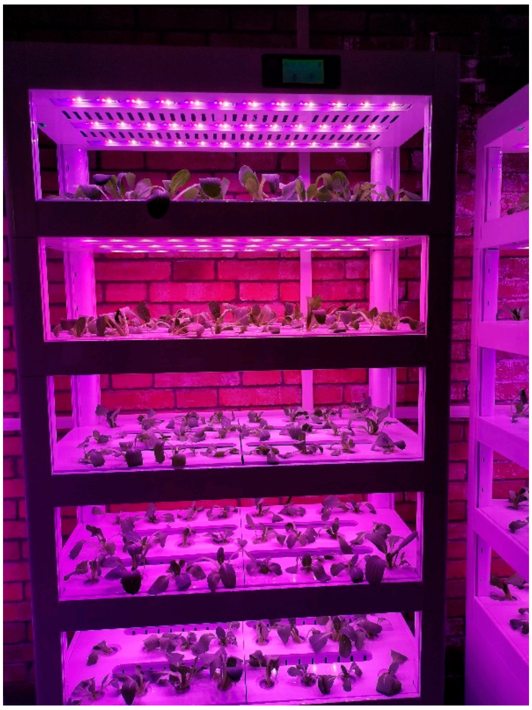

Figure 1. Intelligent culture rack for hydroponic arugula.

2.6.3. Soluble Sugar Content

The soluble sugar content was measured using the phenol–sulfuric acid method [19]. Fresh sample leaves were taken, the surface dust was cleaned, and sample leaves were cut and mixed. A total of 0.20 g of the sample was weighed and placed in a graduated test tube. After adding 10 mL of distilled water, the lid was sealed with a plastic film, and extraction and filtration were performed in boiling water. Then, 0.5 mL of the sample solution was dropped into the test tube, followed by the addition of phenol and concentrated sulfuric acid solution. After color development, the optical density of the solution was measured. According to the standard curve, the soluble sugar content of the sample was calculated.

2.6.4. Nitrate Content

The nitrate content was determined using the salicylic acid–concentrated sulfuric acid method [20]. A 3 g sample of fresh arugula was taken, and 1 mL of 4% zinc acetate solution was added to facilitate grinding. The ground arugula solution was placed in a centrifuge tube and heated in a 70 °C water bath for 30 min. The mixture was centrifuged after cooling to room temperature. Then, 0.4 mL of the supernatant was placed in a 10 mL colorimetric tube, and 5% salicylic acid-concentrated sulfuric acid solution was added. After color development, the volume was adjusted to 10 mL with 8% sodium hydroxide solution. After cooling, the optical density of the solution was measured at a wavelength of 410 nm to obtain the nitrate content.

2.6.5. Cellulose Content

The cellulose content was determined using the concentrated sulfuric acid hydrolysis method [21]. Fresh and clean leaves of arugula were taken, cut into pieces, and mixed well, and 0.20 g of the sample was weighed and placed in a graduated test tube. After adding 10 mL of distilled water, the lid was sealed with a plastic film, and extraction and filtration were performed in boiling water. Then, 0.5 mL of the sample solution was dropped into a test tube, and 5 mL of a mixture of acetic acid and nitric acid was added. The mixture was heated in a water bath for 25 min, and the precipitate was collected after centrifugation. After the precipitate was washed with distilled water, 10 mL each of 10% sulfuric acid and 0.01 mol/L potassium dichromate solution was added dropwise, and the solution was heated in a water bath for 10 min and cooled down. The cellulose content was determined using the titration method using sodium thiosulfate [22].

2.6.6. Sensory Quality Evaluation

Based on the method of Sun et al. [23], the sensory quality evaluation criteria of hydroponic arugula are shown in Table 3. The evaluation indicators included color, smell, leaf state, and decay condition. The maximum score for each indicator was 9 points, and the minimum score was 1 point. The total score was calculated using the weighting method. The sensory quality of the hydroponic arugula was evaluated based on the total score, and the average value was taken. When the sensory quality score was lower than 5.0, the valid HP was deemed to be over.

Table 3. Evaluation criteria for the sensory quality of hydroponic arugula in HP.

Scoring	Color	Smell	Leaf State	Decay Condition
9	The entire leaf is bright green	Strong clear fragrance	Stiff leaves	No decay
7	Area of leaf turning yellow $\leq 1/10$	Mild clear fragrance	The leaves are stiff, with slightly soft edges.	Decay rate $\leq 1/20$
5	$1/10 <$ Area of leaf turning yellow $\leq 3/10$	No clear fragrance	Area of leaf wilting $< 1/2$	$1/20 <$ Decay rate $\leq 1/10$
3	$3/10 <$ Area of leaf turning yellow $\leq 1/2$	Mild odor	Area of leaf wilting $> 1/2$	$1/10 <$ Decay rate $\leq 1/5$
1	Area of leaf turning yellow $> 1/2$	Obvious rancid odor	All leaves are wilting	Decay rate $> 1/5$

2.7. Statistical Analysis

The experiment was repeated three times independently. Microsoft Excel 2018 and Origin Pro 9.0 software were used for data processing and graphing. Analysis of variance was performed with SPSS 21.0 software (IBM, Inc., Chicago, IL, USA). When $p < 0.05$, a relationship was considered statistically significant.

3. Results and Discussion

3.1. Effects of Light Intensity and Photoperiod on Fresh Weight and Water Content

After entering HP, the average fresh weight of arugula under dark conditions was 21.7 g, and the water content was 94.35%. After light treatment, the fresh weight and water content of each arugula group increased to different degrees. When the light intensity was 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and the photoperiod was 12 h, the average fresh weight of arugula was 30.06 g, which was 38.53% higher than that of arugula in the completely dark (control) group. Figure 2 shows that as light intensity increased, the fresh weight of leaves increased significantly; as the photoperiod lengthened, the fresh weight of leaves showed a trend of first increasing and then decreasing; when the photoperiod was 6 h or 12 h, the promotion of fresh weight of leaves was more significant; when the photoperiod was 24 h, the fresh weight of leaves decreased significantly. This may be because under the influence of LED light, the endogenous circadian rhythm of arugula plants is often shorter than 24 h [24], and the relatively short light rhythm can appropriately increase the growth rate of arugula.

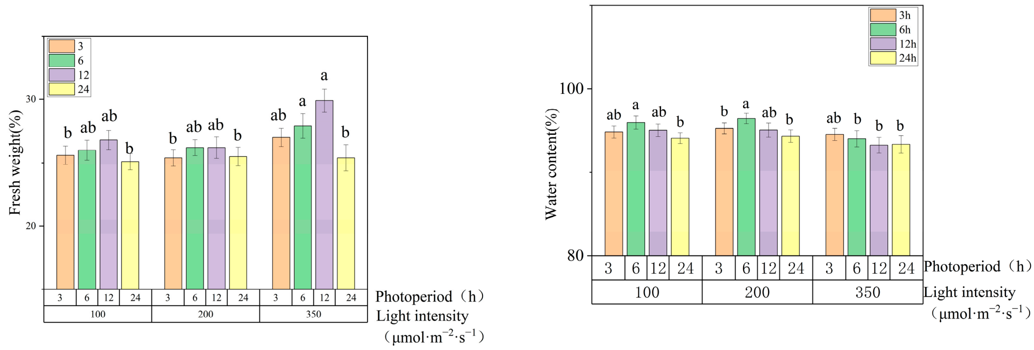

Figure 2. Effects of light intensity and photoperiod on the fresh weight and water content of arugula in HP(Note: a, b, ab represent the significance levels of different light treatment experimental conditions on the experimental indicators, in descending order of significance from high to low: a > ab > b).

The water content of arugula leaves also showed a trend of first increasing and then decreasing with increasing light intensity and photoperiod. This may be due to the long-term light treatment or dark treatment, which can affect the water-use efficiency of arugula plants [25]. Excessively high light intensity or long photoperiod can lead to a lower water content of the leaves. Under the condition of light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h, the water content of the arugula reached the highest level of 96.42.%, which was 2.19% higher than that of the control group.

3.2. Effects of Light Intensity and Photoperiod on the Nutritional Quality of Arugula

3.2.1. Effect on Chlorophyll

According to the variation curve of the chlorophyll content in arugula in HP (Figure 3), the chlorophyll content in the hydroponic arugula in HP showed a decreasing trend over time, but under a light intensity of 200 μmol·m^{-2}·s^{-1} and photoperiod of 6 h, the chlorophyll content of arugula in HP was significantly higher than that of the control group ($p < 0.05$). The chlorophyll loss rates of arugula at the 20th day after entering HP were 24% and 57% under a light intensity of 200 μmol·m^{-2}·s^{-1} and photoperiod of 6 h and in darkness, respectively. The chlorophyll content of arugula under a light intensity of 200 μmol·m^{-2}·s^{-1} was significantly higher than that of other groups, since a certain intensity of continuous light promotes the photosynthesis of arugula leaves in HP [26], and photosynthetic substances accumulate, thereby reducing the loss of chlorophyll [27]. Treatment with a certain light intensity and photoperiod can significantly delay the decomposition of chlorophyll in hydroponic arugula in HP.

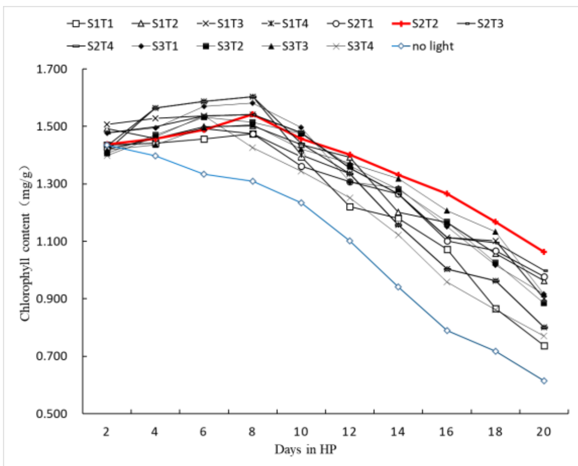

Figure 3. Curves of chlorophyll content in arugula in HP.

3.2.2. Effect on Soluble Sugar

The main function of soluble sugars in plant leaves is to ensure the smooth progress of leaf cell metabolism. Soluble sugar also acts as a signal to regulate leaf senescence in a light environment and is an important regulatory factor for plant growth, development, and gene expression [28].

Figure 4 shows that the soluble sugar content in the arugula showed a decreasing trend as HP went on, but the soluble sugar content under a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h was significantly higher than that of all other groups ($p < 0.05$).

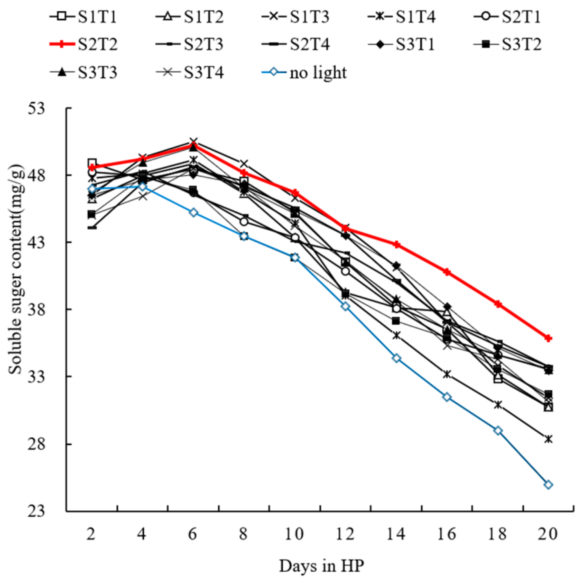

Figure 4. Curves of soluble sugar content in arugula in HP.

Although the soluble sugar content changed slightly within days 2–10 of HP in the control group and other light treatment groups, it showed a significant decreasing trend within days 12–18 of HP, which may have been due to the significantly reduced photosynthetic efficiency of the arugula leaves after 12 days of storage, which can hinder the carbon assimilation of the leaves [29], resulting in a rapid decrease in soluble sugar content. In contrast, under a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h, the soluble sugar content of arugula leaves showed the smallest decrease rate through day 20 of HP, and the slope of the trend was significantly lower than that of other groups.

Within the first 20 days of HP, the soluble sugar loss rates of arugula were 26% and 49% under a light intensity of 200 μmol·m^{-2}·s^{-1} and photoperiod of 6 h and in darkness, respectively, which further validates the effect of light environment on the soluble sugar content of arugula leaves in HP. Therefore, a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h have a significant effect on slowing down leaf senescence, which is conducive to maintaining the nutritive components of arugula.

3.2.3. Effect on Nitrates

Nitrate content is a key factor for evaluating the quality of leafy vegetables. The lower the nitrate content, the better the quality of arugula [30]. Figure 5 shows that there was an overall trend of increasing nitrate content in leaves of arugula within HP under different treatments, and the differences between different treatment groups were significant ($p < 0.05$).

In the whole HP, the nitrate content under the complete darkness was significantly higher than that under different light treatments ($p < 0.05$), and the nitrate growth rate was the smallest under a light intensity of 200 μmol·m^{-2}·s^{-1} and photoperiod of 12 h. In the first 10 days of HP, the nitrate content was the lowest under a light intensity of 350 μmol·m^{-2}·s^{-1} and a photoperiod of 12 h. However, starting from the 10th day, the nitrate content increased significantly in each group, which may have been due to the excessive accumulation of nitrate in the leaves. When arugula is under low light intensity or complete darkness, the photosynthetic intensity is low, so the leaves are unable to provide enough energy for nitrate reduction, resulting in excessive accumulation of nitrate in the leaves [31].

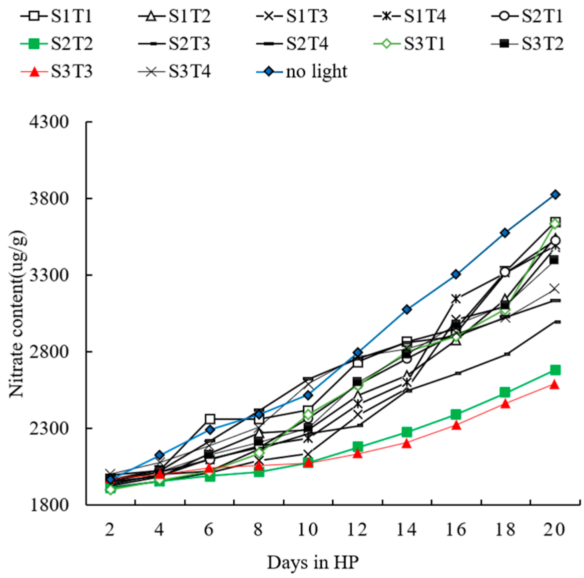

Figure 5. Curves of nitrate content in arugula in HP.

In the first 20 days of HP, the nitrate contents were 2591.6 μg·g^{-1} and 3826.18 μg·g^{-1} under a light intensity of 350 μmol·m^{-2}·s^{-1} and a photoperiod of 12 h and in complete darkness, respectively, indicating that as HP went on, the light treatment with a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 12 h had the most significant inhibitory effect on nitrate accumulation in leaves of arugula in HP. Light treatment with a certain intensity and photoperiod can inhibit the accumulation of nitrate in hydroponic arugula.

3.2.4. Effect on Cellulose

The cellulose content of arugula directly affects its taste and is an important indicator that needs to be considered in real-world production. The lower the cellulose content, the crisper the taste of arugula [32].

In the whole HP, the cellulose content under complete darkness was significantly higher than that under the light treatments ($p < 0.05$). With the increase in light intensity and photoperiod, the cellulose in the arugula leaves showed an increasing trend followed by a decreasing trend. The main reason is that cellulose accumulates when leaf senescence starts, but when the leaves begin to wilt and rot, the cellulose content gradually decreases, as shown in Figure 6.

In the first 10 days of HP, the cellulose concentration was the lowest under a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h. Starting from the 12th day, the leaves under each treatment gradually began to wilt, and cellulose decreased rapidly until the leaves were completely decayed. In those first 10 days, the cellulose concentrations were 57.02 μg·g^{-1} and 69.88 μg·g^{-1} under the treatment with a light intensity of 200 μmol·m^{-2}·s $^{-1}$ and a photoperiod of 6 h and in darkness, respectively, indicating that the light treatment of 200 μmol·m^{-2}·s^{-1} and photoperiod of 12 h had the most significant inhibitory effect on cellulose production in leaves of arugula in HP before the leaves wilted. In addition, under this condition, the overall change in cellulose content within 20 d of HP was the most stable, which shows that light treatment with a certain intensity and photoperiod can inhibit the production of cellulose in hydroponic arugula and slow the senescence of leaves.

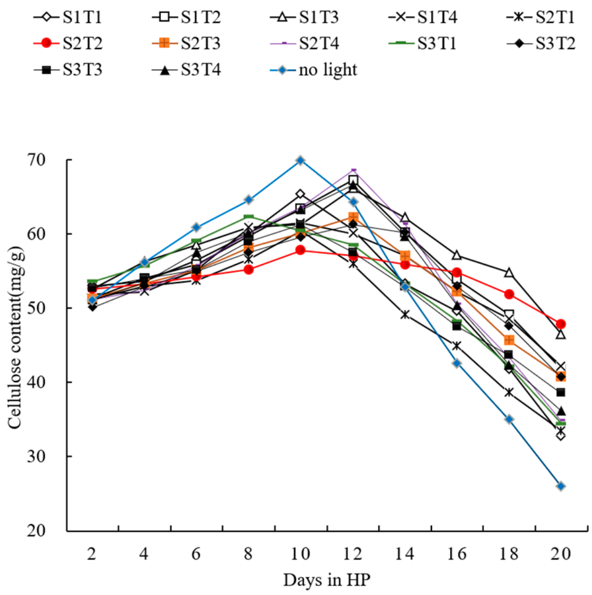

Figure 6. Curves of cellulose content in arugula in HP.

3.3. Effect of Light Intensity and Photoperiod on the Sensory Quality of Arugula

Table 4 shows that as HP went on, the sensory quality of each group showed a significant decreasing trend. In the first 10 days of HP, there was no significant difference in sensory quality between the groups, and all the sensory quality scores were above 7 points. On the 12th day in HP, the arugula leaves of the control group began to appear rotted and wilting, odors were produced, and the sensory quality had fallen to 5.8 points. In contrast, the quality of the arugula under the LED red and blue light treatments was almost unchanged, with only a few leaves showing yellowing and wilting, which was significantly different from the control group ($p < 0.05$). At the 20th day in HP, the arugula leaves in the control group were almost completely withered and rotted; under a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h, only a few leaves showed slight wilting and withered leaf edges, and there was basically no decay, significantly distinguishing them from the control group ($p < 0.05$).

Table 4. Effects of light intensity and photoperiod on the sensory quality of arugula in HP.

Light Treatment	Time in HP/d				
	0	5	10	15	20
S1-T1	9.0 ± 0.0 a	8.6 ± 0.2 a	7.2 ± 0.2 a	6.2 ± 0.3 b	4.5 ± 0.2 c
S1-T2	9.0 ± 0.0 a	8.8 ± 0.2 a	7.8 ± 0.2 a	6.3 ± 0.4 b	5.0 ± 0.3 b
S1-T3	9.0 ± 0.0 a	8.9 ± 0.3 a	8.1 ± 0.4 a	6.6 ± 0.2 b	5.3 ± 0.3 b
S1-T4	9.0 ± 0.0 a	8.9 ± 0.4 a	7.8 ± 0.3 a	6.4 ± 0.2 b	5.3 ± 0.2 b
S2-T1	9.0 ± 0.0 a	8.9 ± 0.3 a	7.5 ± 0.2 a	6.9 ± 0.3 b	5.6 ± 0.4 b
S2-T2	9.0 ± 0.0 a	9.0 ± 0.2 a	8.3 ± 0.3 a	7.5 ± 0.3 a	6.2 ± 0.3 a
S2-T3	9.0 ± 0.0 a	9.0 ± 0.3 a	8.0 ± 0.5 a	7.0 ± 0.2 a	5.9 ± 0.4 b
S2-T4	9.0 ± 0.0 a	8.8 ± 0.4 a	7.6 ± 0.3 a	6.7 ± 0.4 b	6.0 ± 0.2 b
S3-T1	9.0 ± 0.0 a	8.8 ± 0.5 a	7.3 ± 0.2 a	6.4 ± 0.2 b	5.7 ± 0.4 b
S3-T2	9.0 ± 0.0 a	9.0 ± 0.3 a	7.5 ± 0.4 a	6.6 ± 0.3 b	5.6 ± 0.3 b
S3-T3	9.0 ± 0.0 a	8.9 ± 0.2 a	7.9 ± 0.3 a	6.2 ± 0.2 b	5.5 ± 0.2 b
S3-T4	9.0 ± 0.0 a	8.7 ± 0.3 a	7.1 ± 0.5 a	6.1 ± 0.3 b	5.1 ± 0.5 b
Complete darkness	9.0 ± 0.0 a	8.2 ± 0.4 a	6.9 ± 0.4 b	5.7 ± 0.2 b	4.3 ± 0.2 c

Note: T: photoperiod; S: light intensity; different lowercase letters in the same column indicate significant difference ($p < 0.05$).

Therefore, LED red and blue light treatment effectively maintained the sensory quality of arugula in HP, and the best fresh locking effect was obtained under a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h.

4. Discussion

4.1. The Effect of Light Treatment on the Fresh Weight and Water Content of Arugula during Harvest

LED red–blue composite light irradiation treatment is conducive to reducing the decline in fresh weight and water content of stinky vegetable leaves caused by aging of arugula. Under the conditions of a light intensity of 350 μmol·m^{-2}·s^{-1} and a photoperiod of 12 h, the fresh weight of arugula is the highest, reaching 30.06 g, and under the conditions of a light intensity of 200 μmol·m^{-2}·s^{-1} and a photoperiod of 6 h, the water content of arugula is the highest, reaching 96.42%.

4.2. The Effect of Light Treatment on the Nutritional Quality of Arugula during Harvest

LED red–blue light composite irradiation treatment can significantly delay the decomposition of chlorophyll in hydroponic stinky vegetable leaves during the harvest period, reduce the loss of soluble sugar, inhibit excessive accumulation of nitrate, and slow down the production of leaf cellulose. The soluble sugar in stinky vegetable leaves decreases significantly in the later stage of harvest, which is due to the reduced photosynthetic efficiency of stinky vegetable leaves, affecting the carbon assimilation of leaves. During the harvest period, the nitrate content under full light avoidance conditions is significantly higher than that of each group with light treatment. In the early stage of harvest, the nitrate content under 350 μmol·m^{-2}·s^{-1} light intensity and 12 h light cycle treatment is the lowest, but entering the later stage of harvest, the growth rate of nitrate content increases significantly. This is due to the low photosynthetic intensity of arugula and the inability of leaves to provide enough energy for nitrate reduction. During the harvest period, as the light intensity and light cycle increase, the cellulose content of stinky vegetable leaves shows a trend of first increasing and then decreasing. This may be due to leaf aging leading to an increase in cellulose content. When leaves begin to wilt and rot, cellulose content gradually decreases. Before arugula wilt, during the harvest period, stinky vegetable leaves have the lowest cellulose content under 200 μmol·m^{-2}·s^{-1} light intensity and 12 h light cycle treatment, at 57.02 μg·g^{-1}.

4.3. The Effect of Light Treatment on the Sensory Quality of Arugula during the Harvest Period

LED red–blue composite light irradiation is beneficial to maintain the sensory quality of hydroponic arugula during the harvest period. Among them, the sensory quality of stinky vegetable leaves is the best under the treatment of 200 μmol·m^{-2}·s^{-1} of light intensity and a 6 h light cycle. Compared with the full light avoidance control group, using LED red–blue composite light irradiation treatment is beneficial to maintain the normal sensory quality of large-leaf arugula during the harvest period, prevent the rapid loss of nutrients in the leaves, delay leaf aging during the harvest period, and have a significant fresh-keeping and water-retaining effect on arugula. Compared with the conventional full light avoidance treatment of arugula during the harvest period, it can extend the harvest period of arugula by more than 5 days. At the same time, light intensity and light cycle are not as high as possible. Compared with other treatment groups, arugula obtained under daily irradiation treatment at 200 μmol·m^{-2}·s^{-1} light intensity and 6 h light cycle have better quality and a better fresh-keeping effect during the harvest period.

5. Conclusions

The results of this study are (1) LED red and blue composite light treatment was beneficial for reducing the fresh weight and water content losses of the arugula leaves caused by senescence; (2) LED red and blue light composite light treatment significantly delayed the chlorophyll decomposition, reduced the loss of soluble sugar, inhibited excessive accumulation of nitrate, and slowed the production of cellulose in leaves of hydroponic arugula in HP; and

(3) LED red and blue composite light treatment was beneficial to maintain the sensory quality of hydroponic arugula in HP, and the sensory quality of the arugula leaves was the best in the group with a light intensity of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and a photoperiod of 12 h.

These results show that compared with the control group under complete darkness, the use of LED red and blue composite light treatment is conducive to maintaining the normal sensory quality of arugula leaves, prevents the rapid loss of nutrients from arugula leaves, delays leaf senescence within HP, and has a significant fresh locking effect on arugula. Compared with the conventional storage treatment of arugula in complete darkness, the HP of arugula can be prolonged by more than 5 d with light treatments. On the other hand, an excessively high light intensity or long photoperiod can result in a decrease in the fresh locking effect. Compared with the other treatments, the quality of the arugula under the daily treatment with a light intensity of 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and photoperiod of 6 h was best for the fresh locking of arugula in HP.

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