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Research Article

Water content, carbohydrate accumulation, and secondary metabolites in *Allium victorialis* sprouts exposed to shoot cutting in varied irradiations

Changwei ZHOU[1]*, Wenjing CUI[1], Ting YUAN[1], Huayan CHENG[1], Qian SU[1], Peng GUO[2]*

[1]*Guizhou University, College of Life Science, Guiyang 550025, China; changwei.1981@163.com (*corresponding author); 1434875142@qq.com; 790289779@qq.com; 3301759458@qq.com; 2269976212@qq.com*
[2]*Dalian Nationalities University, Environment and Resources College, Dalian 116600, China; gp@dlnu.edu.cn (*corresponding author)*

Abstract

Victory onion (*Allium victorialis*) is an edible vegetation that has significant value as a non-structural carbohydrate and secondary metabolite supplier. Easily measured leaf variables will be useful to predict for the flexible adjustment of physiochemical parameters in a cultural regime in plant factory conditions. Red, green, and blue light-emitting diode (LED) spectra were used to culture victory onion sprouts. Compared to the green-light spectrum, the red-light spectrum promoted leaf width and area, specific leaf area, and dry mass, water content, fine root growth, and starch accumulation in shoots, but lowered concentrations of total flavonoids and saponins. Sprouts had their shoots cut, but there were limited interactive effects with light spectra on most variables. In general, shoot-cutting depressed growth of leaf morphology, shoot weight, water content, and soluble sugar content, but enhanced accumulation of secondary metabolites. We did not find any relationship between leaf variables and secondary metabolites. Instead, wider leaves with a larger area generally had greater dry mass, water content, and soluble sugar accumulation. Leaves with deeper green colours generally had the opposite effects.

Keywords: artificial illumination; LED spectra; triterpenoid saponins; total flavonoids; Victory onion

Introduction

Increasing human population and environmental contamination hasten the use of plant factory for vegetative production (Fedoroff and Cohen, 1999; Li *et al.*, 2021; Wei *et al.*, 2020). Light is one of the most limiting factors for plant growth and quality. Lighting spectral characteristic is a flexible instrument which can be controlled to meet target demand at a cost (Lu, 2021). The adjustment of spectrum not only promotes crop yield (Saito *et al.*, 2020; Carotti *et al.*, 2021), but also boosts production of officinal ingredients in medicinal plants (Wei *et al.*, 2020; Feldzensztajn *et al.*, 2021). The specific illumination condition established for medicinal plants depends on how it affects the production of secondary metabolites. Determining medicinal ingredients is a hard task due to heavy dependences on reagents, equipment, laboratory, and operational

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experience. Accurate predictions of accumulated, biosynthesized secondary metabolites using easily measured variables are essential for plant-factory cultured medicinal plants.

Easily measured variables are an indicator of growth, nutrition, and physiology in a wide range of plant species (Cornelissen *et al.*, 1996; Xu *et al.*, 2019). Leaf metrics determine the capacity to acquire and utilize light. It is frequently a factor in plant production and quality variables (Shipley *et al.*, 2005; Weraduwage *et al.*, 2015). A fast evaluation of leaf metrics at high accuracy is desired to efficiently collect easily measured variables in a plant factory (Getman-Pickering *et al.*, 2020). Leaf morphological growth is a parameter that directly responds to changes in light spectra (Kim and Chung, 2018; Rahman *et al.*, 2021). Leaf-area and green-colour can be easily quantified through digital scanning, and have close relationships with growth and nutrition uptake (Xu *et al.*, 2019). Specific leaf area (SLA) and specific leaf weight (SLW) are two foliar variables that are reliable in predicting leaf thickness and photosynthetic capacity and functions, water uptake potential, and gas exchange (Pearce *et al.*, 1969; Amanullah, 2015; Dieleman *et al.*, 2019). All these leaf variables can be easily monitored when exposed to changed light spectra in a plant factory system. To our knowledge, their correlation with secondary metabolites of medicinal plants has not been fully documented.

Light spectrum can modify secondary metabolites in medicinal plants by inducing a variety of physiological responses (Hashim *et al.*, 2021). The change of components in red, green, and blue lights can impact saponin accumulation by promoting water uptake and dry mass production (Wei *et al.*, 2020). Easily measured leaf variables can be used as a predictor for at least parts of these changed parameters in response to the change of light spectrum. This is highly needed in plant factory programs when content of target components is expected to increase by adjusting lighting spectra. Although several medical plant species have been tested for their response of secondary metabolites to light spectrum (Thoma *et al.*, 2020; Hashim *et al.*, 2021), correlation between easily measured leaf variables and bioactive components has not been full detected.

Victory onion (*Allium victorialis* L.) is a broad-leaved perennial Eurasian species of wild onion. Natural populations of victory onion distribute in mountainous areas of Europe and East Asia at altitudes of 1,000-2,500 m. It contains high concentrations of natural products that benefit human health, including dietary fibre, selenium, protein, flavonoids, and vitamin C (Ba *et al.*, 2002; Golubkina *et al.*, 2010). It is also a well-known vegetable in East Asia. Their value in medical and culinary uses results in their over exploitation. Development from flowering to seeding happens in two to three months and the growth rate is very slow. Therefore, there is a need to produce dry mass in victory onion leaves in a plant factory, where the design of an artificial lighting system depends on monitoring easily measured leaf variables.

In this study, victory onion sprouts were cultured in a plant factory condition with three types of light-emitting diode (LED) spectra as sources of illumination. We determined leaf variables as the independent variables. Water content, carbohydrate accumulation, and secondary metabolites were measured as dependent variables, determined according to previous studies (Xu *et al.*, 2019; He *et al.*, 2020; Li *et al.*, 2021). We hypothesized that all leaf variables correlate with carbohydrate and secondary metabolites in victory onion sprouts.

Materials and Methods

Plant materials and growth condition

Four-year-old bulbs of victory onion (*Allium victorialis* L.) were obtained from Pihe County (43°24' N, 127°32' E), Jilin City, Northeast China. Bulbs were planted in moist peats (40%, v/v) for a month until initial sprouts grew to an average height of 12.14±4.76 cm and bulb-root diameter of 0.46±0.09 cm. Sprouts with an uniform size were dug up with intact bulbs and roots, washed with distilled water, and sterilized by spraying potassium permanganate (0.5%, w/w) (He *et al.*, 2020). Cleared sprouts were transplanted to growth media composed of 20% spent-mushroom residue, 25% perlite, and 55% peat (v/v/v) (Liu *et al.*, 2021). Sprouts were cultured in 212-mL plastic containers (height of 13 cm) at a spacing of 14 cm × 14 cm. Sprouts were firstly watered to full holding capacity and subsequently subjected to a sub-irrigation system (Wei *et al.*, 2020). This was achieved by placing containers in a tank and maintaining the water table at depth of 3 cm twice a week (He *et al.*, 2020). Sprouts were cultured in an indoor laboratory. During the cultural experiment, temperature was maintained between 14.8 °C and 31.7 °C, with an air humidity of 61.5%.

Illumination treatment

Containerized victory onion sprouts were exposed to LED panels (40 cm width and 120 cm length) ~35 cm above aerial-shoot tips. Each panel was equipped with 100 diodes emitting red, green, and blue colour lights. Absolute spectral values along wavelengths from 350 nm to 800 nm increased for red, green, and blue coloured lights as shown in Figure 1. Lighting intensity was controlled by adjusting electrical current in transformers. Electric current for red light was controlled by a 200-W transformer and electric current for both blue and green lights by a 135-W transformer. A specific spectrum is set by adjusting electric currents to proportional irradiations and a percentage of the three different colours of lights (Figure 1D). The three types of spectra in this study had been successfully used to culture tree sprouts in previous studies (Wei *et al.*, 2020). Photosynthetic photon flux density (PPFD) for the three types of lights were controlled to be 69-77 μmol m^{-2} s^{-1} at light intensities of 2300-2700 Lx. Specific traits of the three light types can be found in Wei *et al.* (2020).

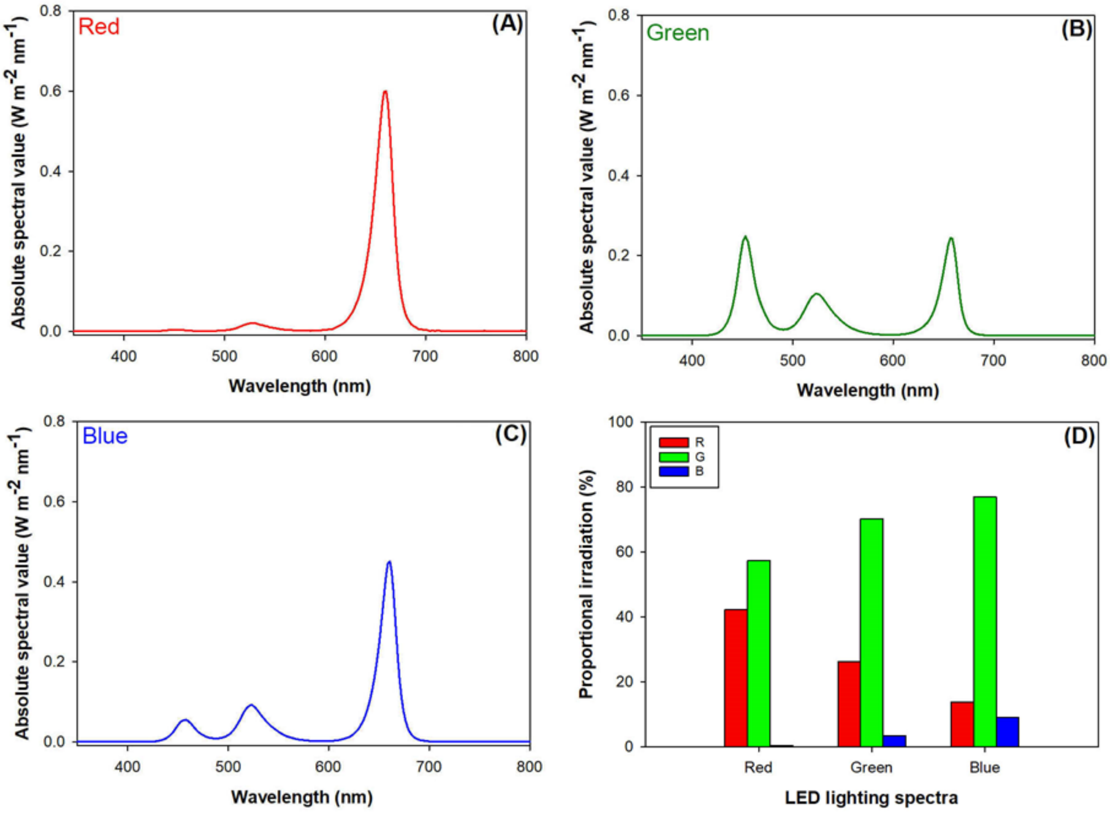

Figure 1. Absolute spectral values for light-emitting diode (LED) spectra with red (A), green (B), and blue (C) colours and proportional irradiations of three coloured lights (D)

Experimental design and arrangement

The experiment implemented a split-block design. The main block was the three LED spectra, and the sub-block was two harvests. For every tank, a container of seedlings would be subjected to combined light spectra and cutting treatments. A total of 16 containerized victory onion sprouts were arranged, each as a basic experimental unit that was subjected to one type of LED spectrum. Every unit was replicated for three times. Basic units were randomly placed to create randomness in the statistical design. When all victory onion sprouts grew to a height of about 30 cm, they were harvested by excising all above-ground organs. This happened 2 months after sprout transplant. They were harvested for the second time when shoot parts sprouted out again from bulbs, about 1.5 months after the first cut.

Sprout sampling and measurement

In each harvest, 16 individual victory onion sprouts were divided into two groups of eight randomly chosen sprouts. Within each group, four sprouts were randomly chosen to be measured for leaf variables and fine root morphologies. The other four were used to measure weight, carbohydrate contents, and secondary metabolites in shoots.

For leaf variables, four individual leaves were excised on the outside verticillation in four orientations. Isolated leaves were immediately dried usings tissue papers and scanned to obtain image at a dots per inch (dpi) of 118.11 pixels cm^{-1} (Wang *et al.*, 2020). Thereafter, leaf area and leaf green index (GI) can be calculated using histogram image with details introduced in Xu *et al.* (2019). SLA and SLW were calculated using the quotient of single leaf area divided by area and single leaf weight divided by area, respectively (Amanullah, 2015).

Fine roots were carefully excised from bulbs and kept in moist towels until scanning. Fine root morphology was analysed using WinRhizo software (Regent Instrument Inc., Calgary, Canada) to quantify fine root length, surface-area, diameter, and tip-number.

For shoot variables, all shoot parts were excised from bulbs, dried using tissue papers, and measured for their fresh weight. Dry mass weight was measured after oven-drying at 70 °C for 3 days. After, water content (fresh weight – dry weight) and water ratio (water content / fresh weight) can be calculated. Dried samples were grinded and used for determining non-structural carbohydrate contents using Wei *et al.* (2020) methodology. Total flavonoid and saponin contents were determined using (Wei *et al.*, 2020) methodology.

Statistical analysis

Data was analysed by SAS software (SAS Institute Inc., NC, USA). Every leaf, shoot, or fine root variable was analysed using a split-block model with randomness in the placement of basic units as was described above. Two-way analysis of variance (ANOVA) was used to detect for interactive effects between light spectra (degree of freedom [*df*]=2) and two harvests (*df*=1) on measured variables. Data from two harvests were analysed by a mixed-model ANOVA as inputs of repeatedly measured variables in response to comparisons among spectra at every harvest. Data was averaged and compared among six combined treatments only when the interactive effect was indicated to be significant by ANOVA (df=2, P<0.05). Otherwise, results were compared by main effects from spectra or harvest to detect significant difference (α=0.05). Pearson correlation was used to detect relationships between leaf variables and water content, carbohydrate content, and secondary metabolites.

Results

Leaf variables

Light spectra and shoot cutting had an interactive effect on leaf length in victory onion sprouts (Table 1). Leaf length of sprouts in the first harvest were all lower than that in the second harvest (Figure 2A). In second harvest, sprouts subjected to the green-light spectrum had lower leaf length than those subjected to blue- and red-light spectra.

Table 1. Analysis of variance (ANOVA) of light-emitting diode (LED) spectra and harvest on leaf variables in victory onion (*Allium victorialis*) seedlings

Leaf variables	ANOVA	Source of variance		
		Light (L)	Harvest (H)	L × H
Leaf length	*F* value	13.41	3130.02	12.66
	P value	0.0009	<0.0001	0.0011
Leaf width	*F* value	12.21	43.75	3.70
	P value	0.0013	<0.0001	0.0562
Leaf area	*F* value	5.01	188.46	0.32
	P value	0.0262	<0.0001	0.7345
Leaf GI [1]	*F* value	4.65	242.09	0.29
	P value	0.0320	<0.0001	0.7553
SLA [2]	*F* value	0.29	73.02	0.90
	P value	0.7522	<0.0001	0.4334
SLW [3]	*F* value	0.09	60.45	0.56
	P value	0.9152	<0.0001	0.5835

Notes: [1] Leaf GI, leaf green index; [2] SLA, specific leaf area; [3] SLW, specific leaf weight.

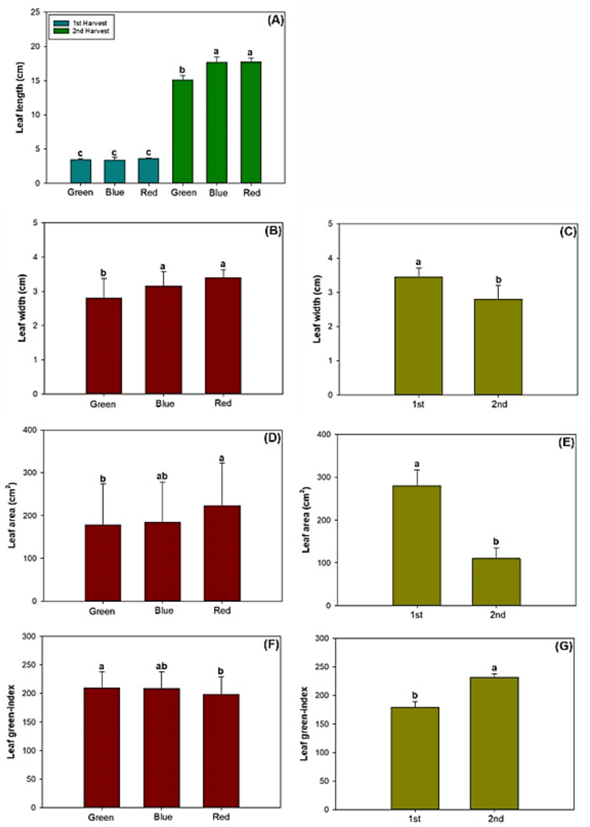

Figure 2. Leaf length (A), leaf width (B, C), leaf area (D, E), and leaf green-index (F, G) in victory onion (*Allium victorialis*) seedlings subjected to LED spectra in green, blue, and red coloured lights and two harvests

Different letters present significant difference identified by statistic of Tukey tests (α=0.05).

Light spectra and shoot cutting had no interactive effect on leaf width, leaf area, and leaf GI (Table 1). Instead, either light spectra or shoot cutting had a main effect on these three leaf variables (Figure 2). Leaf width was lower in sprouts subjected to the green-light spectrum compared to that in the blue- and red-spectra (Figure 2B). Sprouts in 2nd harvest had lower leaf width than those in the 1st harvest (Figure 2C). Sprouts in the red-light spectrum had larger leaf area compared to those in the green-light spectrum, but leaf area in both spectra were not statistically different from that in the blue-light spectrum (Figure 2D). Again, leaf area in the 2nd harvest was 61% lower than leaf area in the 1st harvest (Figure 2E). In contrast, leaf GI was 5% lower in the red-light spectrum relative to that in the green-light spectrum (Figure 2F), and leaf GI in the 2nd harvest was 29% greater than that in the 1st harvest (Figure 2G).

Light spectra had no effect on SLA and SLW either as a main effect or in an interaction (Table 1). Instead, shoot cutting had a significant main effect on SLA and SLW. Compared to the 1st harvest, SLA was 37% lower and SLW was 59% greater in the 2nd harvest.

Aerial-shoot variables

Light spectra and shoot cutting had no interactive effect on any aerial shoot variables (Table 2). Instead, either of the two treatments had a main effect on these variables except for shoot water ratio. Fresh weight, dry weight, and water content in the shoot is greater in sprouts exposed to the red-light spectrum than sprouts exposed to the green-light spectrum by 44%, 37%, and 45%, respectively (Figure 3A, C, E). In addition, shoot fresh weight is 34% greater when exposed to the red-light spectrum than when exposed to the blue-light spectrum (Figure 3A). Compared to the 1st harvest, fresh weight, dry weight, and water content was 42%, 51%, and 40% lower, respectively, in the 2nd harvest (Figure 3 B, D, F).

Table 2. Analysis of variance (ANOVA) of light-emitting diode (LED) spectra and harvest on variables in shoot part of victory onion (*Allium victorialis*) seedlings

Shoot variables	ANOVA	Source of variance		
		Light (L)	Harvest (H)	L × H
Fresh weight	*F* value	6.19	32.91	1.30
	P value	0.0143	<0.0001	0.3086
Dry weight	*F* value	4.26	49.54	0.52
	P value	0.0400	<0.0001	0.6074
Water content	*F* value	4.62	20.99	1.09
	P value	0.0325	0.0006	0.3682
Water content ratio	*F* value	0.14	0.99	0.08
	P value	0.8667	0.3885	0.9194
Soluble sugar content	*F* value	1.06	10.15	1.18
	P value	0.3776	0.0078	0.3407
Starch content	*F* value	4.95	0.09	2.00
	P value	0.0270	0.7737	0.1777
Total flavonoid content	*F* value	19.71	5.12	1.04
	P value	0.0002	0.0430	0.3862
Total saponin content	*F* value	30.91	3.48	0.58
	P value	<0.0001	0.0867	0.5760

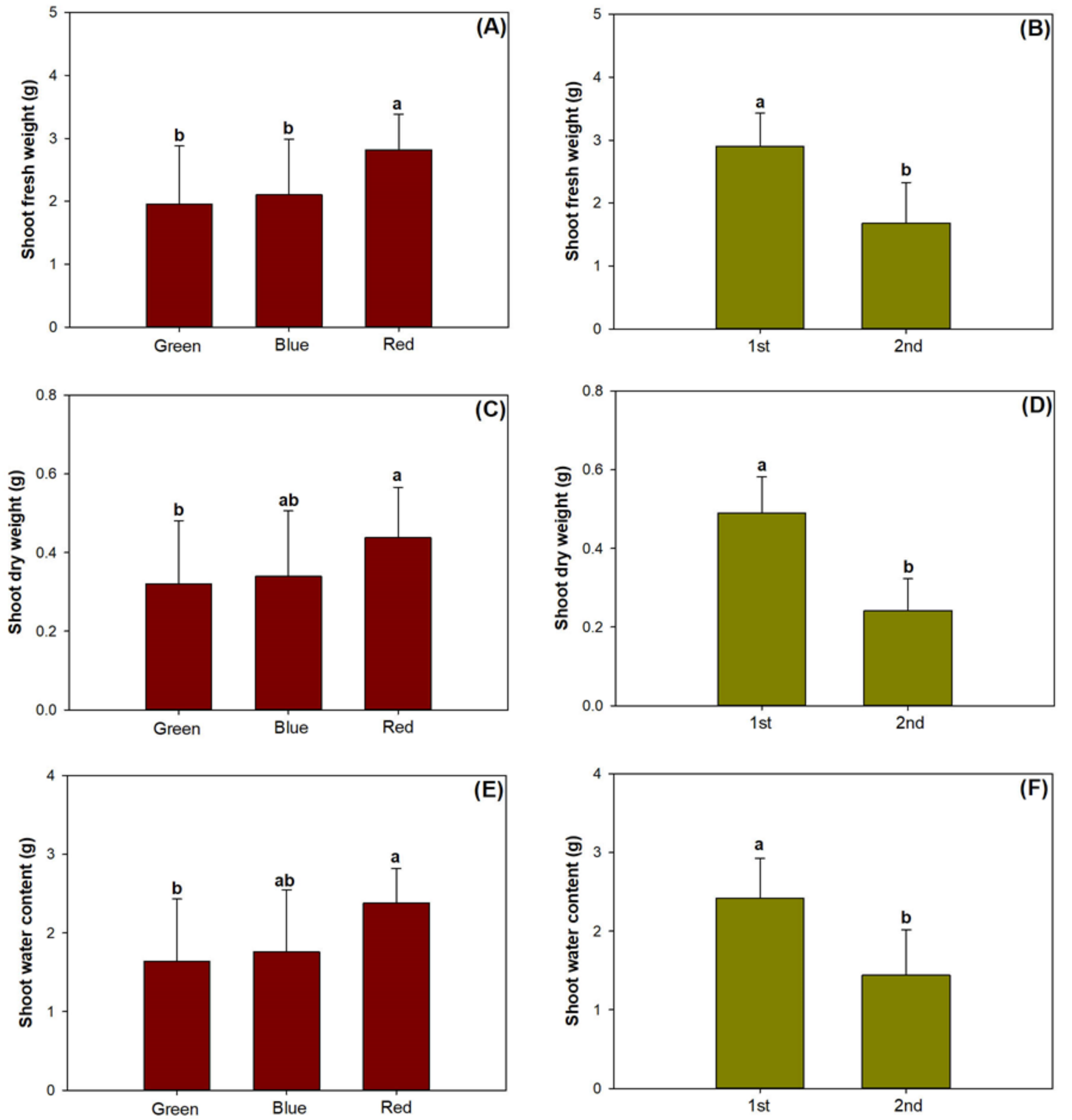

Figure 3. Fresh weight (A, B), dry weight (C, D), and water content (E, F) in shoots of victory onion (*Allium victorialis*) seedlings subjected to LED spectra in green, blue, and red coloured lights and two harvests

Different letters present significant difference identified by statistic of Tukey tests (α=0.05).

Light spectra had no effect on soluble sugar content in of victory onion shoots (Table 2; Figure 4A). Shoot starch content in victory onion sprouts was 41% greater when exposed to the red-light spectrum than when exposed to the green-light spectrum (Figure 4C). Relative to the 1st harvest, soluble sugar content was 42% lower in the 2nd harvest (Figure 4B), but there was no statistical difference in starch content in shoots between the two harvests (Figure 4D).

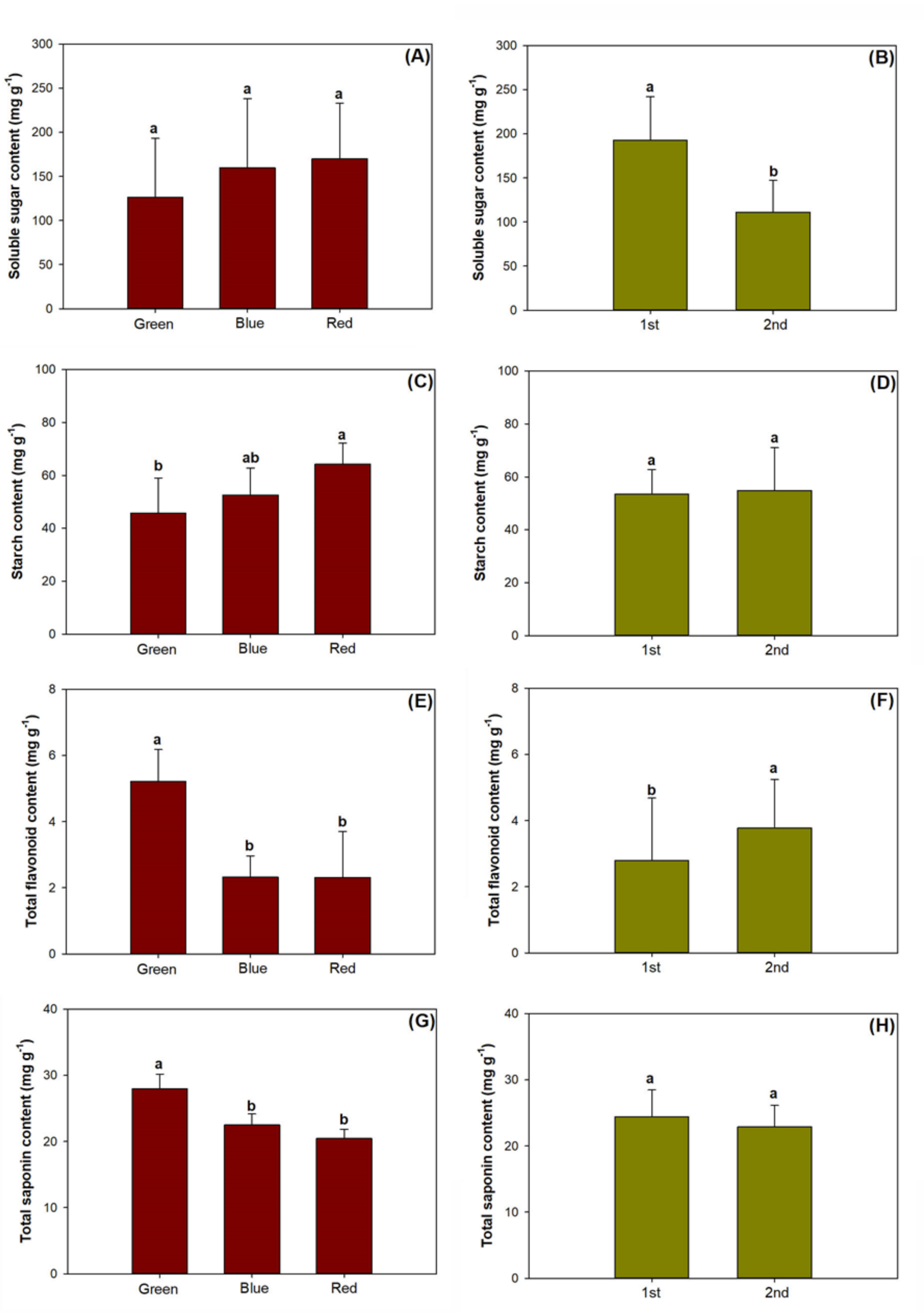

Figure 4. Contents of soluble sugars (A, B), starch (C, D), total flavonoid (E, F), and total saponins (G, H) in shoots of victory onion (*Allium victorialis*) seedlings subjected to LED spectra in green, blue, and red coloured lights and two harvests

Different letters present significant difference identified by statistic of Tukey tests (α=0.05).

Sprouts subjected to the blue- and red-light spectra had lower total flavonoids and saponins content compared to those subjected to the green-light spectrum (Figure 4E, G). Compared to the 1st harvest, total flavonoid content in victory onion shoot was 35% greater in the 2nd harvest (Figure 4F). However, shoot cutting did not affect total saponins content in the shoot (Figure 4H).

Fine root morphology

Shoot cutting had no effect on fine root morphology. Exposure to the red-light spectrum resulted in greater fine root length, surface-area, and tip-number compared to the green-light spectrum (Table 3). Fine root length was also higher in the red-light spectrum than in the blue-light spectrum. However, the blue-light spectrum did not cause any significant difference in fine root surface-area and tip-number compared to the other two light spectra (Table 3).

Table 3. Fine root morphology in victory onion (*Allium victorialis*) seedlings subjected to light-emitting diode (LED) spectra enriched in green, blue, and red lights

Fine-root morphology	LED spectra			ANOVA [1]	
	Green	Blue	Red		
Length (cm)	466.94±178.79b [2]	522.04±169.15b	703.33±191.78a	*F* value	5.66
				P value	0.0077
Surface-area (cm^2)	206.85±90.66b	337.77±128.22ab	378.11±173.12a	*F* value	5.28
				P value	0.0102
Diameter (mm)	1.61±0.25a	1.64±0.24a	1.76±0.31a	*F* value	1.03
				P value	0.3680
Tip number	910.17±261.83b	1180.67±336.13ab	1261.17±285.77a	*F* value	4.62
				P value	0.0170

Notes: [1] ANOVA, analysis of variance; [2] results are presented as means ± standard deviation (SD) with different letters in a row labels significant difference at 0.05 level (Tukey test).

Prediction by easily measured variables

Leaf length, leaf GI, and SLW had a negative relationship with shoot dry weight (Table 4). In addition, leaf GI also had a negative relationship with fresh weight, water content, and soluble sugar content in shoots.

Table 4. Pearson correlation between leaf variables and characteristics in shoot of victory onion (*Allium victorialis*) seedlings

	FreshW [1]	DryW [2]	WaterC [3]	WaterR [4]	Sugar [5]	Starch [6]	Flavonoid [7]	Saponin [8]
LeafL [9]	-0.77447	-0.87911 [10]	-0.74643	0.84482 [11]	-0.79767	0.1343	0.25951	-0.30423
	0.0706	0.021	0.0883	0.0343	0.0573	0.7998	0.6195	0.5577
LeafW [12]	0.95285	0.91108	0.95658	-0.3659	0.85629	0.4144	-0.66574	-0.33673
	0.0033	0.0115	0.0028	0.4756	0.0295	0.414	0.1489	0.514
LeafA [13]	0.91392	0.96885	0.89647	-0.68416	0.8531	0.07584	-0.44984	0.0563
	0.0108	0.0014	0.0155	0.1339	0.0308	0.8865	0.3708	0.9156
LeafGI [14]	-0.90059	-0.96335	-0.88144	0.71021	-0.85285	-0.05411	0.43133	-0.08449
	0.0143	0.002	0.0203	0.1138	0.0309	0.9189	0.3931	0.8736
SLA [15]	0.80299	0.8917	0.77868	-0.77324	0.75251	-0.14253	-0.30766	0.25189
	0.0544	0.017	0.0681	0.0713	0.0843	0.7877	0.5531	0.6301
SLW [16]	-0.77941	-0.87504	-0.75358	0.81296	-0.75365	0.1789	0.2967	-0.28089
	0.0676	0.0224	0.0836	0.0492	0.0836	0.7345	0.568	0.5897

*Notes: [1] FreshW, fresh weight of shoot part; [2] DryW, dry weight of shoot park; [3] WaterC, water content of shoot part; [4] WaterR, water content ratio of shoot part; [5] Sugar, soluble sugar content in shoot part; [6] Starch, starch content in shoot part; [7] Flavonoid, flavonoid content in shoot part; [8] Saponin, total saponin content in shoot part; [9] LeafL, leaf length; [10] values in white colour in a dark-gray cell indicate negative correlations; [11] values in black colour in a light-gray cell indicate positive correlations; [12] LeafW, leaf width; [13] LeafA, leaf area; [14] LeafGI, leaf green index; [15] SLA, specific leaf area; [16] SLW, specific leaf weight.

Leaf width and leaf area had a positive relationship with fresh weight, dry weight, water content, and soluble sugar content in shoots (Table 4). Leaf length and SLW also had a positive relationship with shoot water content. In addition, SLA had a positive relationship with shoot dry weight.

Leaf variables did not have any correlation with shoot total flavonoid and saponin contents (Table 4). Leaf variables also had no correlation with shoot starch content.

Discussion

Shoot cutting will be practical for culturing victory onion sprouts and other medicinal plants. Screening and determining a specific spectrum will be necessary to obtain optimum results in cultivation programs. In our study, leaves of victory onion sprouts were enlarged in morphology by the spectrum with high red-light wavelength rather than that with green-light wavelength. Illumination with the spectrum enriched in red-light was found to be beneficial for leaf length and area in vegetative plants (Stutte *et al.*, 2009; Kubota *et al.*, 2012). Red LEDs emit a narrow spectrum of light in a bandwidth between 600-700 nm, which allows for maximum absorbance by chlorophyll and phytochromes (Goins *et al.*, 1997). This is due to specific spectral output and high photosynthetic photon flux output (Brown *et al.*, 1995). As a result, photosynthetic production increased by inhibiting translocation from leaves (Sæbø *et al.*, 1995). This supports our data-that starch content increased when exposed to red-light spectrum-which explains the enlargement of leaf morphology. Starch accumulation is associated with active growth in vegetative plants (Nii *et al.*, 1993; Zavala-García *et al.*, 2018). Higher reserved starch content reduces water consumption for hydrolysis or translocating flow. Hence, water content was also higher in the red-light spectrum. In contrast, studies show that blue light lowers water content in tomato leaves (Xu *et al.*, 2012). Water content ratio did not significantly change in our study. Water content ratio was also found to be higher in a spectrum with red- plus white-coloured light (Dong *et al.*, 2014). In our study, the red-light spectrum benefits shoot water content in victory onion sprouts.

Victory onion sprouts were found to have lower leaf morphology under the green-light spectrum compared to the red-light spectrum. The green-light spectrum is the most visible to plant leaves because green-light wavelengths are the least absorbed by the photosynthetic apparatus. Although spectra enriched with green-light wavelengths were found to be effective in nutrient utilization for tree seedlings (Luo *et al.*, 2020), they promote the allocation of dry mass to belowground organs and usage of inner nutrients than other types of light spectra (Gao *et al.*, 2021). Accordingly, shoot dry mass was lower in the spectrum with more green-light. A lower input of dry mass can explain smaller leaf size under green-light spectrum.

Leaf GI is a parameter that has a negative relationship with leaf N concentration (Wang *et al.*, 2020). A higher leaf GI after exposure to the green-light spectrum in victory onion sprouts was also occurred to *Bletilla striata* seedlings (Wang *et al.*, 2020). This was reasonable because most green lights are reflected by leaves because they aren't absorbed. Higher leaf GI in the green-light spectrum also suggests lower level of N concentration in leaves although we did not quantify N uptake in this study. Other studies reported that the green-light spectrum tended to limit leaf N concentration compared to other types of spectra in *Pinus koraiensis* and lettuce seedlings. As we did not measure leaf N levels, we can attribute higher GI as a consequence of low N uptake. More relevant explanations need future work to be confirmed.

Greater amounts of secondary metabolites after exposure to the green-light spectrum is due to the stress caused by green light because the capture and utilization of green light photons occur after deep penetration into the tissues of leaves (Terashima *et al.*, 2009). Photosynthetic efficacy in green light may be not as high as that in other types of light, which generates a stress. The green-light spectrum suppressed growth, dry mass production, water content, and starch accumulation, which suggests that green light was not suitable for culturing victory onion sprouts. Higher content of secondary metabolites in stressful light spectrum was also found on *Aralia elata* seedlings (Wei *et al.*, 2020).

Although cutting shoot parts increased leaf length, it reduced leaf width and resulted in longer but narrow leaves. These changes correspond to a decrease in SLA and an increase in SLW. According to Amanullah (2015), leaves of victory onion sprouts subjected to shoot cutting became thinner and were less efficient in obtaining N and CO_2 given an amount of dry mass input to leaves. This can be surmised by an increased leaf GI, which suggests a decline in leaf N concentration (Wang *et al.*, 2020). This also explains how shoot cutting reduced dry mass of the whole shoot. The decline of water content in post-cutting sprouts was due to the decrease of fresh mass production. In contrast, shoot water content increased in shrubs after shoot cutting (Wei *et al.*, 2020). We attribute this difference to the explanation that, for shrubs, cutting removed most of the shoot's woody parts, which doesn't account for a high proportion of water content. However, for victory onions, all shoot parts were non-wood tissues that depends on the size of the shoot for water uptake.

We failed to find any relationship between leaf variables and secondary metabolites. To our knowledge, we cannot explain this with current data. According to Li *et al.* (2020), leaf age, growing stage, and anatomic structure may all affect secondary metabolites content. Given that leaf GI has a negative relationship with leaf N concentration (Wang *et al.*, 2020), the negative relationship between leaf GI and shoot sugar content is due to the synchronization of sugar metabolism and N uptake (Wei *et al.*, 2014; Li *et al.*, 2021). Sugar metabolism depends on depletion of N utilization (Wei *et al.*, 2014; Beatty *et al.*, 2016). In addition, the negative relationship between leaf GI and weight and water content is due to lowered N and C assimilations in plant leaves with high levels of green colour. Although leaf length had a negative relationship with shoot dry mass, leaf weight and leaf area had a positive relationship. These results together suggest that a greater leaf width, but not leaf elongation can benefit dry mass production by enhanced photosynthesis. A negative relationship between leaf length and dry mass was also reported on bamboo (Lin *et al.*, 2020). High levels of SLW mean that leaves grow to be long and wide, which does not work for dry mass production through photosynthetic assimilation. However, this is a beneficial to inhibit transpiration and enhance water content ratio.

Conclusions

Victory onion sprouts did not show significant response in most variables to the interactive effects of three types of LED spectra and two times of harvests. Sprouts subjected to the red-light spectrum generally had increased leaf morphology, shoot growth, dry weight mass, fine root growth, and starch accumulation, but decreased secondary metabolites compared to those subjected to the green-light spectrum. The blue-light spectrum did not evoke too much of a significant response. Post-cutting sprouts grew to be thin and weak and short in soluble sugars. However, shoot cutting can increase total flavonoid content in shoots. As easily measured parameters, leaf morphology and colour cannot be used to predict the level of secondary metabolites. Larger leaves with wide widths can predict greater dry mass production, water content, and sugar accumulation, but leaves in deeper green will indicate low water content and low sugar accumulation. We suggest purpose-target cultural regime for victory onions in plant factory. If an aim was set to harvest greater dry mass and carbohydrate outcomes, the LED spectrum with high red-light is recommended; if the secondary metabolites were the objective, a shoot cutting in the green-light spectrum is recommended.

Authors' Contributions

Conceptualization, C.Z. and P.G.; Data curation, C.Z., W.C., and T.Y.; Formal analysis, C.Z. and H.C.; Funding acquisition, C.Z. and P.G.; Investigation, W.C. and Q.S.; Methodology, C.Z. and P.G.; Project administration, C.Z. and P.G.; Resources, W.C. and T.Y.; Software, C.Z. and P.G.; Supervision, C.Z.; Validation, P.G.; Visualization, C.Z.; Writing - original draft, C.Z.; Writing - review and editing, P.G. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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