Protected Horticulture and Plant Factory, Vol. 29, No. 2:171-180, April (2020)
DOI https://doi.org/10.12791/KSBEC.2020.29.2.171
pISSN 2288-0992
eISSN 2288-100X

Effects of Supplemental Green LEDs to Red and Blue Light on the Growth, Yield and Quality of Hydroponic Cultivated Spinach (*Spinacia oleracea* L.) in Plant Factory

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Abstract. The effect of three different light qualities on growth, photosynthesis, quality and safe parameters of hydroponic cultivated spinach (*Spinacia oleracea* L.) were investigated indoor. Three different light qualities were created of red (660 nm), blue (450 nm) and green (550 nm) LEDs corresponding at ratio R660/B450 = 4/1 (RBL); R660/B450/G550= 5/2/3 (WWL); R660/B450/G550 = 1/1/1 (WL), which were tested at the same intensity (PPFD =190 µmol m-2 s-1). The results showed that the plant height and leaf number were the lowest in WL treatment. The SPAD, Net photosynthesis rate Pn, Fv/Fm, Leaf area index LAI values and all parameters of root characteristics were the highest in RBL treatment and were significantly different from two others. Fresh weight of stem, leaf and root, dry weight of root in the three light qualities were significantly different. In contrast, the highest K^+ content in WL was different from WWL and RBL treatments, while Ca^{2+} and Fe^{2+} content were the highest in the RBL treatment. Vitamin C content was significantly different between the three treatments. nitrate and oxalic acid contents were the highest in WL treatment, whereas soluble–solids contents and vitamin C contents were the highest in RBL treatment. Oxalic acid, nitrate contents were observed tending reduced under WWL although oxalic acid content in RBL treatment was not different from WL and WWL treatments. In all three different light treatments were not detected *Salmonella*, *E.coli*. Our results suggest that RBL may be appropriate light for growth of spinach, but supplementary green light to a combination of red and blue LEDs at the reasonable rate can change the quality of spinach in a positive direction. Hydroponic cultivated spinach was safe for users.

Additional key words : artificial light, soluble-solids contents, nitrate content, oxalic acid, vitamin C

Introduction

Spinach (*Spinacia oleracea* L.) is the preferred plant for selected greenhouse because it allows the production of many shorter cycles in a year and faster economic returns than some other green vegetables (Brandenberger et al., 2007). Moreover, this is also a vegetable with a rich source of protein, vitamins, carotenoids, soluble sugars and phenolic compounds (Lisiewska et al., 2011). As a result, spinach enlarges to bring more potential in the development of vegetable production in Vietnam. But besides increasing the vegetable production, the vegetable safety is also a primary concern matter. Many metabolic compounds in spinach are found in green vegetables having nutrient compounds such as ascorbic acid, oxalic acid and nitrate content (Proietti et al., 2009). Vitamin C is an effective antioxidant, whereas oxalic acid and nitrate ion NO_3^- should be reduced minimum in vegetables to reach the user's safety (DeBolt et al., 2007). Excessive nitrogen uptake or inhibition of nitrogen conversion to protein is due to a number of environmental factors that lead to nitrogen accumulation during plant growth. A small portion of the nitrogen is absorbed through nutrients that are reduced to nitrite by bacteria in the mouth and stomach of users. Nitrit has many other negative effects on human health as it reacts with secondary amines and leads to the formation of carcinogens, mutagens and teratogenic nitrosamines (Oztekin et al., 2018). Some researches reported that leaf crops such as cabbage, lettuce and spinach have fairly large nitrate concentrations whereas storage organs

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Received October 08, 2019; Revised February 06, 2020; Accepted February 27, 2020

such as potato tubers, carrots, leeks, onions, seeds and pods of pea and bean plants have relatively small concentrations. The former include soil moisture, light intensity and temperature and the latter fertilizers, variety and crop protection strategies (EFSA, 2008).

Consequently, growing vegetables in the hydroponic system combined with light emitting-diodes (LEDs) is the one of high technologies, helping to maintain the production of vegetables in the season and off-season, able to create products that are uniform, high quality, high productivity, easy harvesting, fertilizer optimization, less pest and suitable for planting in urban areas (Tomasi et al., 2015).

In addition, the light conditions (light quality, light intensity and photoperiod) are essential for regulating the plant growth and development. Changes in light spectrum have strongly influenced on plant growth, yield and quality (Macedo et al., 2011). On the other hand, according to Terashima et al. (2009) the light in the red and blue regions of the spectrum are mainly absorbed by photosynthetic pigments. About 90% light absorption by plant leaves are blue or red regions. Thus, photosynthetic rate, physiology and plant growth, development are significantly influenced by blue or red light (Chen et al., 2014).

Previously, green light was considered unrelated to photosynthesis but in recent years there are more researches attracting this attention because green light may involve cryptochrome processes in plant growth (Cui et al., 2009). The green light can participate in the photosynthetic process through pigment photoreceptor proteins in phytochromes and cryptochromes, so it may affect plant growth and development. It has important roles of light absorption similar to blue light (Swartz et al., 2001). According to Hogewoning et al. (2010), the blue and green light also had similar positive impact on plant growth, such as significantly increased photosynthetic capacity and plant biomass in cucumber plants. Green light also has some valuable physiological effects. LEDs (510, 520, 530 nm) as well as green fluorescent lamps, supplemental for red and blue LEDs promoted lettuce growth (Johkan et al., 2012). Green LEDs (505, 530, 535 nm) supplemental to HPS (High Pressure Sodium) and natural illumination affected nutrition quality of different baby leaf lettuce varieties reduced nitrate or increased ascorbic acid, tocopherol, anthocyanin concentrations (Samuolienė et al., 2012). The effects of LEDs (470, 500, 525 and 660 nm, respectively, at 50 μmol/m^2/s PPFD) on the growth and the biosynthesis of plant pigments in cabbage leaves were investigated. Red light irradiation induced to enhance the anthocyanin content, although there was no difference in chlorophyll contents and in stem length in a variety. Moreover, in other variety, anthocyanin contents were observed the same level regardless of light quality, and chlorophyll contents were higher under blue and blue-green light than that of green and red light (Mizuno et al., 2009).

As Kim et al. (2004) pointed out, in case the green light combined with red and blue LED light that can promote the plant growth. Indeed, some previous reports indicated that using LEDs as a light source for greenhouse horticulture, it has important meaning for the plants to convert light energy to enhance growth and to promote productivity efficiently. Optimizing LED light conditions could create premise to the development of novel agricultural technologies especially a plant factory.

Therefore, different light quality has different effects on the growth, development and quality of vegetables. The research was carried out to find out the best light quality for growing hydroponic spinach, to improve productivity and quality of this crop in an indoor system.

Materials and methods

1. Plant materials and growth condition

This experiment was conducted in an indoor system at the Institute of Agrobiology, Vietnam National University of Agriculture (in 2018). The room temperature was maintained at 27°C ± 0.4°C and humidity was kept at 65% ± 2%. Heat-treated F1 seeds variety PD512 of spinach (*Spinacia oleracea* L.) were provided by Phu Dien Trading & Production Company Limited. The seeds were cultivated Germany substrate (Klasmann TS-2) in plastic trays (128 holes) with length x width x height respectively 60 cm × 30 cm × 5 cm. Before sowing, seeds were soaked in warm water (about 50°C) at a rate of 3 boiling: 2 cold for about 2 hours Ten days after gemination, the same size seedlings were transplanted into plastic in the circulating hydroponic system. The experiment was conducted in 6 hydroponic systems racks with 4 rigs per a rack. Each rig has got 5 parallel hydroponic solution tubes and 9 plants per a tube, corresponding 45 plants per a rig. Every hydroponic system rack was equipped with a separate light quality (at the same PPFD = 190 μmol·m^{-2}·s^{-1}), corresponding to every treatment. Three using different light qualities were created of red, blue and green LEDs corresponding at ratio R660/B450 = 4/1 (Red-blue light - RBL); R660/B450/G550= 5/2/3 (Warm white light - WWL); R660/B450/G550 = 1/1/1 (White light - WL). The distance between plants was 15 cm, between rigs was 22 cm. The LEDs were manufactured and supplied by Rang Dong Light Source & Vacuum Flask. The plants were grown under a 12-h light/12-h dark photoperiod. Harvest time was 40-50 days after sowing and repeated 3 times for each treatment.

2. Growth parameters

Leaf number, leaf area and plant height were counted and measured. Root structure was performed using Epson Perfection V700 Photo Scanner and WinRHIZO Pro software.

3. Photosynthetic parameters

Net photosynthesis rate (Pn - μmol·m^{-2}·s^{-1}) was measured using portable photosynthetic system Ver.1.2.1 (TPS1, Pp Systems, USA). The leaves were measured as the third mature leaf from the top with a clamp-on leaf cuvette that exposed 6 cm^2 of leaf area. Each measurement was carried out on 3 intact matured leaves and was repeated on 5 plants for each site. In all measurements, the airflow into the machine was atmospheric and the CO_2 concentration was 360 ppm (0.036%). The humidity and temperature of the curvet were not adjusted. Chlorophyll a fluorescence: The measurement was carried using handheld Chlorophyll Fluorescence Meter, OS-30 (ADC, UK). SPAD index was performed using chlorophyll meter (SPAD-502 Plus, Konica Minolta, Japan).

4. Quality parameters

Content of mineral elements: The measurement was carried using atomic absorption spectrophotometry method (Atomic Absorption Spectroscopy - AAS Enduro T2100, GBC Scientific Equipment), at Hanoi National University of Education, Vietnam. NO_3 content was measured using colorimetry method according to TCVN 8742: 2011, at the Food Safety and Environmental Laboratory (Vilas 809) of the Vietnam Academy of Science and Technology, Vietnam. Oxalic acid and Vitamin C were performed using H. HD. QT. 103 (HPLC) and H. HD. QT. 104 (HPLC) method, at National Institute for Food Control (NIFC), Vietnam. Presence of *E. coli* and *Salmonella* were detected by using bacterial isolation method, at Key Laboratory of Veterinary Biotechnology (VILAS 618 and LAS – NN54), Vietnam National University of Agriculture, Vietnam.

5. Statistical analysis

Statistical analyses were conducted with Excel-software and R-software. Data were analyzed by analysis of variance (ANOVA), and differences between the means were tested using Ducan's test ($P < 0.05$).

Results

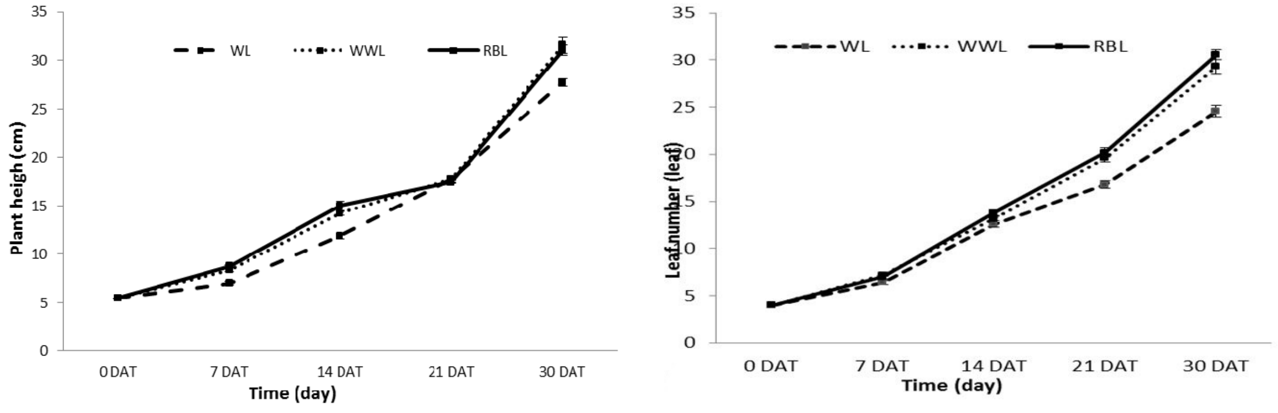
1. Growth parameters and photosynthetic capacity

The results indicated that the hydroponic spinach reached the highest plant height in warm white light treatment and the highest leaf number in the red-green LED light treatment. The difference between height plant and leaf number in warm white light and red-blue LED light was not much. In the period from 7 days to 14 days after transplanting (DAT), the height plant changed slowly, from 14 days to harvest (30DAT), the growth rate of the plant increased rapidly, especially in red-blue light. At that point, the plant height and leaf number in the white light was the lowest (Fig. 1).

SPAD, Pn and Fv/Fm values were the highest in RBL treatment and these were higher respectively 1.05 to 1.06 times, 1.11 to 1.12 times and 1.11 - 1.13 times than two other treatments. However, there was no difference between WL and WWL treatments in these above mentioned parameters. The leaf area was significantly different between the three light qualities. The highest leaf area was in RBL treatment, which was higher than 1.27 times in WWL and 1.57 times in WL treatment (Table 1).

2. Structural characteristics of root

At all parameters of root characteristics: root length,



(A) (B)

Fig. 1. Growth dynamics of plant height (A) and leaf number (B) of hydroponic spinach in different light quality LEDs (at the same PPFD = 190 μmol ·m^{-2}·s^{-1}). The error bars is standard errors.

Table 1. Effect of different light quality LEDs at the same intensity (PPFD =190 μmol·m^{-2}·s^{-1}) on photosynthetic capacity of hydroponic cultivated spinach indoor (30 DAT).

Treatment^z	Plant height (cm)	Leaf number (leaves/plant)	SPAD	LAI	Pn (μmol CO_2/m^2leaf/s)	Fv/Fm
WL	28,72 b^y	24,55 c	36,34 b	6,82 c	39,60 b	0,819 b
WWL	31,53 a	29,27 b	36,71 b	8,43 b	39,99 b	0,806 b
RBL	31,04 a	30,55 a	38,37 a	10,69 a	44,26 a	0,912 a
LSD5%	*1,0*	*0,73*	*0,77*	*0,37*	*3,06*	*0,04*

^{z}Treatment : WL: white light LEDs; WWL: warm white light LEDs; RBL: red-blue light LEDs

^{y}Different in the same column indicated significant differences among treatments ($P \leq 0.05$; n=3).

Table 2. Effect of different light quality LEDs at the same intensity (PPFD =190 μmol·m^{-2}·s^{-1}) on root structural characteristics of hydroponic cultivated spinach indoor (30 DAT).

Treatment^z	Length (cm)	Proj Area (cm^2)	Surf Area (cm^2)	Avg Diam (mm)	RootVolume (cm^3)
WL	915.75 c^y	16.00 b	50.46 c	0.105 c	0.466 b
WWL	1373.33 b	29.20 b	91.98 b	0.191 b	0.492 b
RBL	2071.43 a	52.51 a	174.97 a	0.289 a	2.385 a
LSD5%	*391.22*	*15.6*	*41.54*	*0.035*	*0.29*

^{z}Treatment : WL: white light LEDs; WWL: warm white light LEDs; RBL: red-blue light LEDs

^{y}Different in the same column indicated significant differences among treatments ($P \leq 0.05$; n=3).

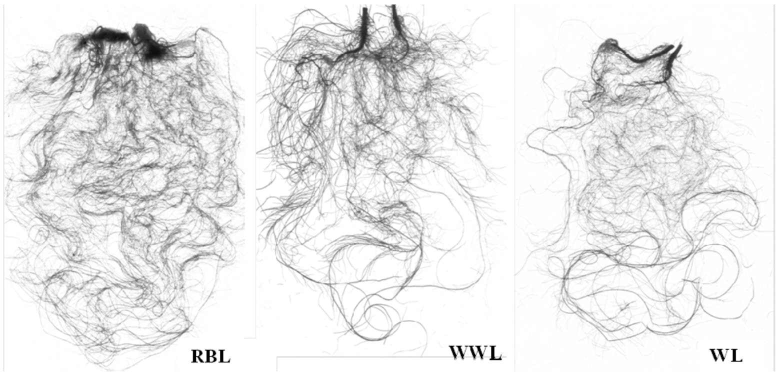


Fig. 2. Hydroponic spinach roots in different light quality LEDs (at the same intensity PPFD =190 μmol·m^{-2}·s^{-1}).

surface-area, project-area, average diameter and average volume were the highest in the RBL treatment. The difference was statistically significant at 5% level between the three treatments in the root length, surface area, and average diameter parameters. There was no significant difference in project-area and root volume in WWL and WL treatments (Table 2, Fig. 2).

3. Productivity

Fresh weight of shoot, fresh weight of root, dry weight of root in the three light qualities were significantly different and the difference was statistically significant at the 5% level. In RBL treatment, the plant weight was the highest (65.46 g/plant), which was higher 2.05 times than in the WL and 1.36 times in WWL treatment. Fresh weight of root was also highest in the treatment of RBL light, was about higher 1.69 and 2.07 than that of in WWL and WL treatments, respectively. Consequently, the actual productivity in three light qualities decreased in the order: RBL > WWL> WL (Table 3, Fig. 3).

Table 3. Effect of different light quality LEDs at the same intensity (PPFD =190 μmol·m^{-2}·s^{-1}) on productivity of hydroponic cultivated spinach indoor (30 DAT).

Treatment^z	FW^y of shoot stem and leaf (g/plant)	FW of root (g/plant)	DW^x of shoot stem and leaf (g/plant)	DW of root (g/plant)	Theoretical productivity (g/m^2)	Final harvest productivity (g/m^2)
WL	31.85 c^w	4.455 c	1.91 b	0.27 c	2312.95	2274.55 c
WWL	48.11 b	5.46 b	2.065 b	0.38 b	3493.75	3395.85 b
RBL	65.46 a	9.23 a	3.58 a	0.62 a	4753.71	4698.04 a
LSD5%	*2.0*	*0.41*	*0.42*	*0.07*	-	*71.1*

^{z}Treatment : WL: white light LEDs; WWL: warm white light LEDs; RBL: red-blue light LEDs

^{y}FW: Fresh weight

^{x}DW: Dry weight

^{w}Different in the same column indicated significant differences among treatments ($P \leq 0.05$; n=3).

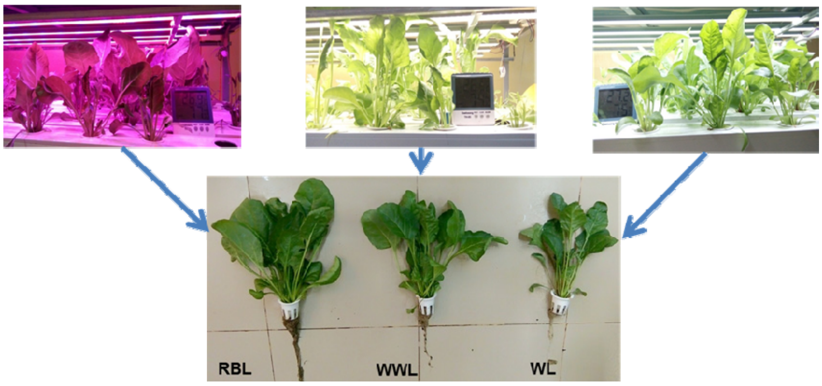


Fig. 3. Hydroponic spinach in different light quality (at the same intensity PPFD=190 μmol·m^{-2}·s^{-1}).

Table 4. Effect of different light quality LEDs at the same intensity (I=190 μmol·m^{-2}·s^{-1}) on content of mineral elements of hydroponic cultivated spinach indoor (30 DAT).

Treatment^z	Ca (mg/g dry weight)	K (mg/g dry weight)	Fe (mg/g dry weight)
WL	1.71 c^y	107.89 a	0.48 c
WWL	11.22 b	101.36 b	0.90 b
RBL	18.37 a	100.82 b	1.24 a
LSD5%	*0.99*	*3.13*	*0.26*

^{z}Treatment : WL: white light LEDs; WWL: warm white light LEDs; RBL: red-blue light LEDs

^{y}Different in the same column indicated significant differences among treatments ($P \leq 0.05$; n=3).

4. Nutrition content and quality

The content of mineral elements varied between treatments and depended on the elements. Content of Ca^{2+} and Fe^{2+} was the highest in the RBL, followed by WWL and WL treatment (with higher about 1.64-10.74 and 1.38-2.58 times, respectively). The difference between the three treatments was statistically significant at the 5% level. In contrast, the highest K^{+} content was observed in WL. This was different from WWL and RBL treatments. But there was no difference between the RBL and WWL treatments (Table 4).

Oxalic acid content was found to be highest in WL treatment, whereas soluble–solids contents and vitamin C contents were observed highest under RBL treatment. Although, the difference in NO_3, soluble–solids contents contents were not statistically significant between WWL and WL treatments, respectively. In which, vitamin C content was significantly different between three treatments. Here, oxalic acid content in RBL treatment was not different from WL and WWL treatment but there was a significant difference between WL and WWL treatments (Fig. 4).In all three different light treatments were not detected *Salmonella, E.Coli* (Table 5).

Discussion

Plants appear green because a part of the natural green light is not absorbed but is reflected. Green light is considered previously not to be absorbed by plant (Ohasi et al., 2007). Whereas some researches showed that green light could play role in stem elongation (Folta, 2004). The photosynthetic capacity was increased significantly under green light if light intensity was higher than 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Johkan et al., 2012). In this study, SPAD, Pn and Fv/Fm values were observed relatively stable and similar when different ratio of green light was supplement to red-blue light. Green light also is known to enhance photosynthesis deeper in the canopy (Bantis et al., 2018), increasing photosynthetic ability and growth (Son et al., 2015; Bian et al., 2018). Previous research has shown that, at the same Pulse frequency (50 Hz and 25 Hz) chlorophyll a, chlorophyll b and carotenoids in red lettuce seedlings exposed to pulsed green LED light under temperature stress higher than exposed to white LED light. In the range of chlorophyll b the highest values were for green light treatment at 25 Hz (Pardo et al., 2016). Moreover, studying effect of light quality on tomato (*Solanum lycopersicum* L) seedling indicated that, compared with yellow light, the values of ΦPSII, ETR, qP and NPQ of plants exposed to green light were significantly increased, showing that green light was beneficial to both the development of photosynthetic apparatus to some degree (Wu et al., 2014). It was suggested that the green light may have a certain role in regulating plant photosynthetic characteristics. Nevertheless, the underlying mechanisms remain unclearly.

In the present study, the root structural characteristics and photosynthetic capacity of spinach were significantly influenced by light qualities. The results pointed out that plants were grown under combination of R and B lights, especially had higher Pn values and enhanced plant growth parameters. The plant growth and development are affected light qualities through many photoreceptors lead to change plant morphology. This was consistent with previous studies (Wu et al., 2014; Su et al., 2014).

Our findings on photosynthetic capacity and growth were also closely coincide with report by Johkan et al. (2012). According to those reseachers, although different light quality for all treatments were applied at the same PPFD level, plants had higher chlorophyll absorption in treatment combination of R and B lights, in particular photosynthetic efficiency was observed maximum under light treatment 80R:20B (Johkan et al., 2012). Hence, supplement green light significantly induced to reduce Pn, which could lead to accelerate leaf senescence and reduce the maximal photochemical efficiency of PSII (Fv/Fm) (Su et al., 2014). Leaf area and fresh weight, root lenght and root weight in this study were also similar to the research of Su et al. (2014).

Our results also had similarities about chlorophyll content to research of Mizuno et al. (2009) in cabbage under LEDs of 470, 500, 525 and 660 nm, respectively, at 50 $\mu mol/m^2/s$ PPFD, which showed that chlorophyll contents were higher under blue and blue-green light than under green light

Besides, our study was also closely coincide with Son et al. (2015), that determined the effect of different proportional LED lights (red, green and blue) on lettuce under PPFD of 173 ± 3 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Their study indicated that, red LEDs

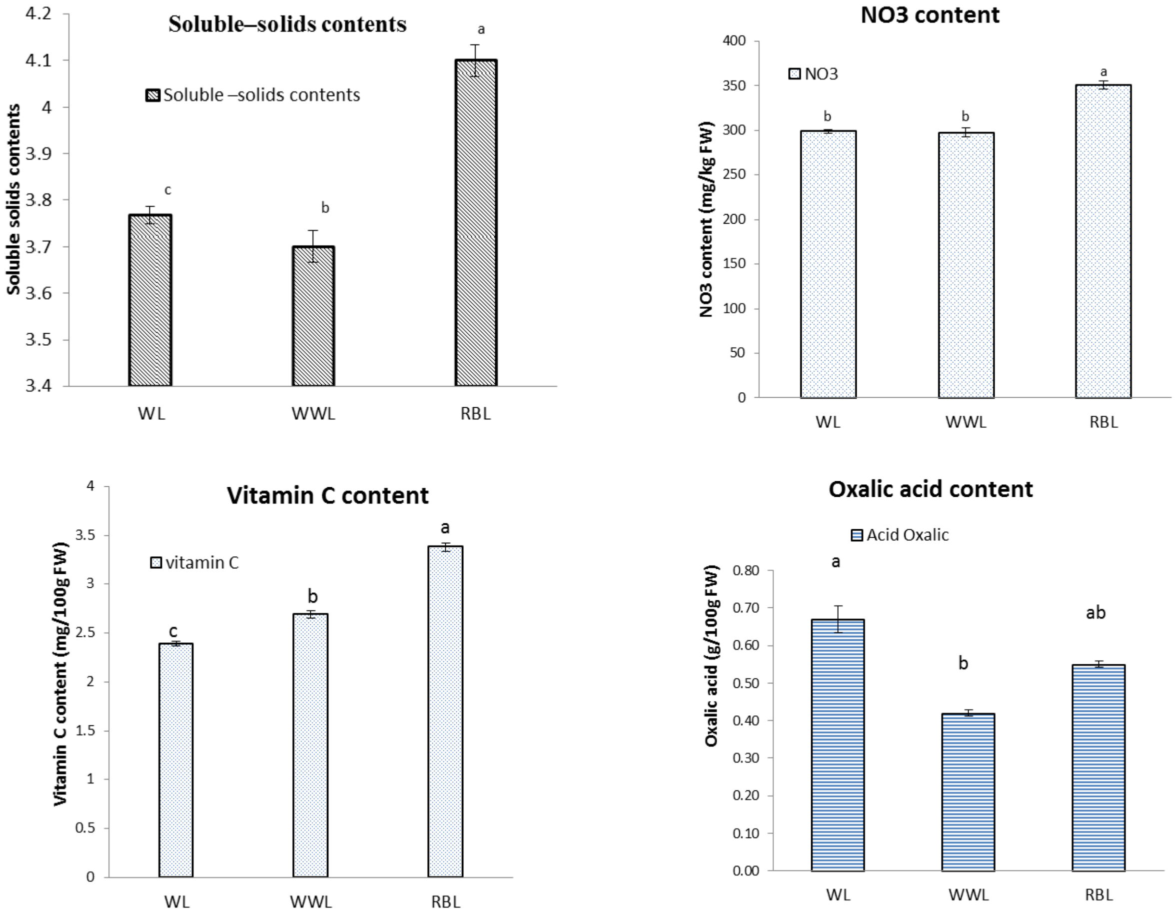


Fig. 4. Effect of different light quality LEDs at the same intensity (PPFD=190 μmol·m^{-2}·s^{-1}) on some nutritional parameters of hydroponic cultivated spinach indoor (30 DAT). The error bars is standard errors.

Table 5. Effect of different light quality LEDs at the same intensity (PPFD=190 μmol·m^{-2}·s^{-1}) on safe vegetable parameters of hydroponic cultivated spinach indoor (30 DAT).

Treatment^{z}	E.Coli	Salmonella
WL	None	None
WWL	None	None
RBL	None	None

^{z}Treatment : WL: white light LEDs; WWL: warm white light LEDs; RBL: red-blue light LEDs

improved some growth characteristics of lettuce such as fresh and dry weight of shoot and root, and leaf area within combination with blue LEDs. These growth parameters increased as the proportion of red LEDs increased in the combination of red and blue LEDs (except for treatments with green LEDs). The replacement of blue with green LEDs in the presence of a fixed ratio of red LEDs has promoted the growth of lettuce. In particular, the fresh weights of red leaf lettuce shoots under R8G1B1 were about 61% higher than that of R8B2. Furthermore, the additional irradiation of green LEDs based on a combination of red and blue LEDs can promote the growth of lettuce. In contrast, increasing the proportion of blue LEDs had a negative effect on the fresh and dry weight of shoot and root, and leaf area. In our results, increasing ratio of green light not was not clearly effect on plant height but reduced leaf number.

Resulting in final harvest productivity matched the red-blue light LED perfectly that can produce optimum wavelengths for plant photosynthesis as Shimokawa et al. (2014).

Our results of the sucrose content through the soluble–solids contents index and some growth parameters were consistent with research of Li et al. (2017). In their study, the effect of different light qualities generated by LEDs with the same PPFD on growth and carbohydrate accumulation in tomato seedling leaves were evaluated. The results showed that, the seedling plant height and stem diameter were significantly promoted by combination of red (R) and blue (B) lights and monochromic R light than others. However, the level of root growth was lower under R and purple (P) light. The leaf Pn of the seedlings was highest in plants grown under 3R1B light. Combination of R and B lights and monochromic B light was found significantly to increased compared with those under white (W) light. Moreover, R light significantly enhanced fructose and glucose content, and combination of R and B lights significantly impove total carbohydrate, starch and sucrose accumulation, especially for 3R1B treatment.

Some researchers have been indicated that oxalic acid can increase the hyperoxaluria that contributes to the formation of kidney stones, so people with a history of kidney and bile stones have limited oxalic acid absorption (Proietti et al., 2013).

Results of the present study showed that when increasing ratio green light (550 nm) supplement may reduce NO_3 and oxalic acid content in the case of an appropriate ratio, here ratio R/B/G was 5/2/1. However, there was no significant improvement in ascorbic acid content in this ratio. From this viewpoint, obviously, the higher ratio of red light treatment induced higher ascorbic acid, lower NO_3 and lower oxalic acid content. This result was similar to Samuoliene et al. (2009) in leafy vegetables. In that research nitrate concentration reduced by 44% to 65% and the content of vitamin C was not directly correlated with the nitrate reduction rate when using 638nm LED (500 $\mu mol/m^2/s$).

Thus, NO_3 content of hydroponic cultivated spinach in this study had safety standards at the permitted limit of Agriculture Ministry under Decision No. 99/2008 /QD-BNN. Even the result of this NO_3 content was much lower than the European Commission's regulation: 1258/2001 (European Commission Regulation, No: 1258/2001, EUR-LEX, 2017).

Spinach can be eaten raw, so problem of food safety is very important. The *E. coli* group of intestinal hemorrhagic colitis (EHEC) and most *salmonella* cause prolonged diarrhea. These bacteria cause gastrointestinal illness: eating contaminated food such as bovine and eat, goat, sheep, unpasteurized cow's milk; vegetables, fruits, etc. These bacteria also spread directly from person to person through the hands or objects contaminated with faces. Our results showed that spinach was not completely infected with the two pathogenic bacteria. The study of the authors on Korean green perilla also showed that E.coli, Salmonella, Worm eggs were not found in hydroponic perilla samples, only Coliforms were detected (1,36 × 100 (CFU/g) but the content was within permitted limit of Vietnam standards (2 × 10^2 (CFU/g)).

The results of this study suggest that the ratio of red, green, and blue LEDs is an important factor for the growth, photosynthetic capacity and biosynthesis of metabolites in hydroponic cultivated spinach. RBL may be appropriate light for growth of spinach, but the supplemental irradiation of green LEDs based on the combination of red and blue LEDs at the reasonable rate can change the quality of spinach in a positive direction. However, there is limited information on the effects of supplementary green light to a combination of red and blue LEDs and the underlying mechanisms remain unclearly. Hydroponic cultivated spinach was the safe vegetable for consumers.

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수경재배 식물공장에서 다양한 보광 LED가 시금치의 생육과 수량에 미치는 영향

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적 요. 본 연구는 폐쇄형 식물공장에서 시금치 수경재배시 세가지의 인공광이 생육, 광합성 및 품질에 미치는 영향을 규명하기 위해 수행되었다. 세가지 광 처리구는 적색 (660nm), 청색 (450nm) 및 녹색 (550nm) LED를 사용하여, R660 / B450 = 4/1 (RBL), R660 / B450 / G550 = 5/2/3 (WWL); R660 / B450 / G550 = 1/1/1 (WL) 비율로 혼합하였고, 동일한 광도로 설정하였다 (PPFD = 190 $\mu mol \cdot m^{-2} \cdot s^{-1}$). 생육조사결과 초장, 엽수는 WL이 가장 적었다. SPAD, 순광합성율, Fv/Fm, LAI, 근권부 생육은 RBL이 가장 높았고 통계적으로 유의하였다. 줄기, 잎, 뿌리의 생체중, 뿌리의 건물중은 세가지 처리구에서 유의한 차이를 보였다. 대조적으로 WL의 칼륨의 함량은 WWL과 RBL 가운데 가장 높았지만, 반면 칼륨과 철의 함량은 RBL이 가장 높았다. 비타민C 함량도 시험구간 유의한 차이를 보였다. 질소와 옥살산 함량은 WL이 가장 높았고, 용해성 고체와 비타민C 함량은 RBL이 가장 높았다. 옥살산, 질소 함량은 WWL에서 감소하는 경향을 보였고, RBL의 옥살산 함량은 WL와 WWL과 차이가 없었다. 모든 처리구에서 Salmonella, E.coli.는 감염되지 않았다. 결론적으로, RBL이 시금치의 생육에 적합하지만, 적색, 청색과 적정하게 혼합된 녹색광은 시금치의 생육에 긍정적인 영향을 미친다고 판단된다.

추가 주제어: 인공광, 질소함량, 옥살산산, 비타민C