Korean J. Plant Res. 32(3):228-236(2019)
https://doi.org/10.7732/kjpr.2019.32.3.228

Print ISSN 1226-3591
Online ISSN 2287-8203

Original Research Article

Growth Characteristics and DPPH Radical Scavenging Activity of Lettuce 'Fidel' in Plant Factory Using Activated Mineral Groups and Light-emitting Diode Lights

Tae-Eui Song[1], Seong-Jik Park[2], Joon-Kwan Moon[3], In Soo Kim[4] and Chang Hee Lee[5]*

[1]Graduate Student and [5]Professor, Department of Horticulture Life Sciences, Hankyong National University, Anseong 17579, Korea

[2]Professor, Department of Bioresources and Rural Systems Engineering, Hankyong National University, Anseong 17579, Korea

[3]Professor, Department of Plant Life and Environment Sciences, Hankyong National University, Anseong 17579, Korea

[4]CEO, Insungtec Company Limited, Yongin 17115, Korea

Abstract - This study is conducted to investigate the effects of growth characteristics (GC) and DPPH radical scavenging activity (DRSA) of the heading lettuce 'Fidel' depending on four concentrations of activated mineral groups (AMG: 1.6% active minerals and 0.03% CaO) added to basic nutrient solutions (diluted by 0, 0.05, 0.1, and 0.2%) and on four different light-emitting diodes (LED; B:R:W ratio = 0:1:12, 0:1:9, 0:5:5, and 2:3:5). Both 0.1 and 0.2% AMG showed better GC of lettuce in plant width, plant length, leaf width, leaf length, and the number of leaves than those of other AMG, while leaf thickness and chlorophyll value did not show significant difference among all AMG. Moreover, 0.1 and 0.2% AMG showed heavier shoot fresh weights than those of other AMG. As for the combinations of AMG and LED, B0:R5:W5 showed the best lettuce GC regardless of AMG compared to other AMG and LED combinations. As shown in the above results of LED, although there was a difference in lettuce growth by LED, the differences of lettuce growth by AMG were statistically significant. The DRSA was the highest at 82.8% in B2:R3:W5, followed by B0:R5:W5 at 77.8%. LED showed differences but AMG did not affect DRSA. Therefore, the optimal conditions in plant factory for GC and DRSA of the lettuce were 0.1% AMG and B0:R5:W5.

Key words – Fidel, Growth characteristics, Heading lettuce, LED, Plant factory, Radical scavenging activity

Introduction

Recently, protection cultivation has been steadily increasing in order to supply consumers constantly with vegetables. Among leafy vegetable, Oriental cabbage was produced the highest in cultivation under structure (37%), followed by lettuce (25%) (MAFRA, 2018). Lettuce is consumed as fresh-cut salads and raw vegetables and produced all the year round. Among the various lettuce varieties, romaine lettuce is used mainly for salads and sandwiches, also butterhead lettuce is known as a loose arrangement of leaves and has a sweet taste and tender texture. Lettuce is made up of 95% water content. It is possible to fill the lack of moisture in the interior of the body, and it contains vitamins A, B, C, E, and a large amount of iron is effective in health promotion (Jang *et al*., 2007).

It has been reported that there is a large difference in growth depending on the environmental conditions, concentration of nutrient solution and the quality and intensity artificial light source. The development of a nutrient solution based on the water uptake rate suitable for hydroponic cultivation of lettuce (Choi *et al*., 2005; Nam *et al*., 1997) has been initiated in the cultivation of lettuce in plant factories. Though N, P, K, Ca, Mg, and SO_4 in the nutrient solution are constantly supplied, but antagonism among minerals can frequently occur at plant factory. For example, calcium absorption is known to be inhibited by antagonism with NH_4, K, Mg (Bangerth, 1979; Choi *et al.*, 1999; Kozai *et al*., 1992). The concentration of EC

*Corresponding author. E-mail : Changheelee@hknu.ac.kr
Tel. +82-31-670-5102

in the nutrient solution is generally suitable for 2.0~2.2 dS·m^{-1} and proper EC also affects the storage quality and chlorophyll value (Cha *et al.,* 2012; Lee and Chang, 2017). Also the pH of the cultivation of lettuce is suitably in the range of 5.0~7.0 (Park *et al*., 1999) and it affects the change of pH concentration according to the composition of fertilizer (Shin *et al*., 2013). The supplement of microelements to the nutrient solution has a goal of promoting resistance to physiological disorders and pests of the plants. Futhermore, certain minerals act as important factors for health promotion and prevention of diseases. Thus, It is necessary to produce more high-quality agricultural products by supplying nutrient solutions suitable for lettuce (Suh *et al.,* 2006). Moreover, differences in wavelengths of light-emitting diodes (LED) in plant factories regulate photosynthesis, growth, and antioxidant activity (Cha *et al.,* 2013; Hiroshi *et al.,* 2011; Li *et al.,* 2019).

This study was carried out to find both the content of a nutrient additive and the appropriate LED wavelength increasing the productivity and antioxidant activity of heading lettuce within a plant factory with environmentally friendly and stable production capacity for all year-round. Thus, the aim of this experiment is conducted to investigate the effects of growth characteristics and DPPH radical scavenger of the heading lettuce 'Fidel' depending on four concentrations of activated mineral groups (AMG) as a nutrient additive added to nutrient solutions and on four different LED.

Materials and Methods

Plant materials and Plant Factory

The experiment was conducted with nutrient film technique (NFT) that cultivation method in plant factory (Insungtec Co., Ltd., Yongin, Korea). The heading lettuce used for cultivation was *Lactuca sativa* L. cv. Fidel purchased from Bayer Crop Science (Seoul, Korea). Environmental conditions within plant factory were maintained at 22.5±2.5℃ and 80±5% RH (Fig. 1). Day/night cycle for light was operated on 13/11 h. The heading lettuces were transplanted to NFT beds on a bed within plant factory at 2 weeks after sowing and then harvested at the 5th week after transplanting in order to investigate their growth characteristics.

AMG and LED

The basic nutrient solutions used in the experiment were shown as follows (Table 1). AMG is composed of complex active minerals (Dr. Mineral®, 1.6%, 23 minerals, Eco-biotec Co., Ltd., Hwaseong, Korea) and natural highly active calcium (CaO, 0.03%, Eco-biotec Co., Ltd., Hwaseong, Korea). As for the chemical properties of AMG, the purity and ionic activity of CaO are high through heat treatment. Also, the ionic activity is 3 to 5 times higher than that of calcium oxide. The high calcium contained in AMG weakens the binding force of oxygen and the electrons are very unstable, but it reacts well with atoms and is easily water uptake (Eco-biotec, 2019). AMG

Fig. 1. Heading lettuce 'Fidel' and NFT system in the plant factory used in this experiment.

Table 1. Comparison of nutrient solutions between Basic and Yamazaki (unit : me·L^{-1})

Nutrinent Solution	NO_3-N	NH_4-N	PO_4-P	K	Ca	Mg	SO_4-S
Basic[z]	12.4	0.6	1.7	6.2	6.2	1.3	1.3
Yamazaki[y]	8.0	1.0	3.0	6.0	2.0	1.5	1.5

[z]Basic : the nutrient solution supplied by Insungtec Co., Ltd. used in this experiment.
[y]Yamazaki : the nutrient solution optimized for lettuce by Yamazaki.

solutions were added to the basic nutrient solution at 0, 0.05, 0.1 and 0.2%, respectively, in order to find AMG concentration suitable for promoting the heading lettuce growth.

In the 1st experiment by the AMG concentrations above, 21 seedlings per 4 blocks (total 84 seedlings per one bay) were transplanted per each AMG concentration. To investigate the changes in the weekly growth of the heading lettuce, we measured shoot fresh weight (SFW) by harvesting 5 seedlings per week up to 5th week after transplanting. Total 40 heading lettuces per treatment were investigated on the 5th week after transplanting. Data on plant width, plant heigh, the number of leaves, leaf width, leaf length, leaf thickness, chlorophyll value (SPAD), and SFW were recorded.

In the 2nd experiment, total 16 treatments were performed by combining the four AMG concentrations used above and the four LED treatments. The LED (DMLED Co., Ltd., Ansan, Korea) consisted of a combination of three color LED (B: blue; R: red; W: white) and the four LED treatments were as follows: B0:R1:W9 (128 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 20W), B2:R3:W5 (119 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 20W), B0:R5:W5 (128 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 20W), and B0:R1: W12 (136 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 24W). 7 seedlings per 3 lines (total 21 seedlings) were transplanted per each combination. Total 21 heading lettuces per treatment were investigated on the 5th week after transplanting. The recorded data was the same as above.

Radical scavenging activity (*DPPH assay*)

A sample (100 mg dry sample+2 mL 60% methanol) extracted from 'Fidel' was diluted in 96 well plate and 100 μL was added. 100 μL of 2 mM DPPH solution (in ethanol) was added there to, and after 30 min of reaction at 37℃, the absorbance was measured at 517 nm and the antioxidant activity was calculated using the following equation.

$$\left(1-\frac{Sample\ Absorbance}{Negative\ control\ Absorbance}\right)\times 100$$

At this time, 60% methanol not containing the sample was used as a negative control, and L-ascorbic acid was used as a positive control to confirm the measurement.

Statistical analysis

All data were subjected to an analysis of variance and means were compared by Duncan's multiple range test (DMRT) at 5% significant level and to ANOVA model (Statistical Analysis System, V9.3, Cary, NC, USA). SigmaPlot (Ver 10.0, USA) was used for graphic results.

Results and Discussion

Growth characteristics in heading lettuce by AMG concentrations added to nutrient solution

The growth characteristics of 0.1 and 0.2% AMG were the best growth characteristics including plant width, plant height, leaf width, leaf length, the number of leaves, and SFW than those of 0 and 0.05% AMG. However, leaf thickness and chlorophyll value were not significantly different from those of other AMG at the 5th week after transplanting. Moreover, there was no significant difference in all growth characteristics between 0.1% and 0.2% AMG (Table 2). The SFWs of 0.1

Table 2. Growth characteristics of heading lettuce 'Fidel' influenced by AMG at the harvest stage[z]

AMG (%)	Plant width (㎜)	Plant height (㎜)	Leaf length (㎜)	Leaf width (㎜)	Leaf Thickness (㎜)	SPAD	No. of leaves	Shoot fresh weight (g)
0	335.50 c[y]	38.76 b	168.93 c	129.77 b	0.249 a	29.96 a	41.3 b	82.09 b
0.05	357.25 b	40.98 a	191.50 b	134.55 b	0.246 a	29.83 a	41.3 b	85.60 b
0.1	369.75 ab	41.42 a	202.03 a	144.85 a	0.254 a	30.72 a	46.3 a	115.04 a
0.2	381.00 a	41.58 a	208.93 a	144.36 a	0.254 a	29.99 a	47.3 a	114.78 a
Significant	***	**	***	***	ns	ns	***	***

[z]Harvest stage: the 5th week after transplanting.
[y]Mean separation within columns by Duncan's multiple range test at P = 0.05.
[NS,**,***]Non-signification or signification at P = 0.01 or 0.001, respectively.

and 0.2% AMG were the heaviest at 115.0 g and 114.8 g, respectively, but there was no statistically significant difference between them. The number of leaves of 0.1 and 0.2% AMG were the highest at 46.3 and 47.3, respectively. Other growth factors are important, but heading lettuce has rosette-type leaves, so productivity can be estimated as SFW.

As shown on Fig. 2, the heading lettuce growth patterns based on SFW increased slowly from 1 week to 2 weeks after transplanting but increased dramatically ranged from 3 to 5 weeks (Fig. 2). All SFWs reached 80~120 g at the 5th week after transplanting. Since the plant is generally shipped about 100 g in a plant factory, the 5th week after transplanting was regarded as the most suitable harvesting time. Thus, nutrient management between 3 and 5 weeks was very important.

Jang *et al.* (2012) reported that the growth and productivity of lettuce increased by 18.12% compared to the control when chelate calcium was foliar-sprayed. Using the calcium salt is rarely reported that related to changes in the quantity. Moon (1999) was reported that the natural liquid calcium extracted from the oyster shell was sprayed on the lettuce in the harvesting season, and the yield was increased by 10.8%. Lettuce was a crop with a high requirement for calcium, but calcium was difficult to absorb into the root, so it was generally treated with foliar-spray method. Ahn *et al.* (2011) reported that the increase of the product by the foliar fertilization improves the

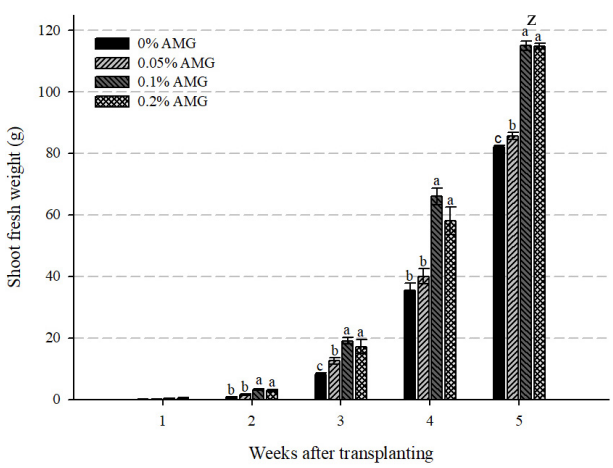

Fig. 2. Weekly changes of the shoot fresh weight of heading lettuce 'Fidel' depending on AMG concentration. [z]Mean separation within columns by Duncan's multiple range test at $P = 0.05$.

quality of the lettuce by spraying the calcium on the foliage even in the suppression of the absorption at the high temperature. In the hydroponic culture, however, the lettuce growth produced by plant factory through the application of the calcium compound added to the nutrient solution have not been almost studied. Since most of the plant factory system adopts the hydroponic cultivation method, it is necessary to study the effect of calcium ions, which are not easily absorbed through the roots, in the nutrient solution and absorb them into the lettuce efficiently to promote the growth. Based on the results described above, the 0.1% AMG and 0.2% AMG added to the nutrient solution increased SFWs 1.39~1.4 times compared to the nutrient solution without AMG. However, 0.1% AMG was the most suitable AMG concentration for 'Fidel' because there was no significant difference between 0.1 and 0.2% AMG in SFW.

Growth characteristics in heading lettuces by the combination of AMG and LED

Through AMG and LED combinations, the growth characteristics of heading lettuce except SFW were measured at 5th week after transplanting as the same method above as follows Table 3. When compared only with AMG concentrations in the AMG and LED combinations, there was a significant difference in the growth characteristics as described in the 1st experimental results above, but the four LED regardless of AMG concentration showed little significant difference such as plant height, leaf thickness, leaf number, and chlorophyll value. As for the results of LED, both B0:R5:W5 and B0:R1:W12 showed significantly higher values than other LED in all growth characteristics except for plant height and leaf thickness. As AMG concentration increased, the average value tended to increase in plant width, leaf length, leaf width, leaf thickness, and the number of leaves, respectively. As shown in Table 3, 0.1% and 0.2% AMG among AMG and LED combinations showed the highest growth characteristics than other AMG regardless of LED.

SFWs at 5th week after transplanting of 0.1 and 0.2% AMG were heavier than other combinations regardless of LED (Fig. 3). In the LED comparison, B0:R5:W5 showed the best SFW and statistically significant difference was observed compared with B0:R1:W9, B2:R3:W5, and B0:R1:W12. Therefore, red

Table 3. Growth characteristics of heading lettuce 'Fidel' influenced by AMG and LED at the harvest stage[z]

AMG (%)	LED ($\mu mol \cdot m^{2} \cdot s^{-1}$)	Plant width (㎜)	Plant height (㎜)	Leaf length (㎜)	Leaf width (㎜)
0	B0:R1:W9 (128)	314.4±12.0	50.5±3.8	166.2±8.7	122.1±5.7
	B0:R5:W5 (119)	340.0±23.5	49.6±5.1	170.9±14.2	119.8±11.3
	B2:R3:W5 (128)	333.3±20.1	44.5±4.8	155.9±4.1	110.4±3.4
	B0:R1:W12 (136)	335.2±17.0	47.5±4.1	170.5±12.7	120.8±11.8
	AVG	330.4b[y]	48.0a	165.6b	118.3b
0.05	B0:R1:W9 (128)	333.9±16.0	43.1±4.3	171.6±8.6	121.5±8.5
	B0:R5:W5 (119)	351.4±16.0	42.4±3.0	173.9±8.6	126.8±10.2
	B0:B2:R3:W5 (128)	327.0±18.0	42.1±3.8	162.6±14.6	117.2±8.6
	B0:R1:W12 (136)	347.4±16.2	44.6±2.1	173.3±11.5	122.6±9.4
	AVG	339.3b	43.0b	170.2b	121.7b
0.1	B0:R1:W9 (128)	345.8±8.8	41.9±2.5	175.0±9.1	121.1±7.8
	B0:R5:W5 (119)	359.2±15.3	39.3±0.5	188.3±13.1	136.6±6.1
	B2:R3:W5 (128)	354.3±9.2	43.8±3.5	190.1±15.1	130.1±6.7
	B0:R1:W12 (136)	368.3±8.6	42.2±6.3	192.6±11.0	134.7±8.5
	AVG	357.4a	41.8b	187.0a	131.0a
0.2	B0:R1:W9 (128)	339.4±18.7	38.3±3.7	182.8±11.6	137.2±10.0
	B0:R5:W5 (119)	364.7±20.1	41.9±3.8	193.4±12.1	133.9±12.9
	B2:R3:W5 (128)	341.1±16.3	40.4±2.0	173.8±14.2	122.9±11.6
	B0:R1:W12 (136)	368.4±9.0	43.6±2.9	193.9±12.8	131.7±5.2
	AVG	353.4a	41.0b	185.9a	131.2a
Significant					
AMG		***	***	***	***
LED		***	ns	***	**
AMG×LED		***	***	***	***

[z]Harvest stage: the 5th week after transplanting.
[y]Mean separation within columns by Duncan's multiple range test at P = 0.05.
[NS,**,***]Non-signification or signification at P = 0.01 or 0.001, respectively.

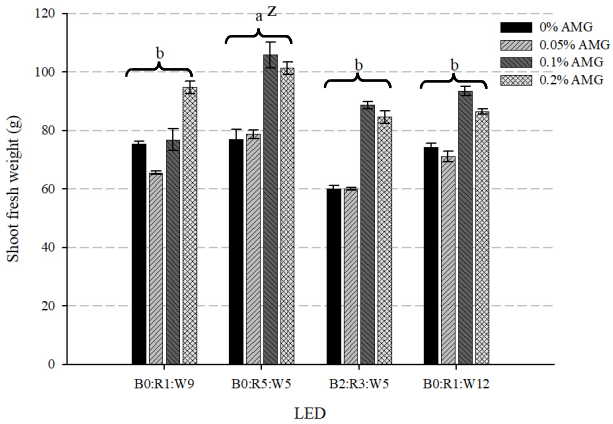

Fig. 3. The shoot fresh weight of heading lettuce 'Fidel' influenced by LED and AMG. [z]Mean separation within columns by Duncan's multiple range test at P = 0.05.

LED was considered to have a positive effect on the heading lettuce growth factors such as plant width, leaf width, leaf length and the number of leaves which determine the productivity of heading lettuce rather than white LED or blue LED. Cha *et al.* (2013) suggested that the combination of LED wavelengths for lettuce cultivation is most suitable for red 50%, blue 30%, and white 20%. Ha *et al.* (2012) reported that the lettuce growth rate was the best increased with red LED among single color LED, and also R4:B1 was the best condition when mixed LED were used.

Park *et al.* (2013) reported that when white LED alone was used, light intensity and photoperiod were the best lettuce growth at 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and 24 h, respectively. Kim *et al.*

Table 3. Continued

AMG (%)	LED ($\mu mol \cdot m^2 \cdot s^{-1}$)	Leaf thickness (㎜)	No. of leaves (ea)	SPAD
0	B0:R1:W9 (128)	0.25±0.02	35.6±2.8	30.5±2.2
	B0:R5:W5 (119)	0.25±0.02	38.7±3.1	30.8±1.2
	B2:R3:W5 (128)	0.24±0.02	34.9±1.7	31.9±1.7
	B0:R1:W12 (136)	0.25±0.02	37.1±2.9	31.2±0.9
	AVG.	0.25b	36.4d	31.1a
0.05	B0:R1:W9 (128)	0.24±0.01	39.9±2.2	28.6±1.1
	B0:R5:W5 (119)	0.25±0.01	40.6±3.2	29.3±0.9
	B2:R3:W5 (128)	0.25±0.01	39.0±2.3	29.5±1.8
	B0:R1:W12 (136)	0.25±0.01	39.9±1.9	29.4±1.4
	AVG.	0.25b	39.8c	30.6a
0.1	B0:R1:W9 (128)	0.23±0.02	39.0±2.2	29.2±2.3
	B0:R5:W5 (119)	0.25±0.01	43.2±1.8	31.1±2.1
	B2:R3:W5 (128)	0.26±0.02	42.7±1.8	31.7±2.9
	B0:R1:W12 (136)	0.25±0.01	42.8±1.3	30.3±2.2
	AVG.	0.25b	42.0b	29.2b
0.2	B0:R1:W9 (128)	0.28±0.02	44.1±2.6	30.4±2.6
	B0:R5:W5 (119)	0.26±0.02	44.8±4.2	32.0±1.5
	B2:R3:W5 (128)	0.26±0.01	42.6±5.4	32.4±1.3
	B0:R1:W12 (136)	0.25±0.02	43.1±1.5	31.2±1.9
	AVG.	0.26a	43.6a	31.5a
Significant				
AMG		***	***	***
LED		ns	*	*
AMG×LED		***	***	***

[z]harvest stage: the 5th week after transplanting.
[y]Mean separation within columns by Duncan's multiple range test at P = 0.05.
[NS,*,***]Non-signification or signification at P = 0.05 or 0.001, respectively.

(2017) suggested that the SFW of the lettuce was higher than that of the other treatments at the R:G:B (6:3:1) with the higher ratio of red LED. Son and Oh (2015) reported that red LED were found to improve growth characteristics such as fresh and dry weights of shoots and roots. furthermore, the SFW of red leafy lettuce under R8:G1:B1 were about 61% higher than those under R8:B2, and thus, green LED also showed some positive effect on lettuce growth. Kim *et al*. (2017) reported that growth characteristics of rapeseed (*Brassica napus* L.) were the most effective in mixed LED light (blue:red=4:6). The mixed LED had the highest fresh weight (42.78 g/plant) followed by red (30.77 g/plant), blue (14.66 g/plant) and fluorescent lamp (4.66 g/plant).

In our results, AMG was more significant than LED in the result of the combination of AMG and LED (Table 3). Noh e*t al*. (2011) reported that the correct addition conditions must be presented because the nutrient uptake rate is proportional to the light intensity and the nutrient uptake rate is different according to the nutrient solution when the EC concentration is the same.

In particular, when vegetables were cultivated in a circulating nutrient solution method, since the concentration of the nutrient solution is generally controlled on the basis of EC, it is not known whether the concentration of the specific element in the

Table 4. DPPH radical scavenging activity of heading lettuce 'Fidel' influenced by LED and AMG

LED ($\mu mol \cdot m^{2} \cdot s^{-1}$)	AMG (%)	DPPH radical scavenging activity (%)
B0:R1:W9 (128)	0	58.09±2.40
	0.05	72.88±3.29
	0.1	70.35±7.18
	0.2	63.11±10.48
	AVG.	67.14c[z]
B0:R5:W5 (119)	0	73.58±3.96
	0.05	82.65±6.23
	0.1	82.53±3.95
	0.2	70.35±15.26
	AVG.	77.87ab
B2:R3:W5 (128)	0	79.01±10.95
	0.05	74.36±9.25
	0.1	87.98±0.46
	0.2	88.62±0.93
	AVG.	82.81a
B0:R1:W12 (136)	0	76.95±10.12
	0.05	65.22±5.02
	0.1	64.83±22.60
	0.2	82.26±5.15
	AVG.	73.00bc
Significant		
LED		**
AMG		ns
LED×AMG		**

[z]Mean separation within columns by Duncan's multiple range test at P = 0.05.
[NS,**]Non-signification or signification at P = 0.01.

nutrient solution is high or low (Cho *et al*., 1997; Noh *et al*., 2011). Moreover, the growth characteristics of lettuce are different from those of other cultivar as the growth of lettuce (Cha *et al*., 2012; Um *et al*., 2011). It was suggested that if the growth rate of lettuce is rapidly increased, the phosphoric acid in the nutrient solution may decrease and then antagonistic action among calcium, magnesium, and potassium may occur. Therefore, adjusting the EC concentration of the nutrient solution to 2.0 or less under high intensity condition could improve the quality of lettuce (Cha *et al*., 2012).

In this study, B0:R5:W5 showed the best growth of heading lettuce among LED, which is believed to be due to the positive effect of red LED on growth, as reported in other studies. Among the LED, B0:R1:W12, which has the highest light intensity (136 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 24W), showed the second best heading lettuce growth because the number of white LED was higher than those of other LED (119~128 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 20W), despite the small number of red LED. However, since the red LED is about 10 times more expensive than the white LED, it is suggested that when combining the red LED and the white LED, the number of white LED is increased to secure an appropriate light intensity, thereby promoting the growth of the heading lettuce economically. As for the combinations of AMG and LED, Both combinations of 0.1, 0.2% AMG and B0:R5:W5 showed the best growth of heading lettuce among AMG and LED combinations. Thus, we recommended that 0.1% AMG and B0:R5:W5 are the most efficient for the heading lettuce growth.

Measurement of DPPH radical scavenging activity

The radical scavenging ability of the heading lettuce 'Fidel' according to the combination of AMG and LED was as follows Table 3. Experimental results showed no statistically significant difference among AMG treatments added to the nutrient solution regardless of LED. On the other hand, the radical scavenging ability of each LED light source was statistically significant. When compared only with LED in the AMG and LED combinations, the highest radical scavenging ability (82.81%) was observed in B2:R3:W5 containing blue light. The B0:R5:W5 showed the second highest radical scavenging ability (77.87%) in the radical scavenging ability. Therefore, LED showed differences in DPPH radical scavenging activity but AMG did not affect DPPH radical scavenging activity. Among the combinations of AMG and LED, both the combination of B2:R3:W5 and 0.2% AMG (88.6%) and the combination of B2:R3:W5 and 0.1% AMG (88.0%) showed the highest activity in DPPH radical scavenger.

Park *et al.* (2017) reported that in a bearish cabbage, the DPPH radical scavenging function by fluorescent lamps, white LED, blue LED, red RED, and mixed LED (R2:B1) were not significantly different. On the other hand, Kim *et al.* (2016) reported that the antioxidant activity of ice plants were the highest under the RBW (red:blue:white=8:1:1, 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$)

in a closed-type plant production system. Son and Oh (2015) reported that antioxidant capacity under R7:B3 were significantly higher at 61~67%, compared with those under R9:B1 and the fluorescent lamp, respectively. Moreover, Son *et al.* (2012) reported that blue LED accumulated antioxidant functions of lettuce. Thus, this study is similar to the one in which the treatment with blue light has the highest DPPH radical scavenging ability. Our results showed that blue LED were more effective at inducing antioxidant activity than other LED, similar to other studies described above.

In conclusion, although the combination of 0.1% AMG and B2:R3:W5 were more effective in DPPH radical scavenging activity of heading lettuce 'Fidel' than the combination of 0.1% AMG and B0:R5:W5. However, considering both the productivity and antioxidant activity of heading lettuce 'Fidel', we recommend the optimal conditions in plant factory for growth characteristics and DPPH radical scavenger of the heading lettuce 'Fidel' were 0.1% AMG and B0:R5:W5 combination.

Acknowledgement

This work was supported by a research grant from Hankyong National University for a academic exchange program in 2018.

References

Ahn, S.H., S.W. Kwon, M.J. Uhm, J.H. Lee and Y.J. Song. 2011. Effects of calcium foliar treatments on leaf calcium concentration and yield of lettuce in summer season. Prodeedings of Symposium. October 2011. Korean J. Hort. Sci. Technol. p. 68.

Bangerth, F. 1979. Calcium-related physiological disorders of plants. Ann. Rev. Phytopathol. 17:97-122.

Cha, M.K., J.S. Kim and Y.Y. Cho. 2012. Growth response of lettuce to various levels of EC and light Intensity in plant factory. Korean J. Bio. Environ. Con. 21:305-311 (in Korean).

Cha, M.K., J.H. Cho and Y.Y. Cho. 2013. Growth of leaf lettuce as affected by light quality of LED in closed-type plant factory system. Korean J. Bio. Environ. Con. 22:291-297 (in Korean).

Cho, Y.R., E.J. Hahn and Y.B. Lee. 1997. Effects of nutrient control on the growth of lettuce in nutrient film technique. Proc. 7th ISHS Symp. In Vegetable Quality. pp. 245-248 (in Korean).

Choi, K.Y., J.H. Bae and Y.B. Lee. 1999. Effects of Ca : K ratios in nutrient solution on photosynthesis, transpiration, growth and incidence of tipburn in butterhead and leaf lettuce. Korean J. Bio. Environ. Con. 8:42-48 (in Korean).

Choi, K.Y., E.Y. Yang, D.K. Park, Y.C. Kim, T.C. Seo, H.K. Yun and H.D. Seo. 2005. Development of nutrient solution for hydroponics of cruciferae leaf vegetables based on nutrient-water absorption rate and the cation ratio. Korean J. Bio-Environ. Con. 14:289-297 (in Korean).

Eco-biotec. 2019. Catalogs of Dr. Mineral®, Homepage of eco-biotech, http://www.eco-biotech.com/contents/product/domestic_agro05.html

Ha, J.M., S.H. Han, J.R. Park and B.H. Kim. 2012. Effects of LED light ratio on lettuce growth. J. Electr. Eng. Technol. 35:263-265 (in Korean).

Hiroshi, S., Y. Saito, H. Nakashima, J. Miyasaka and K. Ohdoi. 2011. Light environment optimization for lettuce growth in plant factory. Proceedings of the 18th World Congress The International Federation of Automatic Control, Milano, Italy. pp. 606-609.

Jang, S.W., E.H. Lee and W.B. Kim. 2007. Analysis of research and development papers of lettuce in Korea. Korean J. Hort. Sci. Technol. 25:295-303 (in Korean).

Jang, Y.h., S.h. Lee and K.S. Lee. 2012. Effects of chelate-Ca foliar treatments on leaf calcium concentration, yield and growth of lettuce. Proceedings of Symposium. October 2012 Korean J. Soil Sci. Fert. p. 198.

Kim, D.G., S.J. Kwon, M.K Lee, J.M. Kim, J. Ryu, S.Y. Kang, C.H. Bae and J.B. Kim. 2017. Effect of various light emitting diode (LED) lights on growth characteristics of rapeseed (*Brassica napus* L.) genotypes. Proceedings of Symposium. April 2017. Korean J. Plant Res. p. 186.

Kim, S.J., G.J. Bok, G.I. Lee and J.S. Park. 2017. Growth characteristics of lettuce under different frequency of pulse lighting and RGB ratio of LED. Korean J. Bio. Environ. Con. 26:123-132 (in Korean).

Kim, Y.J., H.M. Kim and S.J. Hwang. 2016. Growth and phytochemical contents of ice plant as affected by light quality in a closed-type plant production system. Korean J. Hort. Sci. Technol. 34:878-885 (in Korean).

Kozai, T., A. Karino, K.G. Grate and H.O. Ikeda. 1992. New greenhouse management. Asakura. Japan. pp. 117-122.

Lee, J.S. and M.S. Chang. 2017. Effect of nutrient solution concentration in the second half of growing period on the

growth and postharvest quality of leaf lettuce (*Lactuca sativa* L.) in a deep flow technique system. Korean J. Hort. Sci. Technol. 35:456-464 (in Korean).

Li, Y.M., Y.J. Zheng, H.C. Liu, Y.T. Zhang, Y.W. Hao, S.W. Song and B.F. Lei. 2019. Effect of supplemental blue light intensity on the growth and quality of Chinese kale. Hort. Environ. Biotechnol. 60:49-57.

Ministry for Food, Agriculture, Forestry and Fisheries (MAFRA). 2018. The statistics of vegetable production.

Moon, B.W. 1999. Effects of liquid calcium fertilizer for horticultural crops. Korean J. Hort. Sci. Technol. 17:381-385.

Nam, J.Y., Y.R. Cho and Y.B. Lee. 1997. Development of optimum nutrient solution of leaf lettuce in hydroponics. Korean J. Hort. Sci. 25:295-303 (in Korean).

Noh, E.H., J.M. Choi and J.E. Son. 2011. Effects of light intensity and nutrient solution strength during short day treatment on the growth and nutrient absorption of *Kalanchoe blossfeldiana* Rako in ebb and flow system and the accumulation of nutrients in growing medium. Korean J. Bio. Environ. Con. 20:189-196 (in Korean).

Park, H., Y.J. Yu and E.Y. Choi. 2017. Effects of fluorescent light and light-emitting diodes on leaf morphology, growth and antioxidant capacity of *salvia plebeia*. Korean J. Bio. Environ. Con. 26:208-214 (in Korean).

Park, J.E., Y.G. Park, B.R. Jeong and S.J. Hwang. 2013. Growth of lettuce in closed-type plant production system as affected by light intensity and photoperiod under influence of white LED light. Korean J. Bio. Environ. Con. 2:228-233 (in Korean).

Park, M.H., M.Y. Shim and Y.B. Lee. 1999. Effects of pH level and electrical conductivity on growth, nutrient absorption, transpiration and CO assimilation of leaf lettuce in hydroponics. Korean J. Bio. Environ. Con. 8:115-124 (in Korean).

Shin, B.K., J.E. Son and J.M. Choi. 2013. Impact of compositions and concentrations of fertilizer solution on growth of lettuce and changes in chemical properties of root media. Korean J. Bio. Environ. Con. 22:193-201 (in Korean).

Son, K.H., J.H. Park, D. Kim and M.M. Oh. 2012. Leaf shape index, growth, and phytochemicals in two leaf lettuce cultivars grown under monochromatic light-emitting diodes. Korean J. Hort. Sci. Technol. 30:664-672 (in Korean).

Son, K.H. and M.M. Oh. 2015. Growth, photosynthetic and antioxidant parameters of two lettuce cultivars as affected by red, green, and blue light-emitting diodes. Hort. Environ. Biotechnol. 56:639-653.

Suh, J.K., K.H. Lee and M.Y. Jeung. 2006. Effect of natural mineral concentration and treatment method on growth and quality in horticultural crops. Korean J. Bio. Environ. Con. 15:233-237 (in Korean).

Um, Y.C., S.S. Oh, J.G. Lee, S.Y. Kim and Y.A. Jang. 2010. The development of container-type plant factory and growth of leafy vegetables as affected by different light sources. Korean J. Bio. Environ. Con. 19:333-342 (in Korean).

Yamazaki, K. 1982. Management of pH in nutrient solution in hydroponics. Agriculture and Horticulture 57:327-331.

(Received 5 June 2019 ; Revised 19 June 2019 ; Accepted 20 June 2019)