Effects of Light Intensity and Nutrient Level on Growth and Quality of Leaf Lettuce in a Plant Factory[1)]

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Abstract

This study was conducted to investigate the optimum environment for leaf lettuce (*Lactuca sativa* L. var. crispa) in a plant factory to increase mass-production efficiency of quality leaf lettuce. Transpiration rate and CO_2 assimilation rate were increased with increasing the photosynthetic photon flux density (PPFD). The highest fresh weight and dry weight were observed at the PPFD of 200 and 300 μmol $m^{-2}s^{-1}$, respectively. The optimum aerial environment for the growth and quality of leaf lettuce in the plant factory was determined to be over 200 μmol $m^{-2}s^{-1}$ for PPFD. Although the interaction between light intensity and nutrient level was not significant, the lettuce growth was the best under electrical conductivity (EC) of 1.8 mS cm^{-1} at high light intensity (250 μmol $m^{-2}s^{-1}$) and EC of 2.4 mS cm^{-1} at low light level (150 μmol $m^{-2}s^{-1}$), respectively.

Key words : electrical conductivity, hydroponics, photosynthetic photon flux density.

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Introduction

A plant factory is a facility aimed to produce standardized, clean and quality horticultural products through optimization of the environment and the improvement of working efficiency. The optimal control problem is to decide set points of light intensity, temperature, relative humidity (RH) and CO_2 concentration which maximize the fresh weight of the plant. Specially, light intensity was significantly contributed to the lettuce growth. Light intensity, light quality and photoperiod are the essential factors for the growth of the plants since the light is used as an energy source of the photosynthesis.

Optimal light intensity, an essential factor for the growth of the plants, is proportioned to solar radiation, stomatal aperture, transpiration rate and photosynthetic rate up to saturating light intensity. Many studies reported that higher light intensity promoted growth rate (Michell et al., 1991; Knight and Mitchelll., 1983; Tibbits et al., 1983). Iketa et al. (1988) have been analyzed the combined effects on environmental factors on stomatal resistance and CO_2 compensation point of lettuce and turnip grown at 137~316 μmol m^{-2} s^{-1}. Other factors that effect on plant growth in a plant factory are light source and light quality. The growth of the plant under the wavelength of 400 nm, an ultraviolet ray region, was inhibited (Milthorpe and Moorby, 1979). Studies have been reported on increased plant growth by improving light quality (Knight and Michell. 1983; Masamoto, 1992; Park et al., 1992; Yukitsugu et al., 1993). Until now. environmental control technology was partially developed in a horizontal field under natural condition. However, plant factory is an automatic and artificial growing system that can be mass-produced the high quality lettuce. For practical plant factories, more studies are needed concerning the environmental conditions and other factors to product the lettuce. Therefore, the purpose of this study was to determine optimum light intensity and nutrient level condition for growth of leaf lettuce in a plant factory.

Materials and Methods

Leaf lettuce (*Lactuca sativa* L. var. crispa cv. Grand rapids) was grown under different PPFDs of 100, 150, 200 and 300 μmol $m^{-2}s^{-1}$ which were maintained by controlling the distance between the plant and the lamp. Light was supplied by the metal halide and the high pressure sodium lamp. Light intensity was measured at the top of the plant using portable quantum sensor (Skye Instruments, SKP 2200). CO_2 concentration of 1500 mg L^{-1} was treated to leaf lettuce in the controlled rooms. Other conditions, temperature and RH, were maintained at 22/20℃ (day/night) and 70±5%, respectively. Electrical conductivity (EC) and pH were adjusted to 1.8 mS cm^{-1} and 5.8±0.2, respectively.

Another experiment was conducted to

investigate the interactive effect between PPFD and EC level on the growth of reddish leaf lettuce. In this case, reddish leaf lettuce (*Lactuca sativa* L. var. crispa cv. Ttuksom) was grown under different PPFDs of 150, 250 μmol $m^{-2}s^{-1}$ with nutrient levels with EC values of 1.2, 1.8 and 2.4 mS cm^{-1}.

Growth characteristics such as the number of leaves, leaf length, leaf width, leaf fresh weight, root fresh weight, leaf dry weight and root dry weight were measured. Relative content of chlorophyll was measured with portable chlorophyll meter (Minolta, SPAD 502). Anthocyanin content was measured with a UV spectrophotometer at 530 nm after leaf lettuce being extracted with 5 mℓ of 1% HCℓ-MeOH at 4℃ in the dark room on the 30th day from the transplant.

Transpiration rate, CO_2 assimilation rate and stomatal resistance of the plantlets were observed with a steady state porometer (LI-COR, Li-1600) and a portable photosynthesis system (LI-COR, LI-6200).

Means were obtained from 4 samples and mean differences were analyzed using analysis of variance procedures (ANOVA) by statistical analysis system (SAS) program.

Results and Discussion

Increased rates of transpiration and CO_2 assimilation were observed in the leaves applied with PPFD over 200 μmol $m^{-2}s^{-1}$ (Table 1). Effect of PPFD and EC on CO_2 assimilation and transpiration rate of the leaf lettuce was not found (Table 2).

Table 1. Effect of light intensity on transpiration rate, CO_2 assimilation rate and stomatal resistance of leaf lettuce 'Grand rapids' on the 16th day from treatment in the plant factory.

PPFD (μmol m^{-2} s^{-1})	Transpiration rate (μg cm^{-2} s^{-1})	CO_2 assimilation rate (μmol m^{-2} s^{-1})	Stomatal resistance (s cm^{-1})
100	2.65b^z	6.28a	1.53a
150	2.90ab	6.99a	1.20a
200	3.46ab	8.05a	0.55a
300	3.87a	8.42a	0.74a

^{z} Mean separation within rows by Duncan's multiple range test, significant at 5% level.

Plant growth increased with increasing light intensity (PPFD) (Tables 3 and 4). Leaf length, leaf width, fresh weight and dry weight increased with increasing PPFD up to 300 μmol $m^{-2}s^{-1}$. The highest fresh weight and highest dry weight were observed at the PPFD of 200 and 300 μmol $m^{-2}s^{-1}$, respectively. Little growth differences

Table 2. Effects of light intensity and nutrient level on transpiration rate, CO_2 assimilation rate and stomatal resistance of reddish leaf lettuce 'Ttuksom' on the 30th day from treatment in the plant factory.

PPFD (μmol m^{-2} s^{-1})	EC (mS cm^{-1})	Transpiration rate (μg cm^{-2} s^{-1})	CO_2 assimilation rate (μmol m^{-2} s^{-1})	Stomatal resistance (s cm^{-1})
150	1.2	8.15	8.90	1.33
	1.8	8.54	9.56	1.14
	2.4	8.24	8.87	1.08
250	1.2	9.04	8.87	1.08
	1.8	9.40	9.33	1.13
	2.4	9.26	8.36	1.04
Significance				
PPFD		NS	NS	NS
EC		NS	NS	NS
PPFD × EC		NS	NS	NS

NS Nonsignificant.

were found among the PPFDs of 150, 200 and 300 μmol $m^{-2}s^{-1}$ (Table 3). But high visual quality was obtained at the ones grown over the PPFD of 200 μmol $m^{-2}s^{-1}$. On the other hand, there has been a report on the negative effect of high PPFD by Tibbits et al. (1983) that the shoot dry weight of 'Grand Rapids' lettuce did not increase by raising PPFD from 320 μmol $m^{-2}s^{-1}$ to 720 μmol $m^{-2}s^{-1}$. He also reported that chlorophyll content of leaf lettuce 'Grand rapids' was higher at 700 μmol $m^{-2}s^{-1}$ than that of at 320 μmol $m^{-2}s^{-1}$. A similar result was obtained from this experiment. Increased contents of chlorophyll and anthocyanin were observed as PPFD increased (Tables 3 and 5). The contribution of PPFD to the plant growth was shown to be significant but the growth of leaf lettuce was not significantly different with varying nutrient levels (Table 4).

The interactive effects of light intensity and nutrient levels to plant growth were not significant. Their effects on the plant growth were highly correlative except for root weight. The plants grown under different solution ECs and different PPFD levels showed growth differences. The best results of plant growth expressed as parameters such as leaf length, leaf width, fresh weight and dry weigh of lettuce were obtained in the solutions with EC of 1.8 mS cm^{-1} at high light intensity (250μmol $m^{-2}s^{-1}$) and with EC of 2.4 mS cm^{-1} at low light level (150μmol $m^{-2}s^{-1}$), respectively (Table 4).

Table 3. Effect of light intensity on the growth of leaf lettuce 'Grand rapids' in the plant factory.

PPFD (μmol $m^{-2}s^{-1}$)	No.of leaves	Leaf length (cm)	Leaf width (cm)	Leaf wt. ($g\ plant^{-1}$) Fresh	Dry	Leaf dry wt. ratio (%)	Root fresh wt. ($g\ plant^{-1}$)	Reative content of chlo rophyll[y]
100	11.3	20.4a	13.8	24.92b	1.19c	4.77b	4.37b	13.0c
150	13.0	18.4a	16.5	40.78ab	2.19bc	5.37b	7.99a	16.7bc
200	14.0	17.9ab[z]	17.9	50.32a	2.82ab	5.60b	10.10a	20.7b
300	13.1	13.1a	13.1	43.75ab	3.35a	7.66a	10.44a	24.9a

[z] Mean separation within rows by Duncan's multiple range test, significant at 5% level.
[y] Chlorophyll meter SPAD value.

Table 4. Effects of light intensity and nutrient level on the growth of reddish leaf lettuce 'Ttuksom' in the plant factory.

PPFD (μmol $m^{-2}s^{-1}$)	EC ($mS\ cm^{-1}$)	No.of leaves	Leaf length (cm)	Leaf width (cm)	Leaf wt. ($g\ plant^{-1}$) Fresh	Dry	Root wt. ($g\ plant^{-1}$) Fresh	Dry	Leaf dry wt. ratio (%)
150	1.2	20.6	15.4	17.4	67.0	3.41	11.5	0.75	5.08
	1.8	18.8	15.9	17.6	67.7	3.59	13.0	0.60	5.30
	2.4	20.0	15.0	15.6	75.1	3.37	9.3	0.69	4.48
250	1.2	21.8	14.1	16.7	80.1	4.93	16.5	1.25	6.15
	1.8	24.8	14.7	18.3	89.9	5.91	15.9	1.58	6.57
	2.4	21.8	15.4	16.5	71.8	4.73	12.8	0.93	6.58
Significance									
PPFD		NS	NS	NS	**	**	*	**	NS
EC		NS	NS	NS	NS	NS	NS	NS	NS
PPFD × EC		NS	NS	NS	NS	NS	NS	**	NS

NS,*,** Nonsignificant or significant at $P < 0.05$ or 0.01, respectively.

Table 5. Effects of light intensity and nutrient level on the relative content of chlorophyll and anthocyanin of reddish leaf lettuce 'Ttuksom' in the plant factory.

PPFD (μmol $cm^{-2}\ s^{-1}$)	EC ($mS\ cm^{-1}$)	Relative content of chlorophyll[z]	Anthocyanin content ($\mu g\ g^{-1}$ FW)
150	1.2	16.33	18.8
	1.8	19.43	19.6
	2.4	18.63	29.2
250	1.2	18.35	31.2
	1.8	20.03	32.9
	2.4	20.98	33.9
Significance			
PPFD		NS	**
EC		NS	NS
PPFD X EC		NS	NS

NS,*,** Nonsignificant or significant at $P < 0.05$ or 0.01, respectively.
[z]Chlorophyll meter SPAD value.

Consequently, the plant factory enabled mass-production of high quality leaf lettuce under much higher PPFD (above 200 μmol $m^{-2}s^{-1}$) than that of lower PPFD. In the future, these results will be successfully used to adopt a control system of the growth environments for high-tech horticultural production facilities or plant factories.

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식물공장내 광도와 배양액농도가 상추의 생육과 품질에 미치는 영향

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적 요

식물공장에 있어서 생산성 극대화를 위한 최적환경을 구명하기 위하여, 식물공장 시스템하에서 광도와 배양액 농도가 잎상추의 생육과 품질에 미치는 영향을 조사하였다. 실험결과 광이 높아짐에 따라 증산량과 광합성량이 높았으며, 광도 200μmol m^{-2} s^{-1}과 300μmol m^{-2} s^{-1} 에서 생체중과 건물중이 가장 높게 나타났다. 따라서 식물공장내 잎상추의 최적 광도는 200 μmol m^{-2} s^{-1} 이상으로 나타났다. 지상부 환경요인들과의 지하부 환경요인과의 관계를 밝히기 위해서 광도와 배양액 농도간의 관계가 잎상추 생육과 품질에 미치는 영향을 조사한 결과 통계적 유의성은 없었으나 저광도에서는 배양액농도가 높은 편인 2.4 mS cm^{-1}에서 고광도에서는 1.8 mS cm^{-1} 수준에서 생육량이 많게 나타났다.

주제어 : 수경재배, 광합성광자유속밀도, 전기전도도