A THESIS FOR THE DEGREE OF MASTER OF SCIENCE

Investigation of Optimum Environmental Conditions for Ginseng Seedling Production in Plant Factories with Artificial Light

인삼 육묘를 위한 인공광이용형 식물공장의 최적 환경 조건 구명

BY

BYUNGKWAN LEE

FEBRUARY, 2020

MAJOR IN HORTICULTURAL SCIENCE AND BIOTECHNOLOGY

DEPARTMENT OF PLANT SCIENCE

THE GRADUATE SCHOOL OF SEOUL NATIONAL UNIVERSITY

Investigation of Optimum Environmental Conditions for Ginseng Seedling Production in Plant Factories with Artificial Light

UNDER THE DIRECTION OF DR. CHANGHOO CHUN

SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL

OF SEOUL NATIONAL UNIVERSITY

BY

BYUNGKWAN LEE

APPROVED AS A QUALIFIED DISSERTATION OF BYUNGKWAN LEE

FOR THE DEGREE OF MASTER OF SCIENCE

BY THE COMMITTEE MEMBERS

JANUARY, 2020

CHAIRMAN ______________________

Jung Eek Son, Ph.D.

VICE-CHAIRMAN ______________________

Changhoo Chun, Ph.D.

MEMBER ______________________

Ki Sun Kim, Ph.D.

Investigation of Optimum Environmental Conditions for Ginseng Seedling Production in Plant Factories with Artificial Light

BYUNGKWAN LEE

DEPARTMENT OF PLANT SCIENCE

THE GRADUATE SCHOOL OF SEOUL NATIONAL UNIVERSITY

ABSTRACT

The objective of this study was to develop a ginseng seedling production system using plant factories with artificial light (PFAL). In Chapter 1, the growth and morphology of ginseng seedlings as affected by depth and diameter of polyvinyl chloride (PVC) pipes, resulting in different root-zone volumes, were investigated to design a novel plug tray for ginseng seedling production. The stratified seeds of ‘Chunpoong’ cultivar were sown into the cylindrical PVC pipes filled with commercial growing medium and then grown for 20 weeks using sub-irrigation

system in a PFAL under controlled environments. In the first experiment, the plants were grown in PVC pipes having four different depths (15, 20, 25, and 30 cm) with the same diameter of 50 mm. Root length, root fresh and dry weights, and leaf area became higher with greater depth up to 30 cm, while there were no significant differences in root diameter. In the second experiment, seedlings were cultivated in PVC pipes having six different diameters (ø12, 15, 20, 30, 50, and 75 mm) with the same depth of 20 cm. Root and shoot length, fresh and dry weights of root and shoot, root diameter and leaf area all increased with larger diameter up to 30 mm. In Chapter 2, the growth of ginseng seedlings cultivated under different light intensity and photoperiod conditions in the PFAL was studied. Stratified ginseng seeds of 'Chunpoong' cultivar were sown into the plastic containers (520×365×200 mm) filled with commercial growing medium and consequently cultivated under warm-white LED lamps with combinations of four light intensities (50, 120, 190, and 260 μmol m^{-2} s^{-1}) and three photoperiods (8, 12, and 16 h d^{-1}) using overhead irrigation system for 20 weeks. Seedlings cultivated under longer photoperiods up to 16 h d^{-1} and greater light intensities up to 260 μmol m^{-2} s^{-1} showed smaller shoot length and fresh weight, leaf area. In those treatments, the seedlings also showed more bleached and defoliated leaves. The thickest and heaviest roots were harvested from the seedlings cultivated in the treatment of 12-h photoperiod and 260 μmol m^{-2} s^{-1} light intensity. The root growth of ginseng seedlings was well-shaped, long, and thick in PVC pipe with cell depth and diameter of 20 cm and 30 mm, respectively, and could be also promoted at a photoperiod of 12-h and a light intensity of 260 μmol m^{-2} s^{-1}.

In conclusion, the production period for ginseng seedlings can be shorten up to four months when cultivated in a PFAL under optimized environmental conditions compared to about eight months of outdoor cultivation, which makes it possible to harvest three times a year using the production method developed in this study.

Keywords: Cell volume, Environment control, Ginseng seedling production, Light intensity, Photoperiod, Plant factory with artificial light (PFAL)

Student number: 2018-29424

CONTENTS

CHAPTER 2. Growth of Ginseng Seedlings as Affected by Light Intensity and Photoperiod

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Korean ginseng (*Panax ginseng* C.A. Meyer) is a perennial plant that grows slowly and has a long production cycle (4-6 years). When fruits of ginseng are harvested in the fourth year of cultivation from sowing, the seeds inside of the fruits need to be stratified for 100 days. The stratified seeds are sown in the field on March and cultivated until late October. The seedling roots were harvested when the defoliation occurs and the latent buds on the rhizome are developed. After cold storage of the roots, they are transplanted to the main field on March of the following year and cultivated for the rest of the year (RDA, 2014).

Korean ginseng is one of the nation's major exports. In the world, Korea is the second largest exporter of ginseng roots after China with 27,480 tons, accounting for 34% of the world market in 2009 (Baeg and So, 2013). In Korea, as demands of organic and non-pesticide ginseng products increase, seedling production started to expand from long term cultivation to production of ginseng sprouts that can be harvested 40-50 days after transplanting (RDA, 2017). This trend leads to a demand for uniform and good quality ginseng seedlings. However, most of ginseng cultivation is still conducted conventionally and it cause some problems such as exposure to soil-borne diseases, shortage of the preparation field, and low labor efficiency (Kim et al., 1990). To solve this problem, seedling production has been conducted in greenhouse (Kim et al., 2014) with optimal growing media composition (Park et al., 2014) since 2014. Still, these trials seems not enough to secure the supply of ginseng seedlings.

Plant factory with artificial lighting (PFAL) has immerged as a new trend in horticulture with great merits such as controlling environments appropriate for crops, thereby producing uniform, clean, and pesticide-free transplants quickly (Kozai et al., 2004; Kozai et al., 2006). PFAL has been mainly used for leafy vegetables, but recently novel propagation methods using a PFAL have been introduced for strawberry (Park et al., 2017), tomato (Ohyama et al., 2003), and so on.

This study was conducted to develop a production method for ginseng seedling under controlled environment. In Chapter 1, the growth of ginseng seedlings as affected by cell volume using sub-irrigation system in a PFAL was investigated. In Chapter 2, the growth of ginseng seedlings as affected by light intensity and photoperiod in a PFAL was investigated.

LITERATURE REVIEW

1. Ginseng seedling production

1-1. Seed harvesting, stratification, and sowing technique

In general, ginseng plants start to flower and produces the seeds on the summer of 3rd cultivation year. For seed harvesting, the yield and size of seeds harvested on 3rd year are small, but the seeds harvested on 5th year are bigger than those of 3rd year, and it leads to inhibition of root enlargement (RDA, 2014). The size of seeds barely affects the rate of seed coat dehiscence and survival of seedlings. However, the growth of seedlings can be affected by the size of seeds. The germination rate of seeds, growth of ginseng seedlings, and yield of seedling roots were greater as the size of seeds was larger than 4 mm (Kim et al., 1981). Larger seeds (more than 5.0 mm in diameter) showed better growth except root length as compared to the smaller seeds (less than 4.0 mm in diameter) (Lee et al., 2008). Therefore, seeds are harvested on 4th year, and seeds of more than 4 mm are sorted for sowing (RDA, 2014).

The harvested seeds are composed of less than 10% of embryo, which needs after-ripening for 100 days via cold stratification. One study reported that 18-20^{o}C was the optimal temperature for cold stratification (Li, 1995). After cold stratification, the germination rate of dehisced seeds was greatest when kept at 5^{o}C for 100 days (Won et al., 1988). Recently, one study identified that both GA_3 and kinetin enhanced the seed dehiscence, embryo development, and germination rate of ginseng with a short period of cold stratification (45 days) (Lee et al., 2018). For long-term storage, the dehisced seeds could be stored up to 7 years at the air temperature of 5°C and the relative humidity of 30%, and their viability and germination rate were at 89.2% and 73.5%, respectively (Lee et al., 2004). In addition, for long-term germplasm conservation, the moisture of seeds needs to be controlled within the range of 8-10% in order to avoid damages from both desiccation and freezing (Yoon et al., 2005).

Considering the sowing density under direct sowing cultivation, the number of survival plants were significantly enhanced when the seeds were sown at higher density (162 seeds per 1.62 m^2), but the germination rate was highest when sowing at lower density (90 seeds per 1.62 m^2) in a greenhouse (Mo et al., 2015). However, the recommended sowing density under transplanting cultivation is at the distance of 3 cm by 3 cm apart (RDA, 2014). In addition, the optimum sowing depth was 31.1 mm, which gave the greatest root dry weight of 119.9 mg among all the treatments (Proctor and Sullivan, 2013).

1-2. Growth of ginseng seedlings as affected by light intensity

Ginseng is one of the semi-shade plants whose chlorophyll content and Rubisco activation are low, so the CO_2 gas interchange quantity is very small (Yang et al., 1987). Different colors and numbers of layers of polyethylene (PE) shading net, which resulted in different light quality and intensity, have been researched to produce better growth and quality of ginseng in the field and greenhouse (Lee et al., 2006). The chlorophyll content and the photosynthesis rate of ginseng seedlings showed decreasing trend as the light transmission ratio (LTR) increased from 10% to 30% (Jang et al., 2015). At the higher LTR, leaves physiological disorders such as chlorosis, and stems formed hypodermis which is an outer layer of protective tissue (Taiz and Zeiger, 2010), and phloem development inside the vascular tissue shrunk remarkably. However, at the lower LTR, the growth of ginseng seedlings was the greatest and its light saturation point was about 200 μmol m^{-2} s^{-1} (Cho et al., 2008).

2. Growth of seedling as affected by physical properties of growing medium and container sizes

Compaction influences on the size of pores regularity in medium (Glinski, 2018). Porosity in a root medium is in inverse proportion to the bulk density (BD) (Beardsell et al., 1979). Porosity affects the aeration in a medium for plant growth. As the size of pores decreases, oxygen deficiency restricts root respiration, thus negatively influences moisture and nutrient uptake in roots (Raviv et al., 2001). For seedling production, many studies were conducted to investigate the effects of physical properties of media on growth of plants. When the main axes were mechanically compacted, barley seedlings exhibited compensatory growth of lateral roots (Goss, 1977). Root growth of Broccoli seedling occurred in the looser upper layer, maintaining the total root length (Montagu et al., 2001). In addition, Roy et al.

(2008) reported that higher compaction of media resulted in shorter ginseng seedling roots.

Considering the physical properties which improves growth of seedlings, many studies were conducted to find the optimal size of container. Container size affects the air and water ratio in a given root medium. Milks et al. (1989) demonstrated that there was a water content gradient between the top and bottom of the pot and their water content increased from 32% (top) to 69% (bottom) held in a 17 cm tall pot (by volume). Root medium which had 25% of air-filled porosity (aeration) with 60% of water-filled porosity at container capacity was ideal in a 15 cm tall (1.7 L) pot for plant growth (De Boodt and Verdonck, 1971). As cell size increased, growth of spinach (Yeoung et al., 2004), potato (Kim et al., 2008), onion (Suh et al., 2012), seedlings were increased.

LITERATURE CITED

Baeg IH and So SH (2013) The world ginseng market and the ginseng (Korea). J Ginseng Res 37:1

Beardsell DV, Nichols DG, Jones DL (1979) Physical properties of nursery potting-mixtures. Scientia Hortic 11:1-8

Cho JW, Park HW, Kim MJ, Kim HH, Choi JE (2008) Photosynthetic, morphological and growing characteristics by shading materials in *Panax ginseng* C.A. Meyer. Kor J Crop Sci 53:256-260

De Boodt M, Verdonck O (1971) The physical properties of the substrates in horticulture. III Symposium on Peat in Horticulture 26:37-44

Glinski J (2018) Soil physical conditions and plant roots. CRC press

Goss MJ (1977) Effects of mechanical impedance on root growth in barley (*Hordeum vulgare* L.) I. Effects on the elongation and branching of seminal root axes. J Exp Botany 28:96-111

Jang IB, Lee DY, Yu J, Park HW, Mo HS, Park KC, Hyun DY, Lee EH, Kim KH (2015) Photosynthesis rates, growth, and ginsenoside contents of 2-yr-old *Panax ginseng* grown at different light transmission rates in a greenhouse. J Ginseng Res 39:345-353

Kim YH, Yu YH, Lee JH, Park CS, Oh SH (1990) Effect of shading on the quality of raw, red and white ginseng and the contents of some minerals in ginseng roots. Kor J Ginseng Sci 14:36-43

Kim DW, Kim JY, You DH, Kim CS, Kim HJ, Park JS, Kim JM, Choi DC, Oh NK (2014) Effect of cultivation using plastic-film house on yield and quality of ginseng in paddy field. Kor J Medicinal Crop Sci 22:210-216

Kim JM, Choi KY, Kim YH, Park ES (2008) Growth and yield of potato after transplanting of potato plug seedlings grown at different plug cell size and photoperiod. Protect Hortic Plant Fact 17:26-31

Kim JM, Lee SS, Kim YT (1981) Effect of seed Size on seedling performance in *Panax ginseng*. J Ginseng Res 5:85-91

Kozai T, Chun C, Ohyama K (2004) Closed systems with lamps for commercial production of transplants using minimal resources. Acta Hortic 630:239-254

Kozai T, Niu G, Takagaki M (2019) Plant factory: an indoor vertical farming system for efficient quality food production. Academic press. pp17-20

Kozai T, Ohyama K, Chun C (2006) Commercialized closed systems with artificial lighting for plant production. Acta Hortic 711:61-70

Lee JH, Lee SS, Ahn IO, Kang JY, Lee MG (2004) Relationship between storage periods and germination ability of dehisced seeds of *Panax ginseng* C.A. Meyer. Kor J Ginseng Res 28:215-218

Lee JS, Lee SS, Lee JH, Ahn IO (2008) Effect of seed size and cultivars on the ratio of seed coat dehiscence and seedling performance in *Panax ginseng*. J Ginseng Res 32:257-263

Lee JW, Jo IH, Kim JU, Hong CE, Kim YC, Kim DH, Park YD (2018) Improvement of seed dehiscence and germination in ginseng by stratification, gibberellin, and/or kinetin treatments. Hortic Environ Biotechnol 59:293-301

Lee SW, Cha SW, Hyun DY, Kim YC, Kang SW, Seong NS (2006) Shading effect of different colored polyethylene net on seeding growth of *Panax ginseng* C.A. Meyer. Kor J Medicinal Crop Sci 14:113-116

Li TS (1995) Asian and American ginseng—a review. HortTechnology 5:27-34

Milks RR, Fonteno WC, Larson RA (1989) Hydrology of horticultural substrates. II. Predicting physical properties of media in containers. J Amer Soc Hortic Sci 114:53-56

Mo HS, Park HW, Jang IB, Yu J, Park KC, Hyun DY, Kim KH, Seo TC (2015) Effect of seed density, number of seeds sown per hole and thinning treatment on growth characteristics and disease occurrence in greenhouse-cultivated ginseng. Kor J Medicinal Crop Sci 23:198-206

Montagu KD, Conroy JP, Atwell BJ (2001) The position of localized soil compaction determines root and subsequent shoot growth responses. J Exp Bot 52:2127-2133

Ohyama K, Manabe K, Omura Y, Kubota C, Kozai T (2003) A comparison between closed-type and open-type transplant production systems with respect to quality of tomato plug transplants and resource consumption during summer. Environ Cont Biol 41:57-61

Park HW, Jang IB, Kim YC, Mo HS, Park KC, Yu J, Kim JU, Lee EH, Kim KH (2014) Growth characteristics of ginseng seedlings as affected by mixed nursery soil under polyethylene film covered greenhouse Kor J Medicinal Crop Sci 22:363-368

Park SW, Kwack Y, Chun C (2017) Growth of Runner Plants Grown in a Plant Factory as Affected by Light Intensity and Container Volume. Hortic Environ Biotechnol 35:439-445

Proctor JTA, Sullivan JA (2013) Effect of seeding depth on seedling growth and dry matter partitioning in American ginseng. J Ginseng Res 37:254-260

Raviv M, Wallach R, Blom TJ (2001) The effect of physical properties of soilless media on plant performance-A review. Intl Symposium on Growing Media and Hydroponics 644:251-259

Roy RC, Ball BR, Reeleder RD, Bruin AJ, Grohs R, White P, Capell B (2008) Effect of planting bed shape, mulch and soil density on root yield and shape in North American ginseng (*Panax uinquefolius* L.). Can J Plant Sci 88:937-949

Rural Development Administration (RDA) (2014) Standard cultural practice of ginseng. Rural Dev Admin. Jeonju, Korea. pp.104-139

Rural Development Administration (RDA) (2017) Ginseng consumption patterns and response strategies. Rural Dev Admin. Jeonju, Korea. pp.212-222

Suh JK, Ran AS, Im KR, Kim DH (2012) Effect of plug cell size and variety on the production of onion set for pickle. Protect Hortic Plant Fact 21:28-32

Taiz L, Zeiger E (2010) Plant Physiology, 5th Edition, Sinauer Associates, Sunderland, Mass pp. 86-90

Won JY, Jo JS, Kim HH (1988) Studies on the germination of Korean ginseng (*Panax ginseng* C.A. Meyer) seed, 2. Influences of temperature and seed treatment on embryo growth and germination. Kor J Crop Sci 33:54-58

Yang DC, Yoo HS, Yoon JJ (1987) Investigation on the photo-oxidation of pigment in leaf-burning disease of *Panax ginseng*: II. Investigation and analysis of physiological reaction mechanism on the chlorophyll bleaching phenomenon. Kor J Ginseng Sci 11:101-110

Yeoung YR, Jung MK, Kim BS, Hong SJ, Chun C, Park SW (2004) Effect of plug cell size on seedling growth of summer spinach. Kor J Hortic Sci Technol 22:422-425

Yoon JW, Kim HH, Lee JH, Choi JK (2005) Optimal desiccation condition and moisture content of dehisced seeds of ginseng (*Panax ginseng* C.A. Meyer) for cryopreservation. Kor J Crop Sci 50:406-410

CHAPTER 1

Growth of Ginseng Seedlings in Sub-irrigation System as Affected by Cell Volume

INTRODUCTION

Plug seedling production system is well-developed especially for ornamental plants and vegetables (Nelson, 1991; Hartmann and Kester, 1963), and it requires the minimal rooting volume for one plant to produce transplants with good quality in a short period. Container size is the first step to consider and it is main decision for the producers who seek to produce transplants with good quality in an optimized space (Styer and Koranski, 1997). For many commercial transplant producers, the number of cells are important (Vavrina, 1993) because production costs are directly related to container size (Dufault and Waters, 1985; Marsh and Paul, 1988). Despite the development of ginseng seedling cultivation technologies, ginseng performance in cultivation trays or vessels used for commercial seedling production such as pots and plug trays has not yet been fully studied.

To set the container size for ginseng seedlings, cultivation period and the root system are necessary to be considered (Styer and Koranski, 1997). In general, it takes 7-8 months from sowing to harvesting in the field for seedling production (RDA, 2014). Ginseng has a taproot system which grows down vertically to the medium with many smaller lateral roots arising. This is why deep seedbed in the field or greenhouse (25-30 cm) is preferred (Park et al., 2014; Park et al., 2015). Also, ginseng is a storage root plant which goes dormant storing the nutrients in winter. As an ideal form of ginseng seedling roots, straight tap root with more than 14 cm of root length and 0.75 g of root fresh weight is required as transplants (RDA, 2013). Therefore, for the ideal growth of ginseng seedlings, especially for roots, it is necessary to develop the new type of cultivation container for improving ginseng seedling production system.

In this study, therefore, polyvinyl chloride (PVC) pipes that have different depths and diameters, in other words, different root volumes with different dimensions, were tested as a prototype of vessel for ginseng seedling production.

MATERIALS AND METHODS

Plant material and environmental conditions

Stratified ginseng seeds (*Panax ginseng* C.A. Meyer cv. Chunpoong) were sown into cylindrical PVC pipes filled with peat moss and perlite (7:3, v/v) growing media (Golden Root, Nongkyung Co., Ltd., Korea) at a depth of 3 cm and placed in a plant factory with artificial light (PFAL).

The plants were cultivated under a PPF of 130 μmol m^{-2} s^{-1} using cool-white LED lamps (T5, Parlux, Incheon, Korea) with 10 h photoperiod at average air temperature of 23.7/22.1°C (photo-/dark periods) and relative humidity of 67.1±7.2%. After confirming that the sets of true leaves were fully unfolded, the seedlings were fertigated by sub-irrigation method with an irrigation interval of 12 days (20 min/each fertigation) using a nutrient solution for ginseng (NIHHS, RDA, 2015).

Volume of container cell treatments

In experiment 1, the plants were grown for 20 weeks in PVC pipes having four different depths (15, 20, 25, and 30 cm) with the same diameter of 50 mm (Fig 1-1) and the total cell volumes were 294.38, 392.50, 490.63, and 588.75, respectively. In experiment 2, plants were grown for 20 weeks in PVC pipes having six different diameters (ø12, 15, 20, 30, 50, and 75 mm) with the same depth of 20 cm (Fig 1-2) and the total cell volumes were 22.61, 35.33, 62.80, 141.30, 392.50, and 883.13, respectively.

Physical properties of root medium

The bulk density and porosity of root medium was measured according to the method suggested by NIAST (2000).

Measurement of growth

Shoot length, root length, root diameter, fresh and dry weight of shoot and root, leaf area, and chlorophyll content of leaf of ginseng seedlings were measured at 20 weeks after sowing. The total leaf area of each plant was measured with a leaf area meters (Li-3100; LI-COR, Lincoln, NE, USA). The relative average chlorophyll content of three leaves was also measured using a chlorophyll meter (SPAD 502, Konica Minolta Sensing Inc., Sakai, Japan). Dry weights were measured after drying at 80^{o}C for 3 days.

Data collection and statistical analysis

Treatments were replicated three times. The experimental data were statistically analyzed by the Statistical Analysis System (SAS) for window version 9.4 (SAS

Institute Inc., Cary, NC, USA) using Duncan's multiple range tests at $p < 0.05$ confidence level.

Regression analyses were performed by using the Sigma Plot (version 10.0; Systat Software, Chicago, IL, USA).

Figure 1-1. PVC pipes having four different depths (15, 20, 25, and 30 cm) used as growing container in experiment 1

Figure 1-2. PVC pipes having six different diameters (ø 12, 15, 20, 30, 50, and 75 mm) used as growing container in experiment 2

RESULTS AND DISCUSSION

Bulk density and porosity

In Experiment 1, the bulk density was highest in 30 cm of cell depth, and decreased with decreasing cell depth. The porosity was highest in the 20 cm of cell depth, and decreased with increasing cell depth (Table 1-1). However, in Experiment 2, among the cell diameter treatments, no significant differences were observed in bulk density (Table 1-2). Corti et al (1998) reported that high bulk density has the demerit in reducing porosity and increasing transportation cost. The roots of ginseng seedlings cultivated in high bulk density soil were less elongated and their mid-sections were wider than those in middle or low bulk density (Roy et al., 2008). Moreover, when the porosity and air capacity of the soil were high, the yield of seedling roots was notably improved (Lee et al., 1995).

Growth in response to cell depths (Exp. 1)

An increase in cell depth promoted the root growth of ginseng seedlings (Fig. 1-3). Root elongation was inhibited by short cell depth and increased with increasing the cell depth. As root length increased, root fresh weight linearly increased. However, root enlargement showed no significant differences among all treatments (Fig. 1-4). Leaf area increased with increasing cell depth and there was no significant differences between 25 cm and 30 cm of cell depth treatments. The expanded leaf area showed positive correlation with increases of shoot and root dry weights. Shoot length and fresh weight had no significant differences among the treatments (Table. 1-3). Seedling production in the field has been conducted using field preparation which includes filling new mixed substrates (coarse sand and leaf compost at ratio of 3:1 or 4:1) for 30 cm depth and conducting tillage (RDA, 2014). Recently, in the greenhouse, the depth of seedling bed requires 30 cm for the best growth of ginseng (RDA, 2013). Also, when using seedling container, Park et al (2014) filled 25 cm height of substrates. This is because the growth of roots is crucial and should be satisfied with the following standard. Commercial standard for ginseng seedling available for transplanting requires (1) more than 15 cm of root length and (2) more than 0.70 g of root weight, and (3) pencil-shaped roots (RDA, 2013).

Growth in response to cell diameters (Exp. 2)

Shoot and root growth of ginseng seedlings were greatly affected by cell diameter (Fig. 1-5). Root elongation and enlargement were improved as cell diameter increased. However, the effect of an increase in cell diameter was most remarkable when the cell volume increased from 22.61 to 141.30 cm^3; a further increase had only a small effect on root length, diameter, and root fresh and dry weight (Fig. 1-6). Shoot length increased with increasing cell diameter. Also, leaf area, shoot fresh and dry weight increased with increasing cell diameter. However, there were no significant differences between 30 mm and 75 mm of cell diameter treatments (Table 1-4).

As container size increases, plant leaf area, shoot and root fresh weight increases in general (Cantliffe, 1993). However, in seedling production, using smaller containers which can produce more plants and require less production space, is crucial (Vavrina, 1993). When roots are confined in a container that restricts their growth, the root competes for available oxygen (Peterson et al., 1991). In this study, porosities in all treatments had no significant differences. However, the restricted root growth was caused by the decreased cell volume as the root might severely compete for the space in a cell. Nevertheless, we could identify the minimum cell volume (141.30 cm^3) suitable for use in cultivation for ginseng seedlings. This trial may lead to the space utilization in greenhouse cultivation, even in plant factories, for ginseng seedling optimizing the density of planting with cost saving. Consequently, these results can lead to cost and labor saving in ginseng seedling production. Still, it is necessary to conduct further studies on how the seedling roots grown in a small cell volume will perform post-transplanting.

Table 1-1. Cell depth and volume of the container in each treatment, and its bulk density and porosity of growing medium used for Experiment 1 at 20 weeks after sowing.

Cell depth (cm)	Cell volume (cm^3)	Bulk density ($g\ cm^{-3}$)	Porosity (%)
15	294.38	0.151 ab[z]	94.3 ab
20	392.50	0.130 b	95.1 a
25	490.63	0.164 ab	93.8 ab
30	588.75	0.186 a	93.0 b

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

Table 1-2. Cell diameter and volume of container in each treatment, and its bulk density and porosity of growing medium used for Experiment 2 at 20 weeks after sowing.

Cell diameter (mm)	Cell volume (cm^3)	Bulk density ($g\ cm^{-3}$)	Porosity (%)
12	22.61	0.102 b[z]	96.2 a
15	32.33	0.200 a	92.5 b
20	62.80	0.192 a	92.7 b
30	141.30	0.175 a	93.4 b
50	392.50	0.190 a	92.8 b
75	883.13	0.184 a	93.1 b

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

Figure 1-3. Growth of ginseng seedlings as affected by cell depth (15, 20, 25, and 30 cm) at 20 weeks after sowing.

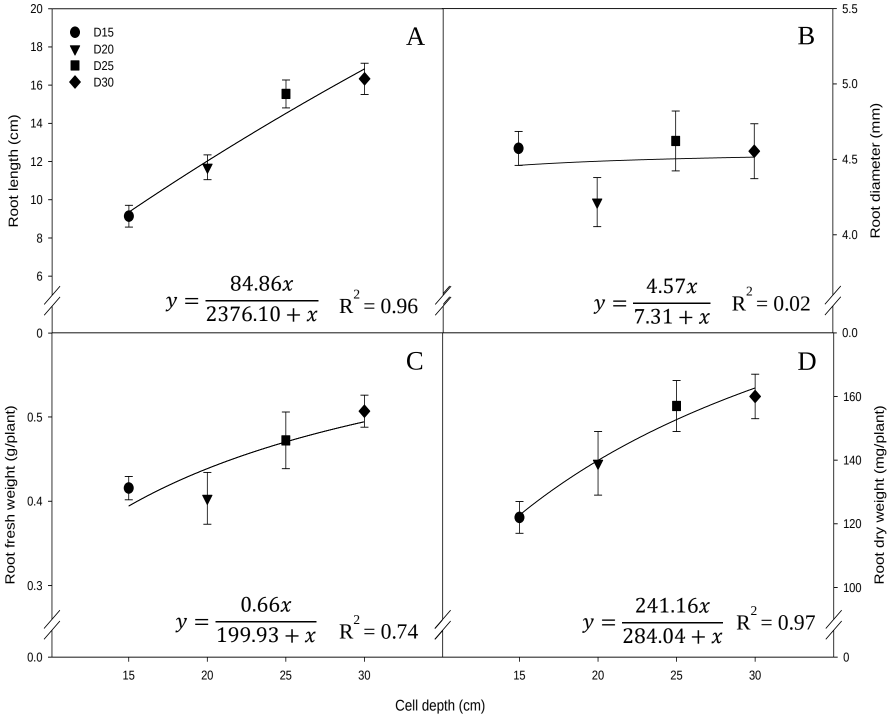

Figure 1-4. Regression analysis between cell depth and root length (A), root diameter (B), root fresh weight (C), and root dry weight (D). The treatments were abbreviated as D15, D20, D25, and D30 for 15, 20, 25, and 30 cm of cell depth. Bars represent standard error. Equations for regression lines are presented for significant correlations with corresponding R^2.

Table 1-3. The shoot length, leaf area, and shoot fresh and dry weight of ginseng seedlings as affected by cell depth at 20 weeks after sowing.

Cell depth (cm)	Shoot length (cm)	Leaf area (cm^2)	Shoot fresh weight (g/plant)	Shoot dry weight (mg/plant)
15	5.95 a[z]	8.28 b	0.18 a	30.0 b
20	6.43 a	9.48 ab	0.18 a	34.9 a
25	6.24 a	10.60 a	0.20 a	35.9 a
30	6.10 a	10.43 a	0.20 a	35.3 a

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

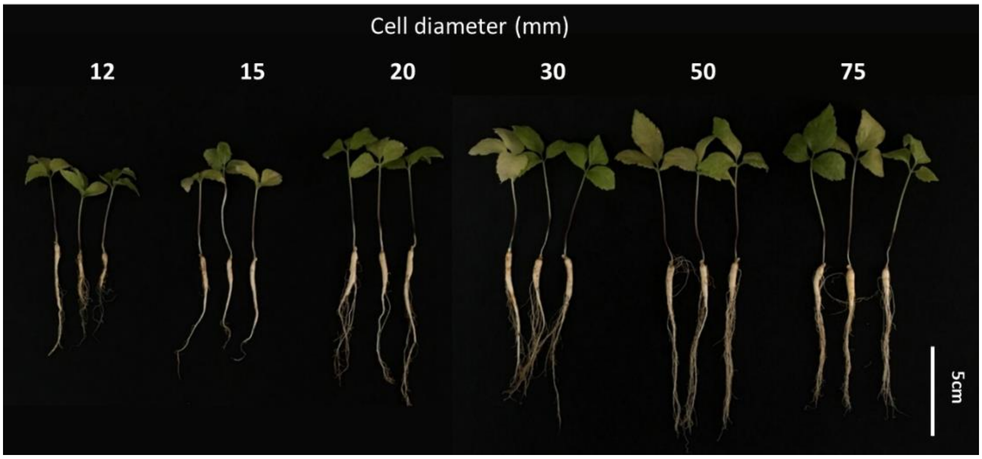

Figure 1-5. Growth of ginseng seedlings as affected by cell diameter (ø12, 15, 20, 30, 50, and 75 mm) at 20 weeks after sowing.

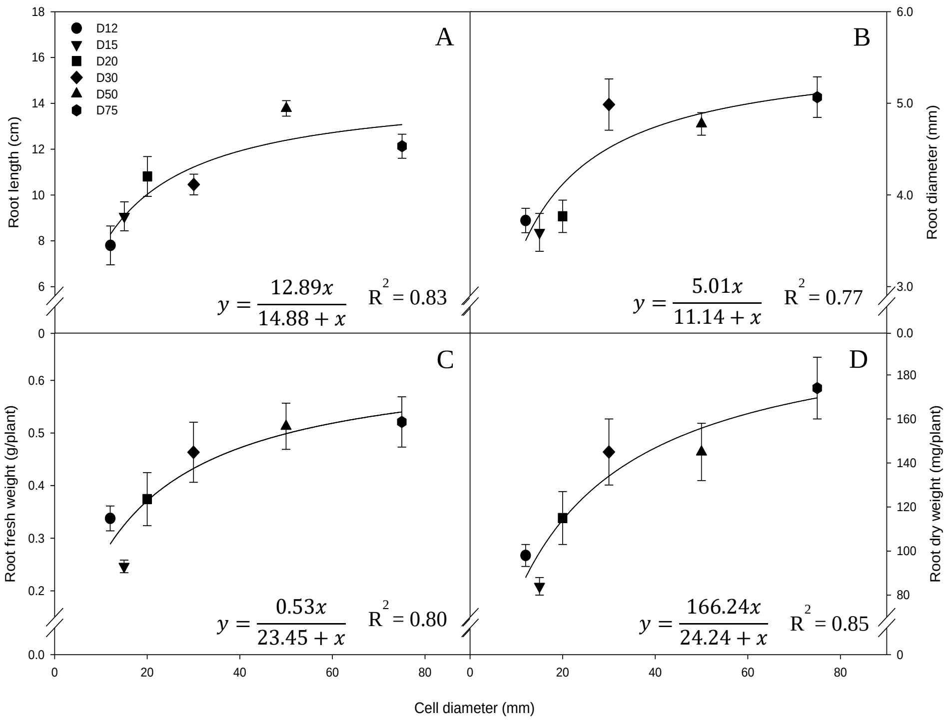

Figure 1-6. Regression analysis between cell diameter and root length (A), root diameter (B), root fresh weight (C), and root dry weight (D). The treatments were abbreviated as D12, D15, D20, D30, D50, and D75 for 12, 15, 20, 30, 50, and 75 mm of cell diameter. Bars represent standard error. Equations for regression lines are presented for significant correlations with corresponding R^2.

Table 1-4. The shoot length, leaf area, and shoot fresh and dry weight of ginseng seedlings as affected by cell diameter at 20 weeks after sowing.

Cell diameter (mm)	Shoot length (cm)	Leaf area (cm^2)	Shoot fresh weight (g/plant)	Shoot dry weight (mg/plant)
12	4.54 d[z]	6.05 b	0.15 b	25.1 b
15	4.95 d	6.44 b	0.16 b	24.8 b
20	5.73 c	7.42 b	0.15 b	26.3 b
30	6.49 ab	10.96 a	0.21 a	36.9 a
50	6.04 bc	10.40 a	0.23 a	32.8 a
75	6.87 a	12.24 a	0.24 a	37.7 a

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

REFERENCES

Default RJ, Waters L (1985) Container size influences broccoli and cauliflower transplant growth but not yield. HortScience 28:299-301

Cantliffe DJ (1993) Pre- and postharvest practices for improved vegetable transplant quality. HortTechnology 3:415-418

Hartmann HT, Kester DE (1963) Plant propagation: principles and practice. Soil Science 95:89

Lee JC, Byen JS, Ahn DJ, Jo JS (1995) Effect of physical properties of soil on ginseng seedling growth in nursery bed. Kor J Ginseng Sci 19:287-290

Nelson PV (1991) Greenhouse operation and management. Prentice Hall. pp.27-29

NIAST (National Institute of Agriculture Science and Technology) (2000) Soil and plant analysis. NIAST, Suwon, Korea

Park HW, Jang IB, Kim YC, Mo HS, Park KC, Yu J, Kim JU, Lee EH, Kim KH (2014) Growth characteristics of ginseng seedlings as affected by mixed nursery soil under polyethylene film covered greenhouse. Kor J Ginseng Sci 22:363-368

Park HW, Mo HS, Jang IB, Yu J, Lee YS, Kim YC, Park KC, Lee EH, Kim KH (2015) Emergence rate and growth characteristics of ginseng affected by different types of organic matters in greenhouse of direct-sowing culture.

Kor J Ginseng Sci 23:27-36

Peterson TA, Reinsel MD, Krizek DT (1991) Tomato (*Lycopersicon esculentum* Mill., cv.‘Better Bush’) plant response to root restriction. J Exp Botany 42:1241-1249

Rural Development Administration (RDA) (2013) Seedling production technique guideline for growing superior ginseng seedlings. Rural Dev Administration. Jeonju, Korea. p.75

Rural Development Administration (RDA) (2014) Standard cultural practice of ginseng. Rural Dev Admin. Jeonju, Korea. pp.104-139

Roy R, Ball Coelho B, Reeleder R, Bruin A, Grohs R, White P, Capell B (2008) Effect of planting bed shape, mulch and soil density on root yield and shape in North American ginseng (*Panax quinquefolius* L.). Can J Plant Sci 88:937-949

Styer RC, Koranski DS (1997) Plug & transplant production. A grower's guide. Ball Publishing. pp.41-46

Vavrina CS, Olson S, Cornell J (1993) Watermelon transplant age: Influence on fruit yield. HortScience 28:789-790

CHAPTER 2

Growth of Ginseng Seedlings as Affected by Light Intensity and Photoperiod

INTRODUCTION

Light condition is one of the crucial factors that influence plant growth and development among many environmental factors (Perez-Balibrea et al., 2008). It is well known that light quality, light intensity, and photoperiod are key components of light condition. Increasing light intensity is well known to promote photosynthesis and enhance the growth of plants such as lettuce (Kang et al., 2013) and strawberry (Park et al., 2017). Moreover, in general, photoperiod affects the vegetative and reproductive growth of plants, the levels of secondary metabolites (Ali et al., 2009) and fresh and dry masses (Ikeda et al., 1988). Light requirements of plants depends on species, cultivar, growth and developmental stages of plant, and environmental conditions. Therefore, further studies on light intensity and photoperiod are needed considering the physiological requirement of plants (Kang et al., 2013).

Ginseng is a semi-shade perennial plant whose growth is sensitive to light environment (Jang et al., 2015). Among light environmental factors, light intensity may be the most crucial factor promoting photosynthetic ability and growth potential in ginseng (Proctor et al., 2010). Cho et al (2008) reported that ginseng grown at high light intensity suffered photo-inhibition, leaf bleaching, and early defoliation. However, ginseng grown at low light intensity resulted in reduced root yield (Proctor and Palmer, 2017). For greenhouse cultivation, 13% to 17% of light transmission rate are recommended in order to increase the yield of ginseng.

On the other hand, no clear studies about light intensity and photoperiod were conducted in PFAL, yet. PFAL has advantage on controlling environmental factors especially light conditions compared to greenhouse (Kozai et al., 2019). This trait could make it possible to find the correct level of light intensity and photoperiod for ginseng seedling production. Moreover, in order to achieve the highest efficiency for cultivation in a PFAL, optimizing light intensity with photoperiod seems important.

The objective of this study were to determine the optimum light intensities and photoperiods in ginseng seedling production in a PFAL.

MATERIALS AND METHODS

Plant material and environmental conditions

Stratified ginseng seeds (*Panax ginseng* C.A. Meyer cv. Chunpoong) were sown into plastic containers (520×365×200 mm, W×L×H) filled with peat moss and perlite (7:3, v/v) growing media (Golden Root, Nongkyung Co., Ltd., Jincheon Korea) at a distance of 3 cm by 3 cm apart with a depth of 3 cm and placed in a plant factory with artificial light (PFAL).

The plants were cultivated under warm-white LED lamps (YHT-020-L5-K, Yuyang DNU Co., ltd., Hwaseong Korea) (Fig 2-1). Each container was irrigated with 1.5 L of tap water at an interval of seven days. Averages in air temperature and relative humidity were 24.3ºC and 58.3%, respectively.

Light treatments

After sowing, three containers were placed in each treatment and grown for 20 weeks under light treatments with a combination of three different photoperiods (8, 12, and 16 h) and four light intensities (50 ± 5, 120 ± 5, 190 ± 5, and 260 ± 5 μmol m^{-2} s^{-1}) for a total of 12 treatments. The light intensity levels were measured by using a light meter (LI-250A, LI-COR Inc., USA) with a quantum sensor (LI-190, LI-COR Inc., USA).

Chlorophyll fluorescence measurement

At nine weeks after sowing, four plants from each treatment were randomly selected and the chlorophyll fluorescence of a matured true leaf was measured using a portable FluorPen FP100 fluorimeter (Photon Systems Instruments, Brno, Czech Republic). All measurements were performed on the adaxial surface of a leaf disc (5 mm diameter). After 20 min of dark adaptation, the measuring pulses were weak light pulses, which are able to induce the minimal chlorophyll fluorescence (Fo). Then, a saturating light pulse at approximately 3,000 μmol m^{-2} s^{-1} was irradiated for 0.8 s to obtain the maximum fluorescence (Fm). The variable fluorescence (Fv) was defined by the difference between Fm and Fo, and used to estimate the maximum quantum efficiency (Fv/Fm).

Data collection and statistical analysis

Recorded data of chlorophyll fluorescence were analyzed using a FluorPen 1.0.4.1 software (Photon Systems Instruments, Brno, Czech Republic). The maximum quantum efficiency of photosystem II (PS II) photochemistry (Fv/Fm) was calculated from the OJIP analysis.

Treatments was replicated three times with about 100 individual plants in each replication. The experimental data were statistically analyzed by the Statistical Analysis System (SAS) for Windows version 9.4 (SAS Institute, Cary, NC, USA) using Duncan's multiple range tests at $p < 0.05$ confidence level.

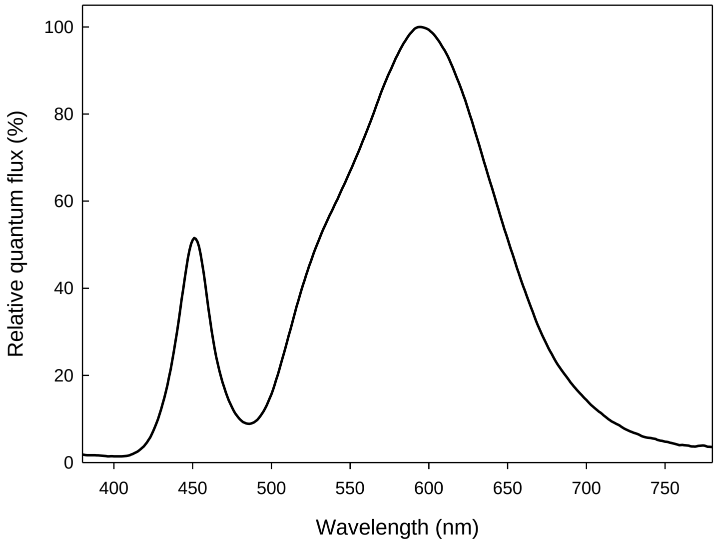

Figure 2-1. Spectral distribution of warm-white LED used for the experiment.

RESULTS AND DISCUSSION

Growth of ginseng seedlings

Shoot growth of ginseng seedlings were greatly affected by light intensity and photoperiod (Fig. 2-2). Shoot elongation and leaf expansion were inhibited by higher light intensity with longer photoperiod at 9 weeks after sowing (WAS) when the leaves were fully unfolded (Table 2-1). At 20 WAS, shoot length and leaf area were shown the same trend as those at 9 WAS. As the light intensity and photoperiod increased, the early defoliation occurred (Fig. 2-3). This trend led to the declining tendency of shoot fresh and dry weights (Table. 2-2). As the leaves are consistently exposed to high light intensity with long photoperiod, the leaf tissues can be damaged by the intense evaporation on the leaf surfaces, consequently the early defoliation may occur (Lee et al., 2011).

In addition, the root growth of ginseng seedlings were greatly affected by light intensity and photoperiod. At a light intensity of 50 μmol m^{-2} s^{-1} with 12 h photoperiod, the root growth was greatest among all treatments. As the chlorophyll was not detected in treatments of 16 h photoperiod, no further root growth might occur. However, at lower light intensity with shorter photoperiod, more root growth could be expected.

Relative chlorophyll contents

High light intensity with long photoperiod decreased the relative chlorophyll contents (SPAD value) of the leaves and this light response intensified with increasing light intensity and photoperiod. At 9 WAS, the SPAD value was the best at the light intensity of 50 μmol m^{-2} s^{-1} among all treatments. It decreased by 14.1, 35.4, and 12.3% from 50 to 260 μmol m^{-2} s^{-1} in 8, 12, and 16 h of photoperiod treatments, respectively (Fig. 2-4A). At 20 WAS, the SPAD value severely decreased compared to 9 WAS by increasing light intensity and photoperiod. It decreased by 58.9 and 29.3% from 50 to 260 μmol m^{-2} s^{-1} in 8 and 12-h photoperiod treatments, respectively. In addition, it reduced from 1.03 to 0.00 as light intensity increased from 50 to 260 μmol m^{-2} s^{-1} in 16 h photoperiods (Fig. 2-4B). The photoperiod also intensified these effects. Under higher light intensity with longer photoperiod condition, the leaves of plants were more yellow than those at light intensity of 50 μmol m^{-2} s^{-1} with 8 h photoperiod (Fig. 2-5). The chlorophyll content is one of the factors in determining the photosynthetic rate (Mao et al., 2007). Reduced chlorophyll contents, especially chlorophyll a, may result in a declined rate of photosynthesis (Naidu et al., 1984).

Chlorophyll Florescence

Analysis of the chlorophyll fluorescence showed that the ratio of Fv/Fm decreased from 0.74 to 0.49 as the light intensity and photoperiod increased at 9 WA WAS (Fig. 2-6). In general, the Fv/Fm value represents the maximum quantum efficiency of photosystem II (PSII) photochemistry in plant leaves (Baker, 2008). In many cases, as an abiotic stress, high irradiance can reduce the ratio of Fv/Fm by damaging the photosynthetic apparatus such as chlorophyll (Lichtenthaler et al., 2005).According to the decreased value of Fv/Fm, a high photoperiod greater than 12 h with higher light intensity can be considered to be excessive. For unstressed leaves, the value of Fv/Fm usually ranges between 0.74 and 0.85, and correlates to the maximum quantum yield of photosynthesis (Bolhàr-Nordenkampf et al., 1989; Deming-Adams et al., 1996). Therefore, as the Fv/Fm values at light intensities of 50, 120, and 190 among 8 h photoperiod treatments were about 0.74, this corresponded to the optimal condition for seedlings growth.

Figure 2-2. Growth of ginseng seedlings as affected by light intensity and photoperiod at 9 weeks after sowing.

Table 2-1. The shoot length, leaf area, and shoot fresh and dry weight of ginseng seedlings as affected by light intensity and photoperiod at 9 weeks after sowing.

Light intensity ($\mu mol\ m^{-2}\ s^{-1}$)	Photoperiod (h)	Shoot length (cm)	Leaf area (cm^2)	Shoot fresh weight (g/plant)	Shoot dry weight (mg/plant)
50	8	8.90 a[z]	14.48 ab	0.24 a	34.6 b-e
	12	8.16 ab	13.31 a-c	0.22 ab	40.1 a
	16	7.72 bc	12.09 cd	0.19 bc	45.4 c-f
120	8	7.07 c	12.50 b-d	0.18 cd	37.5 ab
	12	7.11 c	11.43 c-e	0.18 c-e	41.1 bc
	16	6.03 d	8.85 gf	0.14 f	34.2 ef
190	8	7.47 bc	14.71 a	0.22 ab	40.2 b-d
	12	6.07 d	10.44 d-f	0.15 d-f	35.6 b-e
	16	5.54 d	7.77 g	0.12 f	27.5 f
260	8	7.54 bc	14.58 ab	0.22 ab	42.4 ab
	12	5.65 d	9.36 e-g	0.14 ef	32.8 d-f
	16	5.38 d	9.33 e-g	0.17 c-e	49.0 a
Significance					
Light intensity (A)		***	***	***	NS
Photoperiod (B)		***	***	***	*
Interaction (A × B)		*	*	*	***

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

NS = non-significant; *, **, and *** = significant at $p < 0.05$, 0.01, and 0.001, respectively.

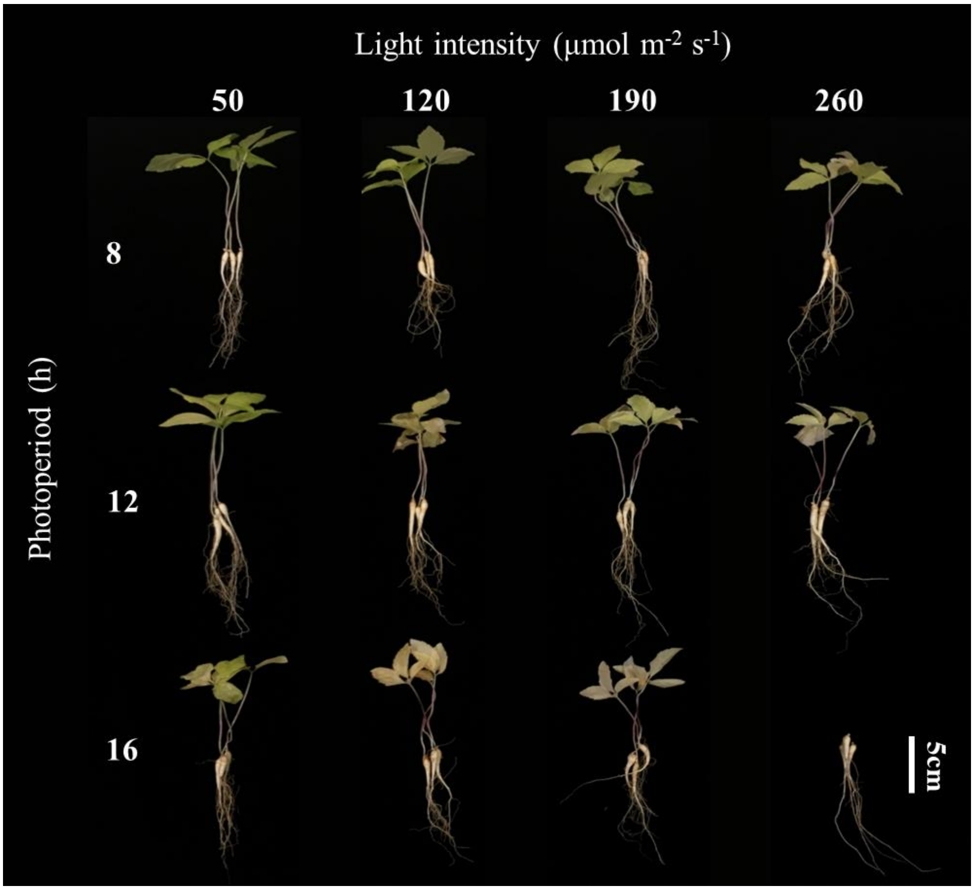

Figure 2-3. Growth of ginseng seedlings as affected by light intensity and photoperiod at 20 weeks after sowing.

Table 2-2. The shoot length, leaf area, and shoot fresh and dry weight of ginseng seedlings as affected by light intensity and photoperiod at 20 weeks after sowing.

Light intensity (μmol m^{-2} s^{-1})	Photoperiod (h)	Shoot length (cm)	Leaf area (cm^2)	Shoot fresh weight (g/plant)	Shoot dry weight (mg/plant)
50	8	9.37 a[z]	12.85 ab	0.23 a	29.0 b-d
	12	8.49 ab	13.53 a	0.21 ab	34.9 a
	16	8.31 bc	10.30 d-f	0.16 de	26.2 b-e
120	8	7.49 cd	11.89 bc	0.20 bc	30.9 ab
	12	7.32 de	9.63 ef	0.17 de	30.2 bc
	16	6.46 ef	7.80 h	0.14 ef	24.8 de
190	8	6.94 de	10.66 c-e	0.18 cd	29.6 bc
	12	6.51 ef	9.24 fg	0.14 ef	27.7 b-e
	16	5.70 f	8.00 gh	0.14 f	23.1 e
260	8	7.69 b-d	11.50 cd	0.19 bc	30.8 ab
	12	5.90 f	7.39 h	0.13 f	25.7 c-e
	16	-	-	-	-
Significance					
Light intensity (A)		***	***	***	***
Photoperiod (B)		***	***	***	*
Interaction (A × B)		NS	***	NS	*

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

NS = non-significant; *, **, and *** = significant at $p < 0.05$, 0.01, and 0.001, respectively.

Table 2-3. The root length, diameter, and root fresh and dry weight of ginseng seedlings as affected by light intensity and photoperiod at 20 weeks after sowing.

Light intensity (μmol m^{-2} s^{-1})	Photoperiod (h)	Root length (cm)	Root diameter (mm)	Root fresh weight (g/plant)	Root dry weight (mg/plant)
50	8	11.49 a-c[z]	3.7 c	0.26 cd	89.7 bc
	12	12.03 ab	4.2 a-c	0.37 a	125.6 a
	16	10.33 bc	4.4 a	0.27 cd	96.2 b
120	8	10.08 bc	4.0 a-c	0.27 cd	94.4 bc
	12	11.04 a-c	4.4 a	0.29 c	95.9 b
	16	9.96 c	4.3 ab	0.24 cd	84.2 b-d
190	8	11.16 a-c	3.8 bc	0.25 cd	76.8 cd
	12	10.42 bc	4.1 a-c	0.24 cd	80.4 b-d
	16	9.73 c	4.2 a-c	0.26 cd	83.2 b-d
260	8	12.82 a	3.9 bc	0.30 bc	88.8 bc
	12	10.43 bc	4.2 ab	0.34 ab	117.2 a
	16	10.63 bc	4.1 a-c	0.22 d	70.8 d
Significance					
Light intensity (A)		*	***	***	***
Photoperiod (B)		*	NS	**	***
Interaction (A × B)		NS	NS	**	***

[z]Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

NS = non-significant; *, **, and *** = significant at $p < 0.05$, 0.01, and 0.001, respectively.

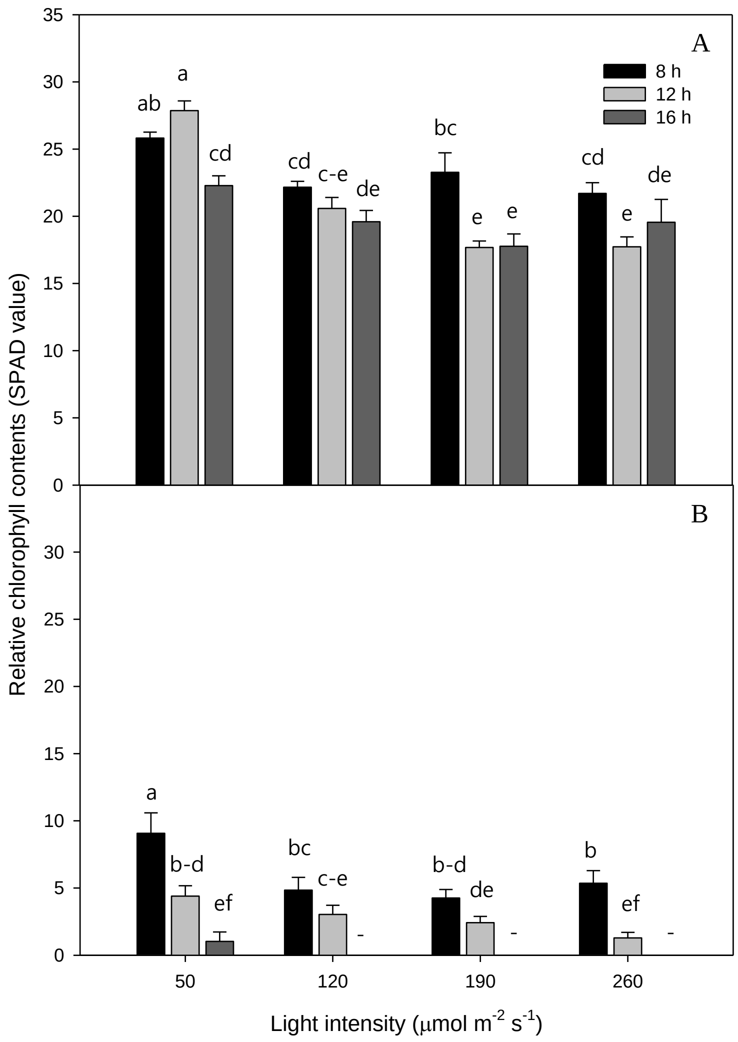

Figure 2-4. Relative chlorophyll contents (SPAD value) of ginseng seedlings as affected by light intensity and photoperiod at 9 (A) and 20 (B) weeks after sowing. Bars represent standard error (n = 9). Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

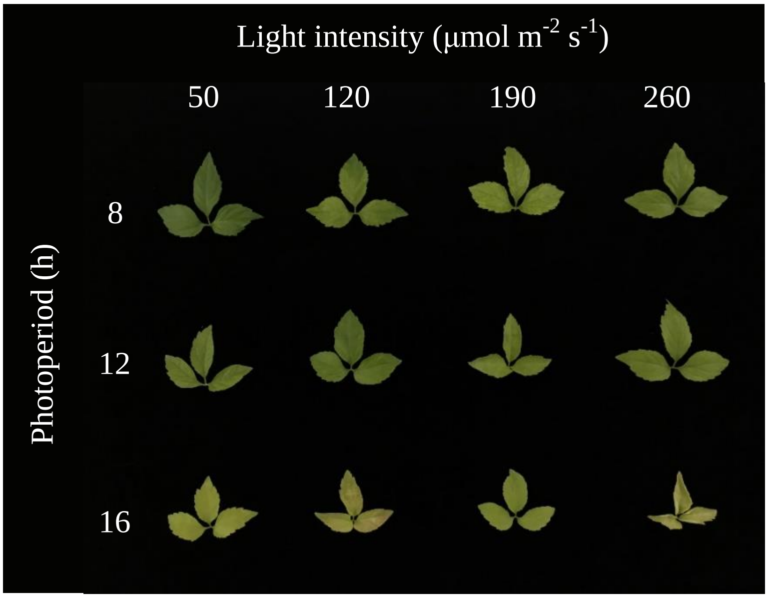

Figure 2-5. Leaf color of ginseng seedlings as affected by light intensity and photoperiod at 9 weeks after sowing.

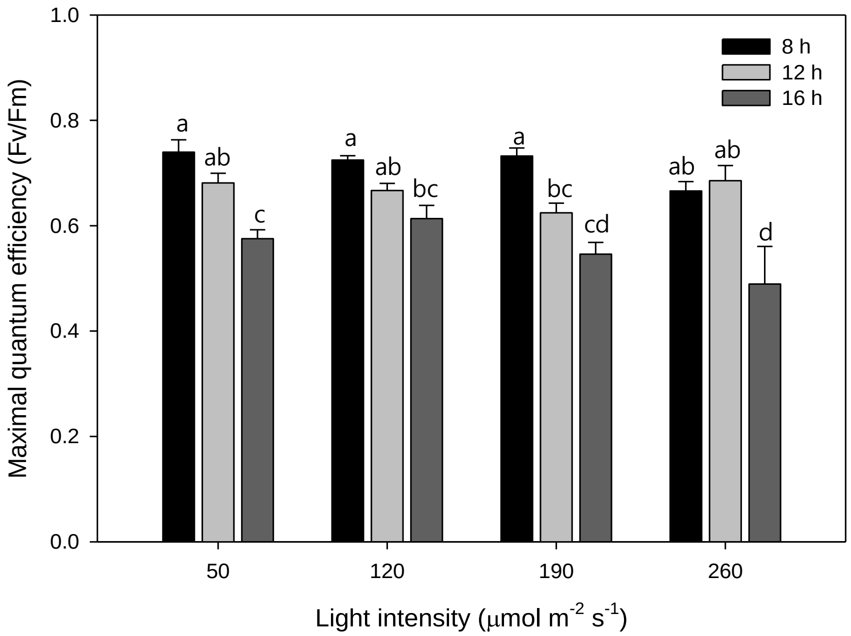

Figure 2-6. Maximal quantum yield (Fv/Fm) of leaves of ginseng seedlings grown under 8, 12, and 16 h photoperiod in combination with light intensity of 50, 120, 190, and 260 μmol m^{-2} s^{-1} after 9 weeks of treatment. Bars represent standard error (n = 4). Means within each column followed by the same letters are not significantly different according to Duncan's multiple range test at $p < 0.05$.

REFERENCES

Ali MB, Khandaker L, Oba S (2009) Comparative study on functional components, antioxidant activity and color parameters of selected colored leafy vegetables as affected by photoperiods. J Food Agric Environ 7:392-398

Baker NR (2008) Chlorophyll fluorescence: a probe of photosynthesis in vivo. Annu Rev Plant Biol 59:89-113

Bolhàr-Nordenkampf HR, Öquist G (1993) Chlorophyll fluorescence as a tool in photosynthesis research. In DO Hall, JMO Scurlock, HR Bolhàr-Nordenkampf, RC Leegood, SP Long, eds, Photosynthesis and Production in a Changing Environment: A field and laboratory manual. Springer Netherlands, Dordrecht. pp.193-206

Cho JW, Park HW, Kim MJ, Kim HH, Choi JE (2008) Photosynthetic, morphological and growing characteristics by shading materials in *Panax ginseng* C.A. Meyer. Kor J Crop Sci 53:256-260

Deming-Adams B, Adams III WW, Barker DH, Logan BA, Bowling DR, Verhoeven AS (1996) Using chlorophyll fluorescence to assess the fraction of absorbed light allocated to thermal dissipation of excess excitation. Physiol Plant 98:253-264

Ikeda A, Nakayama S, Kitaya Y, Yabuki K (1987) Effects of photoperiod, CO_2 concentration, and light intensity on growth and net photosynthetic rates of lettuce and turnip. In Symposium on Biology Aspects of Energy Saving in Protected Cultivation 229. pp.273-282

Jang IB, Lee DY, Yu J, Park HW, Mo HS, Park KC, Hyun DY, Lee EH, Kim KH (2015) Photosynthesis rates, growth, and ginsenoside contents of 2-yr-old *Panax ginseng* grown at different light transmission rates in a greenhouse. J Ginseng Res 39:345-353

Kang JH, Krishna KS, Atulba SLS, Jeong BR, Hwang SJ (2013) Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. Hortic Environ Biotechnol 54:501-509

Kozai T, Niu G, Takagaki M (2019) Plant factory: an indoor vertical farming system for efficient quality food production. Academic press. pp.17-20

Lee SW, Kim GS, Hyun DY, Kim YB, Kim JW, Kang SW, Cha SW (2011) Comparison of growth characteristics and ginsenoside content of ginseng (*Panax ginseng* C.A. Meyer) cultivated with greenhouse and traditional shade facility. Kor J Crop Sci 19:157-161

Lichtenthaler H, Buschmann C, Knapp M (2005) How to correctly determine the different chlorophyll fluorescence parameters and the chlorophyll fluorescence decrease ratio R_{Fd} of leaves with the PAM fluorometer. Photosynthetica 43:379-393

Mao L, Lu H, Wang Q, Cai M (2007) Comparative photosynthesis characteristics of *Calycanthus chinensis* and *Chimonanthus praecox*. Photosynthetica 45:601-605

Naidu R, Krishnan M, Nayudu M, Gnanam A (1984) Studies on peanut green mosaic virus infected peanut (*Arachis hypogaea* L.) leaves. II. Chlorophyll-protein complexes and polypeptide composition of thylakoid membranes. Physiol Plant Pathol 25:191-198

Park SW, Kwack Y, Chun C (2017) Growth of Runner Plants Grown in a Plant Factory as Affected by Light Intensity and Container Volume. Hortic Environ Biotechnol 35:439-445

Pérez-Balibrea S, Moreno DA, García-Viguera C (2008) Influence of light on health-promoting phytochemicals of broccoli sprouts. J Sci Food Agric 88:904-910

Proctor JT, Palmer JW (2017) Optimal light for greenhouse culture of American ginseng seedlings. J Ginseng Res 41:370-372

Proctor JT, Palmer JW, Follett JM (2010) Growth, dry matter partitioning and photosynthesis in North American ginseng seedlings. J Ginseng Res 34:175-182

ABSTRACT IN KOREAN

본 실험은 인공광이용형 식물공장을 이용한 새로운 인삼 공정육묘시스템 개발을 목표로 진행되었다. 제 1 장에서는 공정묘 생산을 위한 플러그 트레이 개발을 목적으로, 플러그 셀의 깊이 및 직경을 달리하여 결정된 근권부 용적에 따른 묘삼의 생육과 형태 변화를 조사하였다. 개갑된 인삼(*Panax ginseng* C.A. Meyer '천풍')종자를 인삼전용상토가 채워진 원통형 폴리염화비닐(PVC) 셀에 파종한 후 저면관수 시스템을 이용하는 인공광이용형 식물공장에서 20 주 동안 재배하였다. 첫 번째 실험에서는 PVC 파이프를 이용하여 직경 50mm 의 직경을 가진 깊이(15, 20, 25, 및 30cm)가 다른 셀을 제작하여 처리구로 이용하였다. 실험결과, 셀의 깊이가 30cm 까지 증가할수록 묘삼의 근장, 근 생체중과 건물중, 및 엽면적이 증가하였다. 두 번째 실험에서는 깊이 20cm 에 직경(ø12, 15, 20, 30, 50, 및 75mm)이 다른 셀을 처리구로 사용하였다. 실험결과, 셀의 직경이 30mm 까지 커질수록 묘삼의 지하부와 지상부 생육이 증대되었다. 이러한 결과는 인삼 육묘용 플러그 트레이 설계뿐 아니라 육묘 중의 적절한 영양 및 수분관리 시스템 개발에 활용될 것으로 사료된다. 제 2 장에서는 백색 LED 조명의 광도와 광주기에 따른 묘삼의 생육과 형태 변화를 조사하였다. 개갑된 천풍종자를

인삼전용상토가 채워진 플라스틱 재배용기(520 × 365 × 200mm)에 파종한 후 warm-white LED 광원을 이용한 광도 4 처리(50, 120, 190, 및 260 μmol m^{-2} s^{-1})와 광주기 3 처리(8, 12, 및 16 시간)의 조합에서 두상관수를 이용하여 20 주 동안 재배하였다. 실험결과, 광주기가 길어지고 광도가 높아질수록 묘삼의 지상부 생육이 감소하였으며, 특히 잎의 황백화가 심했고 낙엽이 증가하는 것을 확인하였다. 지하부 생육은 광주기 12 시간과 광도 260 μmol m^{-2} s^{-1}의 조합에서 가장 높은 것을 확인하였다. 이러한 결과는 인공광이용형 식물공장을 이용한 인삼 공정육묘시스템의 최적 광환경 조건을 제시한 것으로 판단된다. 본 석사학위 논문 연구를 통하여 개발된 새로운 묘삼 생산 방법을 이용한다면 약 8 개월이 소요되는 현행의 노지 육묘 기간을 4 개월까지로 단축하여 1 년에 3 회 묘삼을 생산할 수 있게 되어, 인삼의 모종 생산과 공급 시스템의 획기적 변화를 이루어낼 수 있을 것으로 판단된다.

주요어: 광도, 광주기, 셀 용적, 인공광이용형 식물공장 (PFAL), 인삼 공정육묘, 환경조절

학번: 2018-29424