Research article

Photosynthesis rates, growth, and ginsenoside contents of 2-yr-old *Panax ginseng* grown at different light transmission rates in a greenhouse

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**Abstract**

**Background:** Ginseng is a semishade perennial plant cultivated in sloping, sun-shaded areas in Korea. Recently, owing to air-environmental stress and various fungal diseases, greenhouse cultivation has been suggested as an alternative. However, the optimal light transmission rate (LTR) in the greenhouse has not been established.

**Methods:** The effect of LTR on photosynthesis rate, growth, and ginsenoside content of ginseng was examined by growing ginseng at the greenhouse under 6%, 9%, 13%, and 17% of LTR.

**Results:** The light-saturated net photosynthesis rate ($A_{\text{sat}}$) and stomatal conductance ($g_s$) of ginseng increased until the LTR reached 17% in the early stage of growth, whereas they dropped sharply owing to excessive leaf chlorosis at 17% LTR during the hottest summer period in August. Overall, 6-17% of LTR had no effect on the aerial part of plant length or diameter, whereas 17% and 13% of LTR induced the largest leaf area and the highest root weight, respectively. The total ginsenoside content of the ginseng leaves increased as the LTR increased, and the overall content of protopanaxatriol line ginsenosides was higher than that of protopanaxadiol line ginsenosides. The ginsenoside content of the ginseng roots also increased as the LTR increased, and the total ginsenoside content of ginseng grown at 17% LTR increased by 49.7% and 68.3% more than the ginseng grown at 6% LTR in August and final harvest, respectively.

**Conclusion:** These results indicate that 13-17% of LTR should be recommended for greenhouse cultivation of ginseng.

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1. Introduction

*Ginseng* (*Panax ginseng* Meyer) is a semishade perennial plant whose growth diminishes beyond the optimum light intensity. It should be shaded from direct sunlight by an artificial facility in consideration of the light transmission rate (LTR), in order to increase the yield. For this reason, ginseng has been cultivated under a two-layered black polyethylene net with shading in Korea, a major ginseng exporter, for several decades [1]. Nevertheless, ginseng leaves, which play a critical role in the root yield [2], are easily damaged by air-environmental stresses [3] and various fungal diseases [4]—such as Alternaria blight by *Alternaria panax*, anthracnose by *Colletotrichum gloeosporioides*, and Phytophthora blight by *Phytophthora cactorum*—beyond redemption because of the open environment [5], the nonuniform LTR [6], and the high temperature of still air beneath the polyethylene net [3,7]. To prevent early defoliation by pathogenic fungi in particular, agricultural chemicals are widely used; unfortunately, however, excessive use has led to today’s pesticide residue problem. These negative aspects have a direct influence on the image of ginseng, which is used as a medicine.

Growing ginseng in greenhouses on account of incidence inhibition by rainproof cultivation and improving cultivation efficiency
have become an affordable alternative solution to this comprehensive problem [8]. The data for cultivating ginseng in the greenhouses, however, are scarce, and little is known about the optimum LTR in shaded greenhouses because the majority of previous studies on the growth of ginseng have been based on analyses undertaken in slanted shading where the LTR is subject to changes in solar altitude. Lee et al [6] reported that there were notable differences of more than three times the light intensity among the lines and the rearmost line irrespective of time and weather. As a result of the different natural light influx occasioned by the slanted shading, ginseng growth shows a wide variation according to the planting position, even in the same shading [9]. So the optimal LTR in a greenhouse for ginseng is practically unestablished, and it has customarily been suspended in a black polyethylene net with a polyethylene film above the greenhouse for light interruption, without checking the light influx, although it has been shown that LTRs ranging from 8% to 20% are suitable for increasing the ginseng root yield on the basis of photosynthetic capability [1,10,11].

The purpose of the present study was to examine the photosynthetic and growth characteristics of ginseng grown at different LTRs in greenhouses, including its ginsenoside content, which is recognized as an important factor in determining the quality of ginseng under different natural light levels, and also to determine the suitable LTR for greenhouse cultivation because plant growth can be increased by improving photosynthetic efficiency in an environment similar to ginseng’s natural habitat. Furthermore, our data provide valuable resources for the development of a suitable shading material for greenhouses in which ginseng is cultivated.

2. Materials and methods

2.1. Growth conditions of ginseng in the greenhouse

The experiments were conducted in four greenhouses (with a surface area of 42 m² and a height of 2.5 m) at the Department of Herbal Crop Research, Eumseong (127°45’13.14” E, 36°56’36.63” N), Korea, from March 31, 2014 to October 10, 2014. The light intensities in the greenhouse were measured with a LI-250A quantum sensor (LI-COR, Lincoln, NE, USA) for 5 min both above and below the crop canopy three times during the growing seasons prior to solar noon under clear sky conditions. Light transmission in the greenhouse was controlled by covering polyethylene netting above the greenhouse for light interruption, without checking the light influx, although it has been shown that LTRs ranging from 8% to 20% are suitable for increasing the ginseng root yield on the basis of photosynthetic capability [1,10,11].

A block temperature of 20°C (±1°C), a CO₂ concentration of 400 μmol/mol (similar to natural atmosphere concentration), a relative humidity of 30–40%, a block temperature of 20°C, and an irradiance level of 500 μmol/m²/s photosynthetic photon fluxes [12]. Measurements were taken twice, on June 2, 2014 (when ginseng leaves are fully expanded) and August 11, 2014, under an elevated temperature environment during the hot summer season of 2014. A minimum and maximum wait time for each step were set at 3 min and 5 min, respectively.

2.2. Determination of photosynthetic parameters

The light-saturated net photosynthetic rates (A₅₀₀) and stomatal conductance (gₛ) of the 2-yr-old ginseng leaves grown at different LTRs were measured using a LI 6400 portable photosynthesis system (LI-COR) equipped with an infrared gas analyzer. The middle of the fully expanded leaves was clamped to a 6-cm² leaf chamber provided by a LI 6400-02 LED light source sensor head (LI-COR). The conditions inside the leaf chamber were controlled at an air influx rate of 500 μmol/s, a CO₂ concentration of 400 μmol/m³’s photosynthetic photon fluxes [12]. Measurements were taken twice, on June 2, 2014 (when ginseng leaves are fully expanded) and August 11, 2014, under an elevated temperature environment during the hot summer season of 2014. A minimum and maximum wait time for each step were set at 3 min and 5 min, respectively.

2.3. Measurements of chlorophyll contents and growth

The chlorophyll content of 2-yr-old ginseng leaves was measured with a chlorophyll meter (SPAD-502; Minolta, Tokyo, Japan) three times at the center of the leaves throughout the experiments [13]. The 2-yr-old ginseng leaves were harvested according to a completely randomized design under sunny conditions and directly measured for their growth characteristics using a general ruler, a pair of Digimatic calipers (caliper 500-182; Mitutoyo, Tokyo, Japan), or an electronic scale (RE260; CAS, Seoul, Korea). The leaf surface area was measured with a WindDIAS image analysis system (DeltaT; ADC, London, UK) when the aerial parts were fully foliated. Measurements were taken on June 2, 2014 and August 11, 2014. In the case of underground growth, measurement was taken once more on the final harvest day, which was October 3, 2014.

2.4. Cross section of leaf tissues

Ginseng leaf sections of 2 mm × 3 mm × 3mm were taken and added to 2.5% glutaraldehyde, and then bubbles including tissue were immediately removed. All processes were carried out at 4°C. For the first holding, washing was done for four to five times at intervals of 15 min with 0.1M phosphate buffer (pH 7.2) after 90 min of treatment. In the second holding, treatment was done for 90 min at 4°C with 1% osmium tetroxide and then washed four to five at intervals of 20 min with 0.1M phosphate buffer (pH 7.2) and then passed one night in the final phosphate buffer. Dehydration was done with 40% ethanol, 60% ethanol, 80% ethanol, 90% ethanol, and 95% ethanol for 5 min each and with 100% ethanol for 5 min, 15 min, and 30 min. After dehydration, samples spent 15 min in a 1:1 mixed solution of propylene oxide and ethanol for easier penetration into epon tissues, and then soaked in pure propylene oxide for 5 min, 15 min, and 30 min. Finally, each was treated for 3 h in 2:1 and 1:1 mixed solutions of propylene oxide and epon to embed in the epon and then spent one night in pure epon. The next day, the epon was changed and treatment was done for 15 min, after which epon + D.M.P. 30 (1.5% addition of epon) was put in a silicon mold with sample sections and heat cured at 60°C for 4 d.
make an epon block. Next, 10–15 epon blocks were made per treatment, and three epon blocks were randomly selected from among these. An ultrafine cutter (Ultracut R; Leica Co., Wetzlar, Germany) was used to cut samples to a thickness of 1,500 nm. Distilled water was dropped on a slide glass, and samples were placed on it and dried at 60°C for ≥ 5 h and then stained. For the staining process, manufactured tissue sections were soaked in a 0.5% periodic acid (H5IO6) solution for 30 min and then washed two to three times for 10 min with distilled water, treated for 15 min in Schiff’s reagent, treated for 5 min in 1% sodium bisulfite solution, and then washed for 30 min in running water. Samples having completed staining were dried on a 60°C hot plate for ≥ 5 h for permanent preservation, and then Hystomount was dropped and covered with a cover glass and dried again. Hystomount stuck to the cover glass area was then cleanly removed, and an optical microscope (Axioskop 2; Carl Zeiss Co., Germany) was used to examine microscopically at 200 times and record.

2.5. Analysis of ginsenosides

Ginsenoside components such as ginsenoside Rb1, Rb2, Rb3, Rc, Rd, Re, Rf, Rg1, Rg2, and Rh1 were purchased from a chemical company (Chroma Dex Inc., Santa Anna, CA, USA). MeOH (Merck & Co Inc., Darmstadt, Germany) and other GR-grade solvents were used for the quantitative analysis of ginsenosides by an Agilent 1100 series HPLC system (Agilent Technologies, Palo Alto, CA, USA), using Sep-Pak Plus C18 cartridges (Waters Corp., Milford, MA, USA) for the solid phase extraction.

For each treatment, 100 mg of freeze-dried powder sampled from 30 freeze-dried ginseng plants was used for the extraction of ginsenosides. Each sample was suspended in 1 mL of 70% MeOH in a 2-mL microcentrifuge tube, placed in an ultrasonic bath (Power sonic 410; Hwashin Tech., Seoul, Korea), and extracted by sonication for 60 min. For the solid phase extraction, a Sep-Pak Plus C18 cartridge was eluted slowly using 3 mL MeOH for the lower conditioning, and again using 3 mL dd-H2O for the upper conditioning. One milliliter of the extracted solution (70% MeOH extract) was loaded into the cartridge and eluted slowly using 1 mL dd-H2O to remove any sugar soluble materials, then eluted slowly using 2 mL MeOH to extract the ginsenoside components. The final eluent was adjusted to an exact volume of 1 mL and filtered through a membrane filter (with a pore size of 0.45 μm), and then analyzed by HPLC on a Halo RP-Amide (4.6 mm × 150 mm, 2.7 μm at 50°C with a flow rate of 0.5–0.8 mL/min). The optimized LC elution conditions were as follows: 0–1 min, 27% B; 1–6 min, 28% B; 6–10 min, 28% B; 10–30 min, 34% B; 30–33 min, 80% B and 33–35 min, 27% B. The extracts were analyzed with a UV detector at 203 nm.

2.6. Statistical analysis

All statistical analyses were performed using SAS, version 9.2 (SAS Institute, Cary, NC, USA). The statistical significance of the differences was determined using Duncan’s multiple tests and one-way analysis of variance, evaluating significant differences at p < 0.05. All data were at the 5% significance level and were reported as mean ± standard deviation.

3. Results and discussion

3.1. Effect of LTR on photosynthesis and stomatal conductance

The degree of light transmission could affect the cultivation of ginseng in greenhouses because it directly affects the photosynthesis rate. As photosynthetic parameters, the $A_{\text{sat}}$ and $g_s$ were measured in $P. ginseng$ grown at 6%, 9%, 13%, and 17% of LTR in the greenhouse on June 2, 2014 and August 11, 2014, as shown in Fig. 2.

![Fig. 2. Light-saturated net photosynthesis rate, $A_{\text{sat}}$, and stomatal conductance, $g_s$, of 2-yr-old Panax ginseng grown at 6%, 9%, 13%, and 17% of the light transmission rates (LTRs) in a greenhouse on June 2, 2014 and August 11, 2014. The vertical error bars represent the standard errors (n = 5). The same letters at the top of each bar indicate statistically no difference at p < 0.05 using Duncan’s multiple range test.](image-url)
Both $A_{\text{sat}}$ and $g_s$, of ginseng grown at the higher LTR were significantly higher than those of the lower LTRs in June, i.e., 17\% (3.39 μmol/m² s) > 13\% (3.12 μmol/m² s) > 9\% (2.58 μmol/m² s) > 6\% (2.24 μmol/m² s) on $A_{\text{sat}}$, and 17\% (0.047 mol/m² s) > 13\% (0.045 mol/m² s) > 9\% (0.035 mol/m² s) > 6\% (0.030 mol/m² s) on $g_s$. However, in August, 2014, both parameters similarly increased until 13\% of LRT, but they rapidly decreased at 17\% of LRT, i.e., 13\% (3.22 μmol/m² s) > 9\% (2.83 μmol/m² s) > 6\% (2.20 μmol/m² s) > 17\% (1.66 μmol/m² s) on $A_{\text{sat}}$, and 13\% (0.045 μmol/m² s) > 9\% (0.035 μmol/m² s) > 6\% (0.030 μmol/m² s) > 17\% (0.027 μmol/m² s) on $g_s$. The results for the photosynthetic parameters in June indicated that ginseng leaves are more adaptable to sunlight by 17\%, and that photosynthesis may occur more readily at high light intensity during the early season when there is no high-temperature stress. These results were found to be in agreement with those of previous studies, i.e., that the $A_{\text{sat}}$ and $g_s$ of ginseng were higher in the front rows of the beds under a relatively much higher light influx environment than in the rear rows of the beds [14]. When ginseng that has adapted to a low intensity of radiation is exposed to a high intensity of radiation, the photosynthetic parameter is lower. The reason for this is that as the plant grows under conditions of a low intensity of radiation, the size of the photosystem II’s antenna is bigger than that of the plant growing under a high intensity of radiation [15,16]. The zeaxanthin in the xanthophyll cycle formation ability also becomes lower and causes the activity of the D1 protein to decrease [17]. Conversely, many researchers reported that the $A_{\text{sat}}$ of ginseng rapidly decreased as the LTR increased owing to a reduction of the chlorophyll content [18,19]. This also seems to be similar to the result obtained in August, 2014 in this study, where ginseng grown at an LTR of 17\% was observed to have lower $A_{\text{sat}}$ compared with that in other LTR conditions. It is assumed that the reduction in photochemical efficiency in photosystem II in excessively bleached leaves caused by photooxidation reduced the $g_s$ and, subsequently, the $A_{\text{sat}}$ under an elevated temperature environment during the hot summer season of July and early August [20], because the continuous inflow of too much light causes chronic damage to the photosynthesis system, which decreases quantum efficiency and $A_{\text{sat}}$ [21].

### 3.2. Effect of LTR on chlorophyll contents

In addition to the decrease in the photosynthetic parameter $A_{\text{sat}}$ at 17\% of LTR in August, 2014, we observed yellowish leaves, particularly in ginseng grown at higher LTRs, as shown in Fig. 3A. Thus, the contents of chlorophyll in leaves were examined using a chlorophyll meter. The respective SPAD value of ginseng grown at 6\%, 9\%, 13\%, and 17\% of LTRs were 31.4, 31.1, 30.3, and 24.6 in June, 2014, and 28.8, 27.4, 24.2, and 19.1 in August, 2014, respectively, indicating a steady decrease in chlorophyll over time during the hot summer season ($p = 0.0338$; Fig. 3B). The reduction rates between June and August of the SPAD value in ginseng grown at 6\%, 9\%, 13\%, and 17\% of LTR were 8.1\% (2.54), 11.9\% (3.72), 20.0\% (6.04), and 22.4\% (5.50), respectively, and tended to rise as the LTR increased. Consistently, when the status of chloroplasts in leaves of ginseng grown at 6\%, 9\%, 13\%, and 17\% of LTRs were observed using a light microscope, the intensity of the green color in chloroplasts decreased as LTR increased (Fig. 3C).

In the case of plants growing under a regular sunny condition, the light saturation point exceeds 1,000 μmol/m² s [22]. By contrast, ginseng has a fairly low amount of intensity of radiation of about 250 μmol/m² s [10,11], and photoinhibition takes place, suppressing the electron transport system’s (ETS) electron transfer [23]. In the case of a shade plant that has a higher photosystem II/I ratio than a plant growing under a regular sunny condition, a large amount of photon gets absorbed by photosystem II [24]. This causes the ETS to saturate faster, whereas the electrons and energy that did not get used react with O₂ to create singlet oxygen (1O₂) with a strong acidic toxicity [25]. If one can maintain an adequate amount and decrease the overabsorption of the photon in photosystem II for the ETS of the ginseng to use, one can expect to prevent damages such as pigment bleaching and lipid peroxidation, as well as achieve the maximum root yield. During the early growth stage in June 2014, the SPAD value did not have any significance besides the ginseng grown at 17\% LTR; however, when compared to the 17\% LTR, the O₂ creation would be small up to 13\% LTR, as the ETS did not saturate. However, the decrease in SPAD value was noticeable in August 2014, when the temperature was higher. The high temperature greatly decreased the ETS activity of the ginseng [14], and the ginseng grown at 13\% LTR had a lower SPAD value compared with the one grown at below 9\% LTR. In this study, the steady decrease of chlorophyll in ginseng leaves as the LTR increased reaffirmed the similar results obtained in previous studies. Cheon et al [1] reported that the chlorophyll contents of ginseng leaves decreased remarkably according to increases of 5\%, 10\%, and 20\% under shade, and that ginseng leaves grown at 30\% LTR withered because the rate is too high for the plant to endure the breakdown of chlorophylls inside the leaves.

### 3.3. Effect of LTR on aerial and subterranean growth of ginseng

Previous reports showed different results about ginseng growth depending on LTR, although the growth environment and species of ginseng used in their experiments were different. Cheon et al [1] reported that as the LTR increases up to 30\% in the shading, growth of the aerial part continues to decrease, except for the diameter of 2- and 4-yr-old $P. ginseng$ plants, and that underground growth increases up to 20\%. By contrast, Proctor et al [26] reported that both the aerial and underground growth of 2-yr-old $P. quinquefolius$ increases as the LTR increases up to 30\%. Kim et al [27] reported that the leaves of $P. ginseng$ that grew under a large amount of light in the front row had bigger leaves than the ones in the back row. Because of these discrepancies, growth of aerial and subterranean parts of ginseng was measured separately, depending on different LTRs.

In this study, shoot length, shoot diameter, leaf area, and aerial part fresh weight were measured to examine the aerial part growth of ginseng grown at different LTRs. Shoot length and diameter were not different at all LTRs, whereas the leaf area increased as the LTR increased (Fig. 4). The fresh weight of the aerial part of the ginseng that grew under 6\% LTR in our experiment was lower than at other LTRs, and this may be attributable to the difference in the decrease of the leaves’ surface area because there were no significant difference between shoot length and stem diameter (Fig. 4). Such a result agrees with the results of other studies that reported that the plants have lower aerial part growth when grown under a low intensity of light [28]. Root length, root diameter, and root fresh weight were also measured to examine the underground growth of ginseng grown at different LTRs. The root length of ginseng grown under 6\% LTR was shorter than that of other samples at the final harvest day (Fig. 5). In the case of root diameter and fresh weight, they were bigger or heavier at higher LTRs than at lower LTRs, and they gradually increased by 13\% LTR. However, at 17\% LTR both were not different from those at 13\% LTR. This might indicate that approximately 13\% LTR is the optimum condition for both aerial and root growth of ginseng in a greenhouse. Based on previous studies performed in shading when the average solar radiation intensity was 4.29 kW h/m²/d between April and October during a 28-yr period (from 1982 to 2010) in Korea [1,6,10,18,29], roughly 10–20\% of LTR
Fig. 3. The chlorophyll contents in ginseng grown at the indicated light transmission rate (LTR) in the greenhouse. (A) Leaf color of 2-yr-old *Panax ginseng* grown at 6%, 9%, 13%, and 17% of LTRs in a greenhouse. Photos were taken on June 2, 2014 (top) and August 11, 2014 (bottom). (B) SPAD value of 2-yr-old *Panax ginseng* grown at 6%, 9%, 13%, and 17% of LTRs in a greenhouse on June 2, 2014 and August 11, 2014. The vertical error bars represent the standard errors (*n* = 10). The same letters at the top of each bar indicate statistically no difference at *p* < 0.05 using Duncan’s multiple range test. (C) The status of chloroplasts observed by light microscope (× 200). Greenish spots indicate chloroplasts.
was assumed to be optimal. Our results could help optimize the LTR level for ginseng growth in a greenhouse.

Previous reports showed that early defoliation by leaf chlorosis in ginseng grown at 20% and 30% LTR in conventional shading led to a decrease of 14% and 20%, respectively, than at 10% LTR in the yield of ginseng root [1]. Our results also showed leaf chlorosis and lower photosynthetic rates at 17% LTR, compared to 13% LTR, particularly on August 11, 2014 (Figs. 2 and 3). However, both aerial part and
root fresh weights were not significantly decreased at 17% LTR, compared to 13% LTR (Figs. 4, 5). This could be explained by two ways. First, aerial growth of 2-yr-old ginseng in a greenhouse probably already reaches the maximum or near maximum before leaf chlorosis observed on August 11, 2014 occurs. In fact, the final values of shoot length and fresh weight measured on June 02, 2014 and August 11, 2014 were very similar (Fig. 4). Second, the amount of nutrients provided to roots may be kept stable during the entire

### Table 1
Ginsenoside contents in leaves of 2-yr-old *Panax ginseng* grown at 6%, 9%, 13%, and 17% of light transmission rates (LTR) in a greenhouse on June 2, 2014 and August 11, 2014

| LTR  | Panaxadiol (PD) | Panaxatriol (PT) | Total | PD/PT | Total |
|------|-----------------|------------------|-------|-------|-------|
|      | Rb1 | Rb2 | Rc  | Rd   | Total | Rb1 | Rb2 | Rb3 | Rb4 | Total | Re  | Rf  | Rg1 | Rg2 | Rg3 | Rh1 | Total |
| 2 June | 6   | 1.13(c) | 2.02(c) | 2.62NS | 2.90(c) | 5.87(c) | 12.33NS | 5.44(c) | 0.16(a) | 11.53(b) | 0.38(c) | ND | 17.54(d) | 0.7029 | 29.83(c) |
|      | 9   | 1.23(b) | 2.23(b) | 0.29 | 3.20(b) | 7.25(a) | 14.35 | 7.54(b) | 0.17(a) | 11.96(b) | 0.42(b) | ND | 20.08(c) | 0.7146 | 34.43(b) |
|      | 13  | 1.27(b) | 2.42(a) | 0.34 | 3.67(a) | 6.76(b) | 14.63 | 7.29(b) | 0.12(b) | 13.52(a) | 0.52(a) | ND | 21.46(b) | 0.6817 | 36.09(a,b) |
|      | 17  | 1.41(a) | 2.20(b) | 0.28 | 3.15(b) | 5.89(c) | 14.91 | 9.05(a) | 0.17(a) | 14.07(a) | 0.52(a) | ND | 23.82(a) | 0.6259 | 36.89(a) |
| 11 August | 6  | 2.83(a) | 5.26(a) | 5.02(c) | 7.89(a) | 14.29(a) | 34.63(a) | 12.95(c) | 0.15(b) | 24.38(c) | 0.82(d) | ND | 37.32(d) | 0.9279 | 73.60(b) |
|      | 9   | 1.51(c) | 2.86(d) | 5.33(b) | 4.33(d) | 9.99(c) | 24.22(c) | 18.32(a) | 0.19(a) | 22.22(d) | 0.89(c) | ND | 41.61(c) | 0.5821 | 65.83(c) |
|      | 13  | 2.32(b) | 3.43(c) | 6.88(a) | 5.41(c) | 10.98(b) | 29.08(b) | 16.73(b) | 0.15(b) | 33.12(a) | 1.24(a) | ND | 51.24(a) | 0.5659 | 80.24(a) |
|      | 17  | 2.76(a) | 4.72(b) | 6.66(a) | 7.14(b) | 13.62(a) | 34.91(a) | 16.84(b) | 0.18(a) | 29.90(b) | 1.14(b) | ND | 48.06(b) | 0.7264 | 82.97(a) |

ND, not detected; NS, not significant

1) The same letters at the top of each bar indicate statistically no difference at p < 0.05 using Duncan’s multiple range test (n = 30)
3.4. Effect of LTR on ginsenoside contents in ginseng leaves and roots

Ginsenosides are known as one of the main medicinal properties of ginseng and as an indicator of quality in evaluations of ginseng’s properties [30]. Moreover, ginsenosides are ginseng’s innate defensive substances against stresses that increase steadily under various environmental conditions, including high light levels (30% of solar radiation) [31,32]. Many factors affecting ginsenoside contents in ginseng have been previously reported [33]. In our study, the effect of LTR on ginsenoside contents in ginseng grown at 6%, 9%, 13%, and 17% of LTR in the greenhouse was examined. For this purpose, 10 major types of ginsenosides—including five panaxadiol line ginsenosides (PD), Rx, Rf, Rg1, Rg2, and Rh1 and five panaxatriol line ginsenosides (PT), Re, Rf, Rg1, Rg2, and Rh1—were measured separately.

Changes in the content of ginsenosides followed by light stress were very clear in our experiment. In ginseng leaves, the trend whereby ginsenoside content increases as the LTR increases was more evident in the PT than in the PD line ginsenosides regardless of time (Table 1). Likewise, Lee et al. [34] also reported that until LTR more evident in the PT than in the PD line ginsenosides regardless were very clear in our experiment. In ginseng leaves, the trend measured separately. In ginseng leaves, the trend measured separately. In ginseng leaves, the trend measured separately.

Table 2
Ginsenoside contents in roots of 2-yr-old *Panax ginseng* grown at 6%, 9%, 13%, and 17% of light transmission rate (LTR) in a greenhouse on June 2, 2014, August 11, 2014, and on the final harvest day

| LTR     | Panaxadiol (PD) | Panaxatriol (PT) | PD/PT Total |
|---------|-----------------|------------------|-------------|
|         | Rx | Rf | Rg1 | Rg2 | Rh1 | Rx | Rf | Rg1 | Rg2 | Rh1 | Rx | Rf | Rg1 | Rg2 | Rh1 |
| 2 June  | 6   | 2.98(a) | 0.52(a) | 0.20(a) | 1.34(a) | 1.02NS | 7.07(a) | 2.47(b) | 0.99(c) | 2.91(a) | 0.47(a) | 0.07(b) | 7.02(ab) | 1.0071 | 13.89(a) |
|         | 9   | 2.99(a) | 1.00(a) | 0.20(a) | 1.88(a) | 0.96 | 7.03(a) | 3.54(a) | 1.30(a) | 2.35(b) | 0.37(b) | 0.12(a) | 7.67(a) | 0.9166 | 14.70(a) |
|         | 13  | 2.17(b) | 0.75(b) | 0.15(b) | 1.47(b) | 0.75 | 5.30(b) | 2.67(b) | 1.14(b) | 2.17(b,c) | 0.35(b,c) | 0.07(b) | 6.40(b) | 0.8281 | 11.70(c) |
|         | 17  | 2.36(b) | 0.74(b) | 0.13(b) | 1.44(b) | 1.09 | 5.78(b) | 3.48(a) | 1.36(a) | 1.96(c) | 0.31(c) | 0.11(a) | 7.22(a) | 0.8005 | 13.00(b) |
| 11 August| 6   | 2.88(c) | 0.76(b) | 0.18(c) | 1.79(b) | 0.77(b) | 6.44(c) | 1.84(b) | 0.86(c) | 2.27(c) | 0.37(c) | 0.05NS | 5.49(c) | 1.1730 | 11.88(c) |
|         | 9   | 3.22(b) | 0.82(b) | 0.19(b,c) | 1.96(b) | 0.74(b) | 6.93(bc) | 3.02(a) | 1.39(a) | 2.43(c) | 0.41(b) | 0.06 | 7.31(b) | 0.9480 | 14.25(b) |
|         | 13  | 3.35(b) | 0.81(b) | 0.20(b) | 1.95(b) | 0.73(b) | 7.05(b) | 2.74(a) | 1.14(b) | 2.83(b) | 0.44(b) | 0.05 | 7.20(b) | 0.9792 | 14.24(b) |
|         | 17  | 4.42(a) | 1.05(a) | 0.23(a) | 2.42(a) | 1.03(a) | 9.15(a) | 3.08(a) | 1.42(a) | 3.52(a) | 0.56(a) | 0.05 | 8.64(a) | 1.0590 | 17.79(a) |
| Final harvest | 6   | 2.61(b) | 0.56(c) | 0.15(c) | 1.02(c) | 0.38(c) | 4.73(b) | 2.07(b) | 1.01(c) | 2.96(c) | 0.33(b) | 0.03(b) | 6.31(c) | 0.7496 | 11.03(c) |
|         | 9   | 3.09(a) | 0.73(b) | 0.18(b) | 1.24(b) | 0.45(b) | 5.69(a) | 1.99(b) | 1.21(b) | 2.97(c) | 0.44(a) | 0.04(a) | 6.65(b) | 0.8556 | 12.34(b) |
|         | 13  | 2.94(a) | 0.68(b) | 0.19(b) | 1.44(a) | 0.46(b) | 5.71(a) | 2.03(b) | 1.12(b,c) | 3.58(b) | 0.45(a) | 0.03(b) | 7.23(b) | 0.7897 | 12.93(b) |
|         | 17  | 2.41(b) | 1.03(a) | 0.22(a) | 1.37(a) | 0.62(a) | 5.65(a) | 3.34(a) | 1.34(a) | 3.54(a) | 0.45(a) | 0.02(c) | 10.49(a) | 0.5386 | 16.14(a) |

NS, not significant

1) The same letters at the top of each bar indicate statistically no difference at p < 0.05 using Duncan’s multiple range test (n = 30)

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Conflicts of interest

All contributing authors declare no conflicts of interest.

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Growing period. In fact, the values of root diameter or fresh weight were slightly higher on August 11, 2014 compared with those recorded on June 2, 2014, and were highest on the final harvest day (Fig. 5).

jasmone-responses genes might be consistently stimulated by photooxidation stress, causing the ginsenoside content to increase [35,36]. To prove such results, further studies are needed to confirm the expression level of jasmone-response genes, PgSS or PgSE genes, in ginseng depending on the various degrees of light stress.
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