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Growth and Eco-Physiological Characteristics of *Panax ginseng* Grown under Three Different Forest Types

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We collected basic data on the physiological characteristics of *Panax ginseng* in order to identify the forest stands that provide the best growth environment. Our research sites included oak, pine, and mixed-forest stands, in which ginseng seed had been sown several years earlier. Heights and dry weights of forest ginseng were better under oak trees than in the pine or mixed stands. In addition, photosynthetic rates for ginseng were highest in the oak forest, particularly at a light intensity of 200 μmol m^{-2} sec^{-1}.

Keywords: growth, *Panax ginseng*, photosynthesis, stomatal conductance

P. ginseng is an important plant resource in Korea. This medicinal herb exists naturally in only three regions: Korea, Manchuria, and the littoral province of Siberia. Because of its stringent requirements for growth, e.g., ideal temperature zone, adequate summer rainfall, the Korean peninsula is the best place for producing this valuable crop to meet the worlds demand for an emergent medicine and tonic for long life.

In Korea, most *P. ginseng* is cultivated on farmland, under artificial shade. Those fields generally must be abandoned after harvest because of the high rate of nutrient depletion from the soil. In contrast, forests can provide ideal environmental conditions for ginseng production because of their natural shading, sufficient organic matter, suitable relative humidity, and good interactions between trees and ginseng plants (Woo and Lee, 2002). In addition, forest-grown crops contain more of the desired active ingredients than does ginseng cultivated in fields. To increase their incomes, many farmers currently grow ginseng in the forest, either via direct sowing or transplantation of young seedlings. However, little physiological research has been conducted to determine the best cultivation methods or ideal soil and other environmental conditions for producing good ginseng crops in Korean forests (Kim et al., 1995; Suh and Shim, 1997; Woo and Lee, 2002). Such evaluations must include the monitoring of temperature, light intensity (shading), humidity, and soil and water conditions. Therefore, the objectives of our study were 1) to collect basic data on ginseng growth, and 2) to identify the best forest environments for promoting optimum photosynthetic rates, stomatal conductance, and plant development.

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MATERIALS AND METHODS

Research Sites

Research sites were located in the central region of Korea, near Sangju city (Fig. 1 and 2). We selected three forest stands with very similar geographical properties to minimize environmental variations. This area has gentle, southeast-facing slopes (4 to 7°) and a mean elevation of 110 to 120 m above sea level (Table 1). The only difference among these sites was in their species composition (i.e., oak, pine, or an 85%/15% oak/pine mix), which influenced light intensities on the forest floor. Canopy cover is a critical component in *P. ginseng* growth as well as a determinant of medicinal quality after harvest.

Seed Collection, Plant Materials, and Growing Conditions

Seeds of *P. ginseng* were collected at the Korea Ginseng Association, and were refrigerated at 4°C. Prior to sowing, they were soaked in tap water for 24 h and surface-sterilized by agitating in 2%

Figure 1. Location of study area.

sodium hypochlorite solution for 15 min. The seeds were then sown in each of our three forest types.

Net Photosynthesis

Net photosynthesis (A_n) was measured on all ginseng plants within the research areas, using the fully expanded mature leaves from each shoot apex. With the aid of a LiCor-6400 Portable Photosynthesis System (Li-Cor, USA), each leaf was sealed in a broadleaf cuvette, in which the CO_2 concentration was maintained at the ambient level and the temperature was held at 25°C. Air flow through the analyzer was adjusted to a constant relative humidity of 60 to 70% during the measurement period. Net photosynthesis was then calculated as:

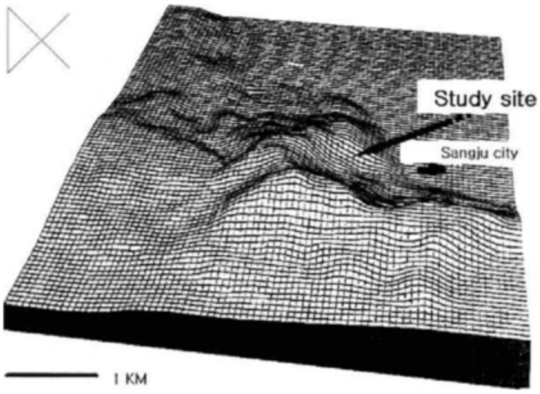

Figure 2. Geographical image of study area (Bae et al., 1996).

$$A_n = \frac{U_e(C_e - C_c)}{100s} - C_c E$$

where, A_n = net photosynthesis (îmol CO_2 m^{-2} s^{-1}); U_e = mole flow rate of air entering the leaf chamber (µmol s^{-1}), C_e = mole fraction of CO_2 in the chamber (îmol CO_2 mol^{-1} air); C_c = mole fraction of CO_2 entering the chamber (îmol CO_2 mol^{-1} air); s = leaf area (cm^2); and E = transpiration rate (mmol H_2O m^{-2} s^{-1}).

Stomatal Conductance

Stomatal conductance was measured on all of the ginseng leaves as described above, using the LiCor-6400 Portable Photosynthesis System. Again, the average cuvette temperature was maintained at 25°C. Stomatal conductance was then calculated as:

$$G_{sw} = \frac{1}{(1/G_{tw}) - (K_f/G_{hw})}$$

where, G_{sw} = stomatal conductance to water vapor (mol H_2O m^{-2} s^{-1}); G_{tw} = total conductance to water vapor (mmol H_2O m^{-2} s^{-1}); G_{hw} = boundary layer conductance to water vapor (mmol H_2O m^{-2} s^{-1}); and $K_f = (K^2+1)/(K+1)^2$, where K was an estimate of the ratio of stomatal conductance of one side of the leaf to the other.

Light Intensity

Light intensity was monitored every 2 h throughout the daytime (0900 h to 1700 h) with a calibrated Li-Cor light sensor placed 30 cm above the ground.

Soil Analysis

Soil was collected from a 20 cm depth at all three sites in order to analyze its texture, pH, amount of organic matter, and water content. In addition, nutrient content was measured with an Inducted Coupled Plasma.

Data Analysis

Analysis of variance (ANOVA) was conducted to estimate the significance of treatment effects while a Duncans multiple range test was used to separate treatment means. All statistical analyses were performed with SPSS PC+.

RESULTS AND DISCUSSION

Stand and Soil Conditions for Ginseng Growth

Our three research forest stands were similar in terms of their tree ages (20 to 25 years), heights (7.8 to 8.5 m), and DBH (14 to 18 cm) (Table 2). Crown

Table 1. General environmental conditions for three research sites.

Classification	Latitude	Longitude	Aspect	Slope (°)	Elevation (m)
Pure oak stand	36° 22' 30"	128° 8' 00"	SE	4	120
Pure pine stand	36° 22' 30"	128° 8' 00"	SE	5	110
Mixed stand (85% oak, 15% pine)	36° 22' 30"	128° 8' 00"	SE	7	115

Table 2. Stand characteristics of three research sites.

Classification	Stand age (years)	DBH (cm)	Mean height (m)	Crown coverage (%)	Origin
Pure oak stand	20	17	8.5	80	Regenerated
Pure pine stand	25	14	7.8	75	Reforested
Mixed stand (85% oak, 15% pine)	20	18	7.9	80	Regenerated

Table 3. Soil characteristics at research sites.

Classification	Pure pine stand	Pure oak stand	Mixed stand
Soil texture	Sandy loam	Sandy loam	Sandy loam
pH	5.07	5.25	5.20
Organic matter (%)	4.97	5.23	7.26
Water content (%)	43.00	46.00	54.00
P_2O_5	10.65	9.43	8.42
Na	9.38	8.45	8.45
Mg	105.85	67.07	87.45
Total N (%)	0.16	0.10	0.24
B	0.15	0.00	0.14
Ca	434.20	208.06	569.40
Cu	0.05	0.07	0.04
K	67.40	78.52	74.20
Mn	85.83	58.56	59.40
Ni	0.07	0.10	0.11
Zn	1.54	1.03	1.84

coverage ranged from 75% (pine) to 80% (pure oak or mixed forest) in those stands. Both the oak stand and the mixed-species forest had regenerated naturally in the past 20 years whereas the pine stand was established from transplanted stock 25 years before.

Soil texture at all three sites was a sandy loam (Table 3). In general, the soil pH for the coniferous forest was lower than in the deciduous stand because of the composition of the litter on the floor. Greater soil acidity results when respiratory CO_2 combines with water to produce carbonic acid. Acids may also be produced during the decomposition of soil organic matter; the litter of conifers and mosses such as *Sphagnum* becomes very acidic as it decomposes (Kimmins, 1987).

Climatic Conditions at Research Sites

Temperatures at our forest stands during the growing season (May through August) ranged from 17 to 25°C (Table 4). Mean annual precipitation, relative humidity, and wind speed for the previous year were reported as approximately 990 mm, 64%, and 4 m/sec, respectively.

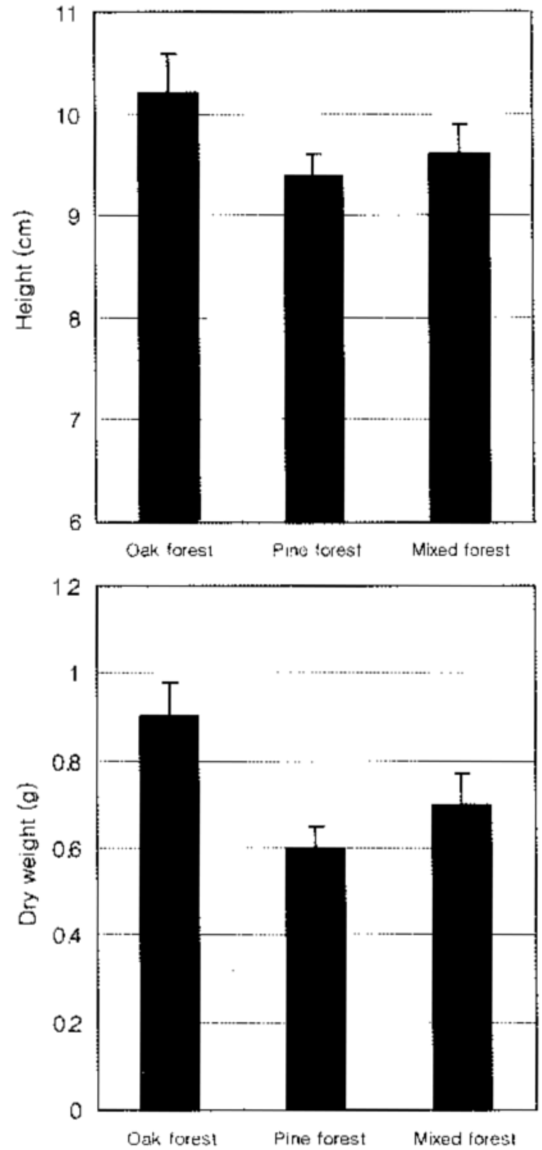

Figure 3. Heights (left) and root dry weights (right) of *P. ginseng*. Bars indicate standard deviation (N=10).

Growth of *P. ginseng*

Although differences were not significant for our five-year-old ginseng plants, their above-ground growth rates were slightly better in the oak stand than in

Table 4. Meteorological data for Year 2002 at research sites.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean temperature (°C)	-2.0	0.2	5.4	12.4	17.4	21.5	24.3	24.6	19.5	13.3	6.3	0.3
Precipitation (mm)	21.3	29.1	49.7	88.7	103	168.8	271	23.8	127	46	41	22
Humidity (%)	58.7	56.9	57.4	55	59.7	68.7	77.7	77.3	71.4	65.9	65.3	61.7
Wind speed (m/sec)	5.9	5.7	4.9	4.8	3.8	2.9	3.8	3.1	5.6	4.4	5.0	4.6

(Korea Meteorological Administration, 2003)

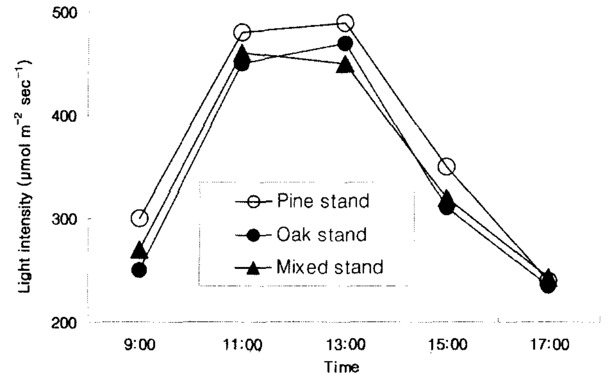

Figure 4. Variations in daylight intensity among research stands.

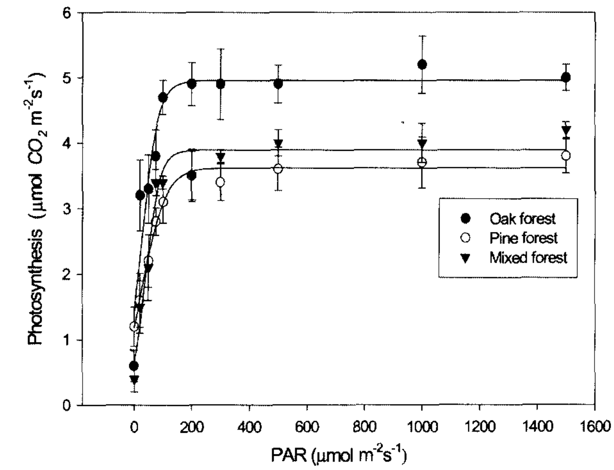

Figure 5. Light response curves to photosynthesis by *P. ginseng* seedlings. Measurements taken at 25°C chamber temperature, 65% relative humidity, and 360 ppm CO_2 concentration.

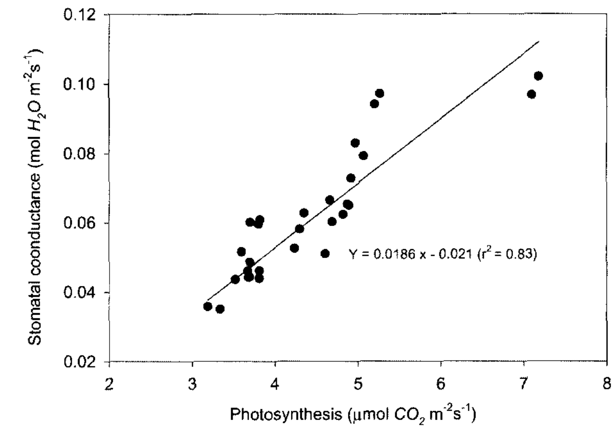

Figure 6. Stomatal conductance in leaves of *P. ginseng* seedlings. Measurements taken at 25°C chamber temperature, 65% relative humidity, and 360 ppm CO_2 concentration.

either the pine or the mixed stands (Fig. 3). Root dry weights in particular were also greater from the oak forest. Nevertheless, shoot heights, root collar diameters, and root lengths and weights were lower for ginseng produced in the forest compared with plants of the same age cultivated in agricultural soil (Woo and Lee, 2002).

Light Intensity

The intensity of daylight in all three stands was 200 to 500 μmol m^{-2} sec^{-1} (Fig. 4) with values being slightly higher among the pure stand of pine (due to the nature of their needles and smaller area of crown coverage) than in the oak or mixed forests (Table 2). Therefore, the ginseng grown under those pine trees was exposed to more sunlight, which inhibited the growth of this naturally shade-tolerant, cooler-temperature species (Korean Ginseng Research Institute, 1978).

Photosynthesis and Stomatal Conductance

Photosynthesis was significantly greater in seedlings grown in the oak stand compared with those from the pine or mixed forests (Fig. 5). This higher level of activity probably contributed to the better growth performance by ginseng recorded at our pure-oak site. The maximum photosynthetic rate was measured at a light intensity of 200 μmol m^{-2} sec^{-1}, regardless of forest type. This light saturation point for *P. ginseng* is noticeably lower than for other forest species (Kozlowski and Pallardy, 1997), a response that is typical of shade-tolerant plants (Oliver and Larson, 1996). Photosynthesis by such species is as efficient at high light intensities as it is at lower levels (Kimmins, 1987; Kozlowski and Pallardy, 1997). In our trials, stomatal conductance was strongly correlated with photosynthesis for ginseng plants grown in any of the three stand types (R^2 = 0.83; Fig. 6).

In summary, this study was the first to measure photosynthesis patterns and physiological characteristics of Korean ginseng grown in the forest. Heights, dry weights, and photosynthetic rates for those plants were better in the oak stand than in either the pure-pine or mixed forests. The greater canopy coverage associated with these oak trees provided an ideal microenvironment of low light intensities and adequate soil moisture for sustaining this shade-tolerant species.

Cultivation of ginseng is labor-intensive, hard to mechanize, and requires much experience and great skill. Because of that, large-scale production is fairly difficult. When raised in nursery beds, those plants must have strong and artificial shading facilities. Moreover, after a crop is harvested from the field, the farmer must wait 10 to 15 years before establishing the next plantation because of the serious depletion of soil nutrients. Therefore, we believe that forested sites are the best places for cultivating ginseng, in terms of higher yields of biomass as well as the better quality of ginsenosides produced under such conditions. We also suggest that future research include antioxidant assays of ginseng to identify exactly which type of forest is best for obtaining the most desirable medicinal ingredients for commercial purposes.

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