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Original Research Article

Effect of Temperature Variables on Growth and Inorganic Nutrient Contents of *Codonopsis lanceolata*

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ABSTRACT This study was conducted to investigate the effects of temperature and shade, which are basic environmental conditions, on growth, yield, inorganic components, and general components of *Codonopsis lanceolata*, in order to obtain basic data for improving yield capacity. In natural light, in the 15, 20, and 25°C groups, the plant heights ranged between 218.9 cm and 223.9 cm, and there was no significant difference between groups. However, the leaf size was larger in shade, and the leaf area was significantly larger in the 15 and 30°C groups. In natural light, root length and diameter were shorter and thinner when the temperature was higher, and growth was highly suppressed at 30°C. With regards to macroelements, the contents of Na, Mg, and P increased as temperature increased, regardless of the plant part; however, no constant tendency was observed in K and Ca according to temperature. The contents of Mg and Ca (from highest to lowest) were in the order leaf>stem>root, whereas the contents of Na, P, and K were in the order stem>leaf>root. Contents of general components varied according to temperature, and were highest at 30°C. While the plant height was increased under the constant 25°C +DIF (Difference between day and night temperature) condition, growth was suppressed in the −DIF group, in which the night temperature was higher than the day temperature, which suggests that a change in night temperature is one of the factors that affects the growth of *C. lanceolata*. As in the growth of the above-ground parts, fresh weight of the root was high in the constant 25°C group and +DIF group. Notably, it was more than 2.5 times the fresh weights in the constant 15°C group, constant 20°C group, and −15 DIF group.

Keywords : *Codonopsis lanceolata*, DIF, mineral nutrients, proximate composition, shading

Codonopsis lanceolata is cultivated in different regions of South Korea and the total area of cultivation is increasing. However, research on the cultivation of *Codonopsis lanceolata* is limited in comparison to that of other major crops and research on its yield according to temperature, light, and other growth conditions. Especially considering that *Codonopsis lanceolata* grows in cool and semi-shaded areas in mountains, problems are likely to occur when growing the crop in high temperature and under direct sunlight. Morphogenesis of plants is influenced by temperature, light, soil, and growth regulating substance among other factors, and temperature morphogenesis refers to shape of a plant reacting to temperature (Erwin *et al*., 1989). In particular, change between day temperature and night temperature has a substantial effect on growth of plants (Tangeras, 1979), such as interference with flower bud development (Grimstad and Frimanslund, 1993) and delay of flowering time (Grimstad, 1995). Response of plant growth is reported in tomatoes to differentiate between day temperature and night temperature (Moe and Heins, 1989), cucumber (Challa and Brouwer, 1985), *Euphorbia* (Berghage and Hein, 1991; Ueber and Hendriks, 1992), etc. It is reported that plant growth is suppressed more when the night temperature is higher than day temperature, and when the temperature is constant

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or day temperature is higher than night temperature.

In the present study, the effects of temperature and shade on growth, yield, inorganic components, and general components of *Codonopsis lanceolata*, was investigated in order to obtain basic data for improving the yield.

MATERIALS & METHODS

Temperature and Shading treatment

Seeds of *Codonopsis lanceolata*, were harvested in Muju in 2014, that were used as an experimental material. It was sown on March 2, 2015, and hastened to sprout in the glasshouse of Woosong Information College. After the leaf appeared, each unit was transplanted into a 15cm-diameter vinyl pot. On May 15, the plants were placed in the rooms of 15, 20, 25, and 30°C each in a biotron room, and grown in natural light and shade for which 90% of natural light was blocked by using cheese cloth. Growth above ground part was invested gated on September 5, the same year, and then, on September 15, the plants were harvested to investigate the yield including root length, root diameter, and fresh weight. Also, inorganic components in the roots of *Codonopsis lanceolata* from each temperature group were analyzed.

Analysis of inorganic components

The sample was incinerated at 600°C for 12 hours and then decomposed by wet combustion method (Woo & Ryoo, 1983) and then made its quantity fixed with deionized distilled water to test the liquid. After adding 10 ml of thick nitric acid to 2 g of the roots of *Codonopsis lanceolata* for each region, the solution was heated with low temperature at first and then gradually increased the heating temperature to decompose it. Decomposed solute ion was chilled when the solution become white and transparent, and then added distilled water to the solution and made its quantity fixed to 100 ml, and then filtered it to make the remained liquid as the sample. The quantity of each mineral content was examined by ICP (Inductively Coupled Plasma, 3300DV, PerkinElmer Optima, USA). The condition of analysis was maintained in the following; plasma 15 l/min for the gas flow rate, 0.5 l/min for the auxiliary, 0.8 l/min for the nebulizer, 1,300 watts for the RF power, 1.0 ml/min for the flow rate, 18.48 rpm for the speed, 1.0 ml/min for the sample flow rate, 30sec for the sample flush time, 4.0 ml/min for the sample flush rate, and 30 sec for the delay time (Jung *et al*., 2012).

Analysis of proximate compositions

The general components of the sample were analyzed by AOAC method (AOAC, 1990). Moisture was analyzed by ambient drying at 105°C and the ash contents were examined by dry ashing method. Crude protein contents were measured by Kjeltec protein analyzer (Tecator, Sweden) with using micro- Kjeltec method, and crude fat contents were analyzed by Soxhlet method.

DIF Treatment

The same testing materials as in test 1 was sown on March 10, 2015, and after the leaf appeared, each unit was transplanted into a 15 cm-diameter vinyl pot. On April 20, they were placed and grown in rooms with constant temperature (15, 20, 25 and 30°C) and alternating temperature (25°C /20°C, 20°C /25°C, 30°C /15°C and 15°C /30°C) in a biotron room. The temperature was maintained at a day temperature from 6 AM to 6 PM and changed to and maintained at night temperature from 6 PM to 6 AM. Growth above ground was invested gated on July 2, and, after harvesting, growth underground was investigated on July 8.

Statistical analysis

Using the SAS program (SAS, 9.2, Institute Inc, USA), comparisons between treatments were conducted by Duncan's multiple range test (p=0.05).

RESULTS & DISCUSSION

Growth and yield of *Codonopsis lanceolata* in response to temperature and shading

In the present study, the growth of above-ground part of *Codonopsis lanceolata* is presented in Table 1. In natural light, in the 15, 20 and 25°C temperature, the plant heights ranged between 218.9 cm and 223.9 cm and there was no significant difference. However, the plant height (85.2 cm) was significantly shorter under 30°C than others temperature regimes. Contrary, in the shade at 15, 20 and 25°C temperature, the plant height was significantly shorter than the natural light, but there were no significant differences between different temperature groups. However, the plant height exhibited higher in shade than in natural light under 30°C. In natural light, the leaf size was slightly smaller under 30°C temperature group, but there were

Table 1. Effects of air temperature and light intensity on the growth of *Codonopsis lanceolate*.

Temperature (°C)	Light intensity[z]	Plant height (cm)	Leaf width (cm)	Leaf length (cm)	No. of branches
15	H	229.4d[y]	4.2ab	4.6ab	17.3de
	L	148.6c	5.3c	5.6c	12.2bc
20	H	218.9d	4.3ab	4.5ab	19.4e
	L	159.5c	4.9bc	5.1bc	14.3cd
25	H	223.9d	4.5ab	4.7ab	17.1de
	L	160.4c	4.6bc	4.9bc	12.9bc
30	H	85.2a	3.8a	4.0a	6.4a
	L	129.7b	4.7bc	5.1bc	11.0b

[z]H, high light intensity (=natural light); L, low intensity (=10% natural light)
[y]Values followed by the same letters in the same column are not significantly different (P = 0.05, Duncan's multiple range test).

Table 2. Effects of air temperature and light intensity on the root characteristics of *Codonopsis lanceolata*.

Temperature (°C)	Light intensity[z]	Length (cm)	Diameter (mm)	Fresh weight (g)	No. of lateral roots
15	H	9.7c[y]	9.3c	20.2d	12.2d
	L	8.2bc	7.2bc	6.4c	7.7c
20	H	8.4bc	8.7bc	19.5d	12.5d
	L	6.5b	6.3b	9.3c	5.1c
25	H	6.8b	8.0bc	6.0c	6.0c
	L	6.4b	7.3bc	5.2bc	4.6bc
30	H	3.0a	3.7a	0.5a	0.5a
	L	4.2a	6.1b	2.1ab	1.3ab

[z]H, high light intensity (=natural light); L, low intensity (=10% natural light)
[y]Values followed by the same letters in the same column are not significantly different (P = 0.05, Duncan's multiple range test).

no significant differences between different temperature groups. However, the leaf size was larger in the shade, and the leaf area was significantly larger both the 15 and 30°C temperature groups. Under natural light, the number of branches was also significantly smaller at 30°C temperature, but there were no significant differences among the 15, 20 and 25°C temperature groups. Under the shading treatment, the number of branches was significantly lower in the 15, 20 and 25°C temperature groups, but, it was interestingly higher in the 30°C temperature group (Table 1).

The changes of characteristics and yield of the underground part of *Codonopsis lanceolata* in response to temperature and shading treatment are presented in Table 2. Under the natural light, the root length and diameter were shorter and thinner when the plant was exposed to high temperature, and the growth was highly suppressed at 30°C temperature. Under the shading treatment, there was no significant difference among the 5, 20 and 25°C temperature groups. At 30°C in shading treatment, as in natural light, the root length was significantly suppressed, but the root diameter was less suppressed and showed no significant difference from the root diameter under natural light. Under full sunlight condition, fresh weight of 15°C and 25°C temperature group showed a significant difference in each of 20.2 g and 6.0 g. This result was possibly occurred due to the difference in the number of lateral roots between the 15°C, 20°C, and the 25°C group. In all of the 15, 20 and 25°C temperature groups, there was significant decrease of fresh weight by shading treatment. At 30°C temperature, the fresh weight was higher under shading than the natural light condition, but the difference was not significant (Table 2).

The findings observed from the present investigation is similar to the previously reported study, whereas the growth of

Codonopsis lanceolata decreases under high temperature and root growth is suppressed under shade condition (Lee *et al*., 1992). In this study, the above-ground growth of *Codonopsis lanceolata* was optimal in slightly low temperature, 20~25°C, while the yield of the underground part was higher under low temperature.

In the present study, results revealed that shading lowers the air and soil temperature in mid-summer. Although shading treatment is effective in actual cultivation, it simultaneously decreases the yield of the underground part. Therefore, during the temperature is lower than the optimum period, cultivation under natural light is believed to be ideal. In other words, when cultivating *Codonopsis lanceolata*, shading treatment at high temperature was applied to lower the air and soil temperature by avoiding direct sunlight rather than have direct effects on the physiology of the plants.

Taken together, the results obtained from the present study suggest that shading can be effective for reducing growth inhibition of the above-ground and underground parts caused by high temperature during mid-summer.

Analysis of inorganic and general components under different temperature variation

The inorganic components of different parts of *Codonopsis lanceolata* are presented in Table 3 according to temperature variation. In the case of macroelements, the contents of Na, Mg and P increased as temperature increased, regardless of the part, and no constant tendency was observed in K and Ca according to temperature variation. The Mg and Ca contents showed highest in the following pattern as leaf>stem>root, and Na, P and K contents as stem>leaf>root order. This suggests that contents of inorganic components of *Codonopsis lanceolata* are higher in the stem and leaves than in the root. In the case of microelements, in general, there was no constant tendency observed in contents of inorganic components according to temperature variation, and the contents were high in leaves. Co was not found in any part regardless of the temperature, and Pb was found in the leaves and stem in small quantities, but none in the root, which is used for eating (Table 3). Lee *et al*., 1995 reported that the contents of inorganic components vary according to regional environment and contents of main inorganic components of *Codonopsis lanceolata* varied in different plantations, and a

Table 3. Comparison of mineral nutrients contained in the parts of *Codonopsis lanceolata* were cultivated at different temperatures.

Plant part	Temperature (°C)	Mineral nutrients (ppm)											
		P	K	Ca	Mg	Fe	Mn	Cu	Zn	Na	Ni	Pb	Co
Leaf	15	748.2	512.8	6369	3062	1068.0	41.07	5.156	37.79	200.7	2.091	<0	<0
	20	853.1	521.3	10955	4486	257.4	29.63	4.215	22.53	402.0	1.978	0.831	<0
	25	1582.0	678.0	9673	2385	204.0	24.86	4.707	16.14	270.3	2.077	4.149	<0
	30	1236.0	365.8	9047	3568	264.2	26.48	7.936	33.83	200.9	2.076	2.335	<0
Vine	15	796.9	753.5	4361	1408	66.0	8.99	1.933	6.33	66.6	1.054	2.057	<0
	20	799.2	413.0	4336	583	52.2	11.87	2.262	9.24	90.1	2.147	3.544	<0
	25	1375.0	442.6	3741	1793	75.0	7.29	2.842	16.69	284.9	1.747	1.438	<0
	30	4229.0	818.1	5260	2874	69.5	13.88	14.620	24.91	641.7	1.514	1.660	<0
Root	15	959.6	437.5	1298	1040	114.6	10.89	3.182	15.89	71.1	0.937	<0	<0
	20	767.6	357.3	8935	593	383.4	11.17	3.828	11.66	31.4	1.174	<0	<0
	25	957.1	330.4	1756	1369	161.0	18.65	3.081	11.47	93.2	1.134	<0	<0
	30	1316.0	274.7	2401	1524	159.9	19.77	5.633	15.78	304.7	2.018	<0	<0
Significance													
Plant part (A)		*	**	*	*	**	**	NS	NS	*	NS	NS	NS
Temperature (B)		*	*	*	*	**	**	NS	**	*	NS	NS	NS
A×B		NS	NS	**	**	NS	NS	NS	NS	NS	NS	NS	NS

[NS,*]Nonsignificant and significant at P = 0.05 and 0.01, respectively.

Table 4. Comparison of major constituents of proximate composition in *Codonopsis lanceolata* under different temperature conditions.

Temperature (°C)	General nutrients (%)					
	Moisture	Crude protein	Crude fat	Crude fiber	Crude ash	Sugar
15	18.0b[z]	3.5b	1.3bc	5.1b	3.5b	39.0a
20	20.1b	3.3b	1.3bc	4.4ab	3.6b	37.5a
25	25.7c	2.3a	0.7a	3.7a	2.7a	37.4a
30	12.6a	6.1c	1.8c	10.7c	4.5c	35.8a

[z]Values followed by the same letters in the same column are not significantly different (P = 0.05, Duncan's multiple range test).

Table 5. Effects of DIF on the growth of *Codonopsis lanceolata*.

Day/Night Temperature (°C)	Plant height (cm)	Leaf width (cm)	Leaf length (cm)	No. of branches
15/15(0)[z]	13.8a[y]	2.8ab	1.6a	0.2a
20/20(0)	19.2ab	2.9ab	2.0ab	0.5a
25/25(0)	46.4d	2.5a	1.9ab	1.7b
30/30(0)	20.8ab	3.1b	2.4b	0.3a
25/20(+5)	36.5c	2.8ab	1.9ab	0.1a
20/25(-5)	30.3b	2.9ab	2.0ab	0.1a
30/15(+15)	37.7c	3.2b	2.0ab	0.6a
15/30(-15)	13.0a	2.6a	1.7a	0.3a

[z]DIF value

[y]Values followed by the same letters in the same column are not significantly different (P = 0.05, Duncan's multiple range test).

similar result was also observed in ginseng (Ko *et al*., 1996).

Content of constituents varied according to temperature variation, and it was highest at 30°C. The moisture content at 25°C was 25.7%, slightly higher than in other temperature groups, and it was lowest at 30°C. Crude protein was lowest (2.3%) at 25°C, and highest (6.1%) at 30°C. Crude fat, crude fiber, and crude ash contents were also higher in the 30°C temperature group. Sugar contents were similar between different temperature groups, ranging between 35.8% and 39.0% (Table 4). Although a previous report suggested, in *Codonopsis lanceolata*, there was no characteristic difference in general components according to cultivation and environmental factors of the habitat (Lee, 1984). In this study, the contents of general components showed the highest under high temperature. Also, the general components of *Codonopsis lanceolata* roots were found to be high under high temperature. This supports another report that has been reported earlier (Lee *et al*., 1992).

Growth and yield of *Codonopsis lanceolata* according to DIF treatment

The changes of the growth of the above-ground part according to the difference between day and night temperature (DIF) is presented in Table 5.

While the plant height was high in the constant 25°C group +DIF treated group, plant height was suppressed in a -DIF group, in which the night temperature was higher than the day temperature, which suggests that change of night temperature is one of the factors that affects the growth *of Codonopsis lanceolata*. There was no significant effect of temperature consistency on the leaf length and width. The number of branches of the plants grown at constant 25°C was 1.7, which was significantly higher than other groups, but those of the rest of the groups were similar to one another as 0.1 to 0.6 (Table 5). The low number of ramifications could have been caused by inactive development of ramification during the early growth stage. Growth of the plant and height of the stem is further suppressed by -DIF

Table 6. Effect of DIF on the root characteristics of *Codonopsis lanceolata*.

Day/Night Temperature (°C)	Length (cm)	Diameter (mm)	Fresh Weight (g)	No. of lateral roots
15/15(0)[z]	7.5c[y]	5.2a	2.1ab	2.2ab
20/20(0)	8.6d	5.5a	2.3ab	1.5a
25/25(0)	10.1e	6.7b	6.0d	3.8c
30/30(0)	5.0b	5.6a	2.8b	2.7b
25/20(+5)	8.2cd	6.2ab	5.6cd	5.1d
20/25(-5)	6.8c	5.8a	5.0c	4.7cd
30/15(+15)	7.1c	6.0ab	5.9d	5.1d
15/30(-15)	3.2a	5.3a	1.5a	0.9a

[z]DIF value
[y]Values followed by the same letters in the same column are not significantly different (P = 0.05, Duncan's multiple range test).

treatment, in comparison to constant temperature (Mortensen and Moe, 1992; Bertran and Kalsen, 1994), and, although it has been reported that DIF treatment has effects on leaf primordium (Erwin *et al*., 1989), plant form, chlorophyll content (Tangeras, 1979; Moe, 1990), etc. In this study, increase of night temperature had an effect of the height of *Codonopsis lanceolata* but almost no effect on the leaf size and plant form. This seems to be related to the fact that DIF has an adverse effect during the most active growth period of plants (Hussey, 1965), while, in this study, the treatment was applied to a plant in the early growth stage, and different plants show various reactions.

The changes of the character and yield of the underground part according to DIF treatment are presented in Table 6.

As in the growth of the above-ground part, fresh weight of the root was high in the constant 25°C group and +DIF group. Particularly, it was over more than 2.5 times of the fresh weights in the constant 15°C group, constant 20°C group, and −15 DIF group. This results supports a report that reported previously whereas the growth of the underground part of *Codonopsis lanceolata* is suppressed more when the night temperature is higher than the day temperature, and -DIF treatment has an effect on development of the underground part (Nilwik, 1981). Also, although the root lengths were short in the constant 30°C group and −15 DIF group, there was no significant difference among the rest of the groups. The root diameter was high (6.7 mm) under the constant 25°C temperature group, but those of the rest of the groups were similar to one another, ranging between 5.2 mm and 6.2 mm. The number of lateral roots was higher in the DIF groups than in the constant temperature groups, but lowest (0.9) in the -15 DIF group (Table 6).

The overall findings suggest that DIF has an important effect on growth of the above-ground and underground part during the early growth stage of *Codonopsis lanceolata*, and although it is not the conventional cultivation condition, thereby the yield may increase during the early growth stage by applying DIF.

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