PHYSIOLOGICAL RESPONSE OF *PANAX GINSENG* TO LIGHT

Hoon Park
Korea Ginseng Research Institute
Seoul, Korea

Abstract

Physiological response of Panax ginseng var. atropurpureacaulo (purple stem variety, Pg) to light was reviewed through old literatures and recent experiments. Canopy structure, growth, pigment, leaf anatomy, disease occurence, transpiration, photosynthesis (PS), leaf saponin, photoperiodism and nutrient uptake were concerned. P. ginseng var. xanthocarpus (yellow berry variety, Px) and Panax quinquefolius(Pq) were compared with Pg if possible. Compensation point(Cp) increased with increase of light and ranged from 110 to 150 at 20°C but from 140 to 220 at 30°C with 4 to 15 Klux indicating occurence of light and temperature-dependent high photorespiration. Characteristics of Korea ginseng to hate high temperature was well accordance with an observation 2000 years ago. Korea ginseng showed lower Cp and appeared to be more tolerant to high light intensity and temperature than American sheng although the latter showed greater PS, stomata frequency and conductance, chlorophyll and carotenoids. Px showed lower PS than Pg probably due to higher Cp. Total leaf saponin was higher in leaves grown under high light. Ratio of diol saponin and triol saponin(PT/PD) decreased with increase of light intensity during growing mainly due to decrease of ginsenoside Rg_1 but increase of ginsenoside Rd. Leaves of Pg and Px had Rh_1 but no Rb_3 which was only found as much as 20% of total in Pq leaves, and decreased with increase of light intensity. Re increased in Pg and Px but decreased in Pq with increase of light. PT/PD in leaf ranged 1.0–1.5 in Pg and Px but around 0.5 in Pq. Korea ginseng has Yang characteristics(tolerant to high light and temperature), cultured under Eum(shade) condition and long been used for Yang efficacy (to build up energy) while Pq was quite contrary. Traditional low light intensity(3–8%) for Korea ginseng culture appeared to be strongly related to historical unique quality. Effect of light quality and photoperiodism was not well known. Experiences are long but scientific knowledge is short for production and quality assessment of ginseng. Recent scientific knowledge of ginseng should learn wisdom from old experiences.

Introduction

Korea ginseng(*Panax ginseng* C. A. Meyer) has long been known as the emperor of the Oriental herb medicine and the empress of health food. Since ginseng grows very slowly it takes at least six years for good quality even under most favorable condition of cultivation but the yield is very low comparing with other crops. Thus many pseudoginsengs and surprisingly nonginsengs are sold in the name of ginseng. Since the word ginseng was originated from Korea ginseng(gin = man, seng = medicinal plant having three petioles or three benefits). Ginseng should be used only to Korea ginseng(*Panax ginseng*) and others are called seng or sheng.

Most consumers in the world market cannot help being content with pseudoginseng furthermore with Acanthopanax senticcosus, so called Siberian ginseng. For most consumers to reach real ginseng it's yield should be increased per unit area.

In order to obtain high yield of ginseng, first of all physiological characteristics should be understood. Korea ginseng has long been cultivated under shade even though ginseng has green leaves. According to author's observation and one experiment early of this centry(1) ginseng can grow until early August without shade. It could not survive more than four months without shade(2). Since ginseng growth primarily depends on photosynthesis response to light seems very important.

We should quantitatively define the shade loving characteristics of ginseng. Innovation of cultivation method may not be easy since experience is long and scientific knowledge is short. But improvement could be expected in certain extent.

In this paper, response to light including observation in the old literatures was reviewed and discussed with recent research results in relation to canopy structure, phototropism, photoperiodism, pigments, leaf anatomy, transpiration photosynthesis, disease infection and quality(leaf saponin).

Materials and methods

Plant growth: Two year-old Korea ginseng i.e. P. ginseng var. atropurpureacaulo(purple stem variety), P. ginseng var. xanthocarpus (yellow berry variety) and American sheng(P. quinquefolius) were transplanted in early April. Some of them were in bottomless vinyl column easy to remove for the measurement of photosynthesis later in a growth chamber. Three Panax species were grown as usual in row by row under 5%, 15% and 30% of whole sun light using straw and white and black muslin at Jeung Pyong Ginseng Experiment Station. In other experiment 4 years old P. ginseng were grown under 5, 10, 20 and 30% of whole light intensity using similar materials.

Chlorophyll: Ten leaflets were collected from 10 plants on 11, August. Disks taken by cork borer were extracted with methanol and used for chlorophyll a and b determination(3).

Carotenoids: Total carotene was measured by A.O.A.C. method(4) using 0.5 gr. of fresh leaf on 22, August.

Stomata: Stomata frequency(number of stomata per mm^2) was measured by counting micro relief impression method using manicure replica of lower surface of a leaf. Stomata index (percentage of guard cell per total number of epidermal cells) was measured using photograph of replica(5). Stomatal conductance was measured by isobutyl alcoholethyleneglycol infiltration method(6).

Transpiration: Palmate leaves of P. ginseng grown under 5, 10, 20 and 30% of whole light intensity was subjected to transpiration measurement using potometer at various light intensity in growth chamber at 20° C on 24, July.

Leaf anatomy: Representative two palmate leaves from each replicate plot were taken at 8a.m.on 9, August. The middle leaflet was cut by 4 × 47 mm including midrib, fixed with FAA, embedded by paraffin method and stained with safranin and fastgreen. Samples were sectioned into 12 μ and subjected to light micro-cope(7). For electronmicroscopy a leaf was cut by 1 mm × 2 mm including midrib, fixed with glutaraldehyde and OsO_4. After embedding it was stained with uranylacetate and lead citrate. All others were followed according to usual method(8,9). Chloroplasts were observed using an electron-microscope(Hitachi PS-7S, 50 KV).

Photosynthesis and respiration: Plants in a vinyl pot were moved to a growth chamber(Goitotron HLL-25A-S). One palmate leaf was put into an acryl chamber(30 × 30 × 3 cm) for measuring photosynthetic activity at various temperature and light intensity. Flow rate of air was 2 to 3 per minute. Infrared CO_2 analyzer(Horiba ASSA-1610) measured one sample for 10 second and six samples were measurable every minute. One sample on one temperature and light intensity was measured every six minutes for one hour then light intensity was changed. The mean value during second half hour was used. Light compensation point was read from light intensity vs. photosynthesis curve. Compensation point was determined in closed system until no more CO_2 concentration was changed. Respiration was measured at the end of photosynthesis measurement at various temperature in dark.

Leaf saponin: Five palmate leaves were collected and pooled from five plants per treatment on 25 August, dried at 60° C for 24 hrs. and pulverized with pestle in mortor. Analysis were based on other reports(10, 11). For crude saponin one gram of leaf powder was extracted twice with 50 ml of 90% methanol at 60 to 65° C for 4 hrs. using flask with reflux condenser. The pooled extract was filtered through Toyo No. 2 filter paper. Filtrate was dried in vaccum at 60° C, desolved into 3 ml of distilled water 3 times, and pooled into fraction funnel. Nonpolar fraction was transfered to 20 ml of chloroform layer and discarded five times. Then added 20 ml of water saturated butanol and pooled butanol layer 2 times, dried in vaccum at 60 to 65° C until no butanol was smelled. Dried crude saponin was weighed. Crude saponin was desolved into 2 ml of methanol and 20 μl was injected for high pressure liquid chromatogram(Waters Associates Model ALC/GPC 244) for analysis of each ginsenoside. Column material was n Bondapak for carbohydrate analysis(solvent system $CH_3CN/H_2O/BuOH$ = 80/20/15., 1.5ml/min of flow rate, 1.0 cm/min. chart speed, and 8X attenuation). Each peak was identified using standard ginsenosides (Rb_1, Rb_2, Rb_3, Rc, Rd, Re, Rf, Rg_1, Rg_2, Rh_1, and prosapogenin) and co-chromatography when needed. Relative amount of each ginsenoside was based on the peak area.

Results and Discussion

Light requirement under field condition: Wild ginsengs are growing under mixed forest where the light intensity is various depending on crown density. Korea ginseng has long been grown under thatch roof, while American sheng has been grown under wooden lath. Table 1 shows light intensity for Panax under field condition (12–19). Korea ginseng requires 3 to 8% of full sun light while American sheng requires 20 to 30%. It suggests that P. quinquefolius might be more tolerant to light. However it seems not true as will be seen later. In the morning Korea ginseng receive all light.

Yield response to light: There is no data of

Table 1. Light requirement of Panax under field condition.

	Optimum intensity	Remark	Reference	
Ginseng	3–5%	Seedling	Vorobjeva	(1960)
	30%	After 2 years		
	8%		Kim	(1964a)
	8–19%		Kim	(1964b)
	3000–6000 lux		Hong	(1974)
	5–10%	(Sandculture)	Kuribayashi and	
	(2000–4000 lux)		Ohashi	(1971)
	3000–4000 lux		Miyazawa	(1975)
	4300 lux		Yang	(1975)
Quinquefolius	20%	Southern,	Veninga	(1973)
		Midwestern		
		Far western		
		(USA)		
	33%	Northern states	Veninga	(1973)
	25% (3/4 shade)	Summer	USDA	(1978)

Table 2. Growth response of Panax to light (cm, June, 24).

	P. ginseng var. atropurpureacaulo			P. ginseng var. xanthocarpus			P. quinquefolius		
LTR (%)	5	15	30	5	15	30	5	15	30
Stem diameter	0.54	0.44	0.46	0.40	0.43	0.39	0.33	0.35	0.33
Stem length	19.8	19.5	19.1	16.4	16.3	14.9	16.0	7.5	7.0
Petiole length	6.9	6.5	7.1	6.5	6.2	6.2	7.2	5.0	5.0
Leaf length	11.9	10.0	11.4	11.7	11.1	10.7	9.3	8.9	8.1
Leaf width	5.4	4.9	5.1	5.1	4.8	4.7	5.8	5.4	5.0
Peduncle length	18.1	16.2	16.4	15.9	13.2	13.2	6.8	5.5	4.6

root yield in relation to light intensity under field condition. Korea ginsengs are transplanted in five lines. Light intensity is decreasing from first line to 4th and slightly increasing again in 5th line as shown in Fig. 11. Yield of each line may be principally affected by light intensity as have long been thought. Relative yield was much higher in first and 2nd line than others(20). Statistical analysis of percentage contribution of each line to total yield showed no significant difference among lines from 1st to 3rd and between last two lines(21). But percentage yield of 1st and 2nd lines was over 50% and yield was decreasing from 1st to 5th line at average. Thus low light intensity could be a factor to decrease yield in the rear under thatch roof. But other factors except light should not be ruled out under field condition.

Canopy structure and growth: Stem length was decreased as the increase of light intensity (Table 2) resulting in lower canopy height. Stem length increases gradually until the line next to the last which slightly decreases under the shade. Stems are bending toward sun light and leaves are aranged to harvest maximum sun light(22) indicating strong phototropism. Stems of last line tend to stand streight or bend backwards due to strong light in afternoon. The change of canopy structure components were shown in Table 2 at various light intensities under which ginseng plants were grown.

The length of stem, petiol, leaf, peduncle and leaf width were decreased by the increase of light intensity(Table 2). But stem diameter was not consistent. Stem and peduncle appear to be most sensitive. American sheng seems to be more sensitive to light in growth response. The greatest effect of light at 15% LTR in P. ginseng was not known.

Number of stems were increased with the increase of light intensity. Fig. I showed percent increase of multistem plants per year. Percentage of multistem plants were highest in the highest light intensity(23). Multistem plants hold greater leaf area and yielded greater roots. Thus the higher the multistem frequency is the more the yield. In general one stem of multistem plant showed superior growth than others.

Relative growth rate(RGR) and net assimilation rate(NAR) were higher at the line under high light intensity but leaf area ratio(LAR) evidently decreased(24). Leaf weight ratio(LWR: leaf weight/total plant weight) was greater at the line under high light intensity in young plants, but the reverse was observed in old plants. Specific leaf weight(SLW: mg/cm^2) increased under higher light intensity indicating that leaf thickness increases with light.

Pigments: Chlorophyll content of Korea ginseng was maximum at 3.5% light and decreased in the case of less or greater than that(22). Chlorophyll content in leaf decreased with the increase of light intensity as shown in Fig. 2. Korea ginseng showed greater decrease than American sheng though chlorophyll content was higher in Korea ginseng at 5% of light transmittance rate (LTR). P. ginseng yellow berry variety(var. xanthocarpus, proposed by author, Px) was lowest in chlorophyll content and followed the pattern of P. ginseng(Purple stem variety var. atropurpureacaulo, proposed by author,Pg).

Chlorophyll a/b ratio was maximum at 15% LTR as shown Fig. 3. But the difference was not significant. Chl. a/b ratio was increased with the increase of light intensity in other shade plants(25).

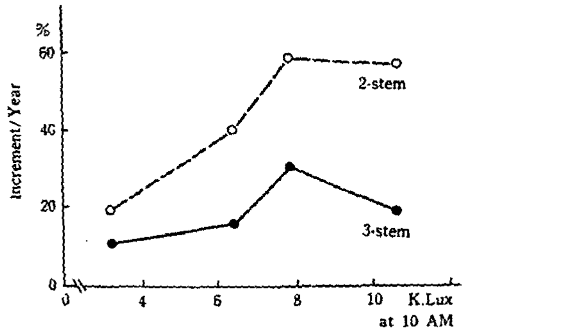

Fig. 1. Effect of light intensity on number of stem per Plant in *Panax ginseng* (Hong & Oh, 1976).

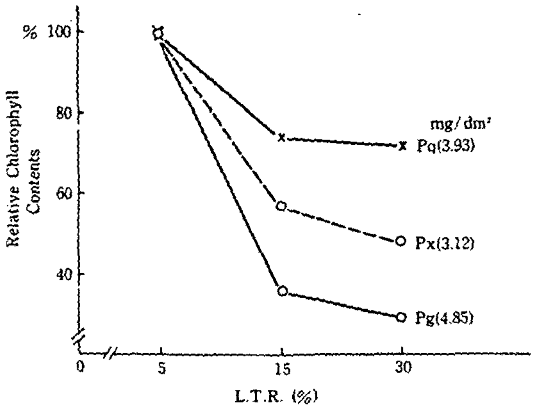

Fig. 2. Change of total chlorophyll contents at various light intensity in *Panax ginseng*.

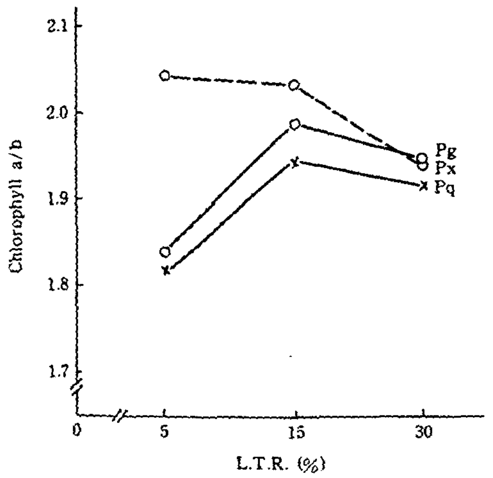

Fig. 3. Change of ratio of chlorophyll a and b at various light intensity in *Panax ginseng*.

Carotenoid content was also greatly decreased with light intensity in Korea ginseng but little in American sheng as shown in Fig. 4.

Carotene was known not only as antenna pigments to collect photons but as scarvenger of sing-

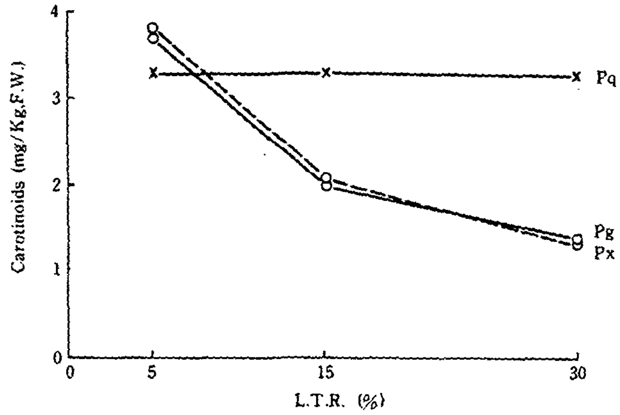

Fig. 4. Change of carotinoid content in leaves *Panax ginseng* grown under different light transmission rate. (L.T.R.). **Pg**: *P. ginseng var. atropurpureacaulo* **Pq**: *P. quinquefolius* **Px**: *P. ginseng var. xanthocarpus*

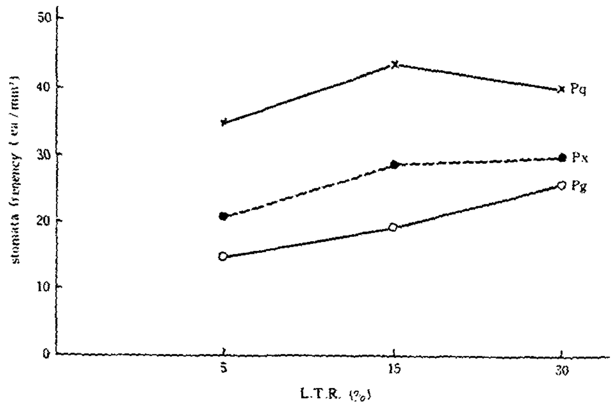

Fig. 5. Light effects on stomata frequency of *Panax* grown at different light intensity.

let oxygens which produced during photosynthesis and caused chlorophyll decomposition (26). Relatively smaller decrease of chlorophyll content with the increase of light intensity in Pq might be due to high carotene content. In view of pigment change Pq seems to be more tolerable to high light intensity than Pg is.

Color of stem petiole and peduncles is quite different from plant to plant in Korea ginseng. Px has green stem and no purple tint in stem, petioles, peduncle and even any other part. P. ginseng var. caeruleacaulo, (name of variety is proposed by author) is green stem variety but with red berry. It looks quite similar to Px. But in the later stage of senescence purple tint tends to appear in upper side portion of mid vein of leaf. Gene analysis among three Korea ginseng varieties were done on color expression of stem and berry by crossing study(27).

Pg var. atropurpureacaulo has dark purple color in stem, petioles and peduncle. But color intensity and, colored portion are quite different among organs and individual plants. Some plants show only purple color in the base of petioles and some plants that show dark purple in whole stem but petioles have green peduncle. Since light affects little on purple color, quality and quantity of pigments seems strongly inheritable suggesting that many strains exist in Pg var. atropurpureacaulo.

When roots are exposed to sun light color turns to green in all Panax and then purple only in Pg in one week. Px did not show any purplish color in root but Pq showed very slight purple tint by one month exposure. This fact strongly indicates that purple pigment, probably one of anthocyanin, is affected by light but threshold light intensity for pigment change seems extremely low. Most of Pg have no purple tint in lower side of petioles but dark purple in upper side and there is clear straight border line between these two part though the stems tend to be of slightly darker purple in lower side when they bend toward sun. In very rare case whole parts of petiole show purple color in Pg as most Pq are such. Purple color in stem of Pq is much lighter than that of petioles.

Red pigment in berry coat of Pg seems not be affected by light. Yellow berry has transparent coat and no red color anthocyanin pigment. Yellow pigment is in berry flesh. Px might be a red anthocyaninless mutant. Pigment change by light appears to be very slight in all Panax.

Leaf anatomy: Stomatal frequency of Panax grown under various light intensity was shown in Fig. 5. Stomatal frequency(number of stomata per mm^2) increased with the increase of light intensity. It is more prominent in Pg which is low in frequency at 5% LTR. Pq being highest in frequency showed maximum frequency at 15% rather than at 30% LTR. Stomatal index(percentage of guard cell to total number of epidermal cells) also increased with the increase of light intensity and reached to plateau at 15% LTR. Pq had higher stomatal index than Pg did. Size of stomata appears to be smaller in Pq than in Pg(Fig. 6).

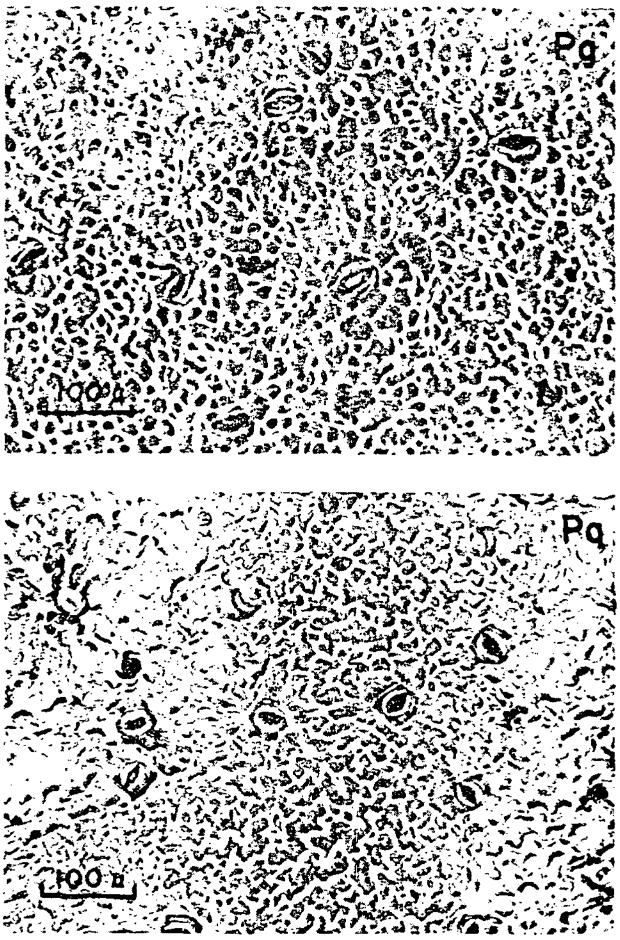

Fig. 6. Stomatal aperture (at noon, 22, Aug.) of Panax leaves grown at 30% light. Pg: P. ginseng, Pq: P. quinquefolius.

Stomatal frequency of Pg was increased under high light intensity(28, 29, 30) but under the same shade roof stomatal index was remained as constant(30). Px has greater stomatal frequency than Pg. Response of Px in stomatal frequency to light is quite similar to Pg.

Stomatal conductance measured by infiltration method increased with the increase of light intensity under field condition as shown in Fig. 7. Pq showed highest stomatal conductance as expected from higher stomatal frequency and index. Px also showed greater stomatal conductance than

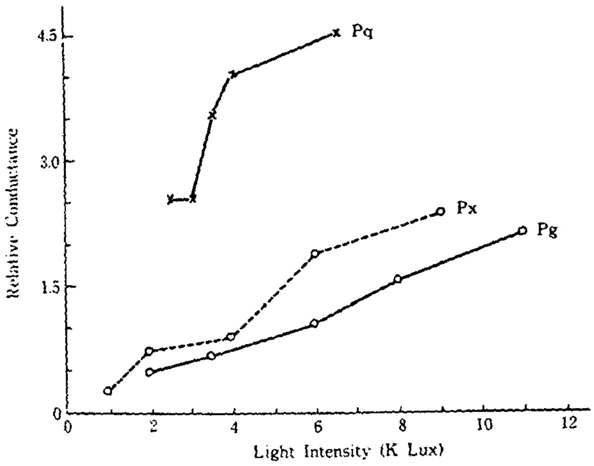

Fig. 7. Change of stomatal conductance of Panax leaf at various light intensities under field condition.

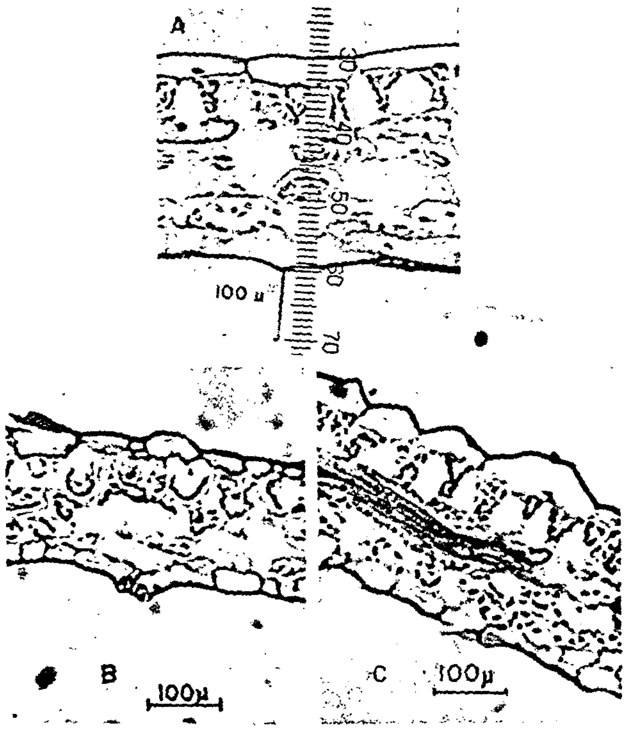

Fig. 8. Light micrograph of Panax leaves.
A: P. ginseng grown at 5% light
B: P. ginseng grown at 15%. C: P. quinquefolius grown at 15% light.

Pg. In both Pg and Px stomatal conductance increased steadily until 11 Klux, the highest light intensity tested. Stomatal conductance increased with the increase of light intensity in Pg(28, 29). According to microrelief of leaf epidermis stomata aperture was greater under higher light intensity indicating that stomatal conductance depends

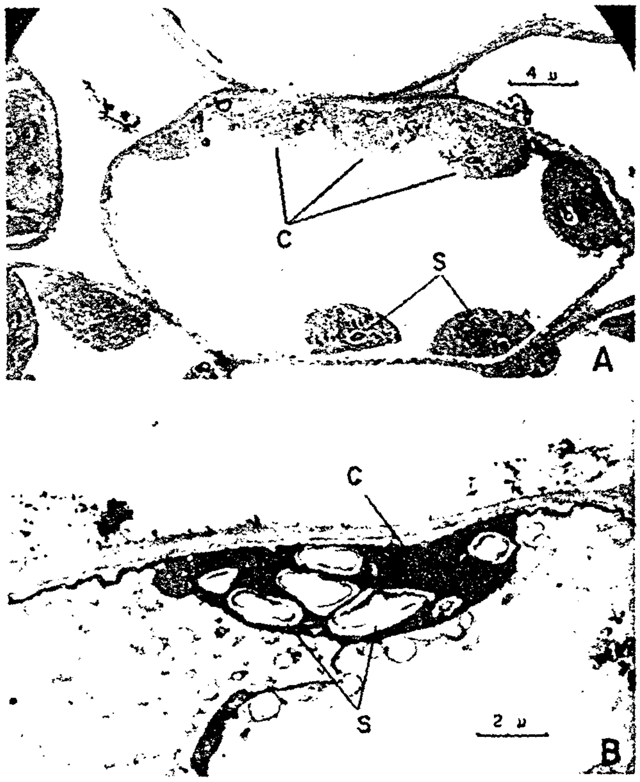

Fig. 9. Electronmicrograph of P. ginseng leaves.
A: grown at 5% light. B: grown at 30% light.

much on aperture. According to stomata response to light Pq seems to be more tolerable to high light intensity than Pg, and Px than Pg.

Korean ginseng leaves have no clearly distinguished compact palisade cells but mostly sponge type mesophyll cells in 3 years old leaves as shown in Fig. 8. In leaves grown under 5% LTR palisade-like cells appeared rarely (Fig. 8 A) and mesophyll cells were also rare. Air space was greater and chloroplasts were distributed evenly in cells. Under 15% LTR mesophyll cells were relatively compact (Fig. 8B).

No clear difference was seen among species. Helical tracheids were frequently observed in leaf cross section of Pq(Fig. 8C). This might be well accordance with greater number of viens in leaf and may indicate better transpiration system which may necessary to resist high light intensity.

Electron micrograph of Pg leaf grown under 5% LTR revealed that chloroplasts were intact and contacted to cell membrane but starch granules were small and rare as shown in Fig. 9A. In the leaves grown under 15% LTR starch granules were well developed and chloroplast were still intact (Fig. 9 B). Under 30% LTR starch granules were not seen in chloroplasts. The leaves of American sheng showed small chloroplasts and comparablly insensitive in ultrastructure to light intensity. According to ultrastructure 15% LTR appears to be optimum for Korea ginseng.

Transpiration: Transpiration rate at 20°C of Pg at various light intensities grown under various LTR was shown in Fig. 10. It increased with the increase of light intensity partially due to the increase of stomatal conductance as mentioned above. Also transpiration rate was higher in the leaves grown under higher LTR. Transpiration rate tended to reach maximum at 10 Klux which is saturation light intensity for photosynthesis. This results strongly indicate that adaptation capacity to higher light intensity of Korea ginseng leaves can be increased to certain extent by the increase of LTR during leaf expansion stage. The 30% of LTR for Pq in field condition to be related with leaf anatomy, especially characteristics of stomata. Stomatal conductance of Korea ginseng leaves grown under shade was increased with the increase of sun light intensity under shade condition(below 5 Klux) but that of leaves grown without shade roof was decreased with the increase of sun light(over 10 Klux) probably due to high temperature(29). Without shade roof leaves receive direct solar irradiation and radiant heat increases leaf temperature subsequently may induce incipient wilting and stomatal closure resulting in lower transpiration rate.

Palmate leaf of 6 years old Pg showed greater transpiration rate at 23°C than at 29°C under shade(31) and transpiration rate of Pg leaves was gradually decreased above 23°C(29). No stoma was found in upper side of ginseng leaves. But transpiration of upper side of leaf was about 10 to 25% of that of whole leaf(29). Cuticular transpiration was greater than stomatal transpiration below 2700 lux(30). Cooling down of leaf by transpiration seems to be important for Korea ginseng to tolerate high intensity of sun light.

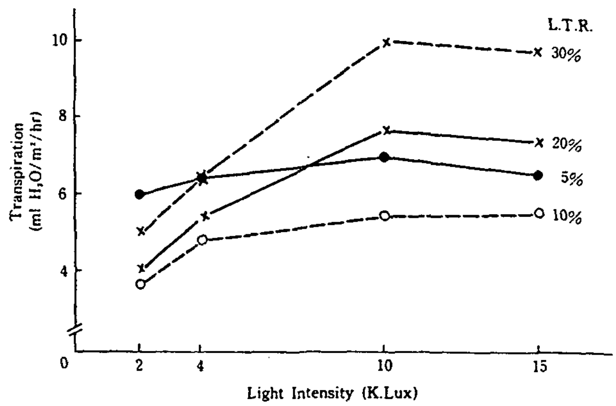

Fig. 10. Change of transpiration of *Panax ginseng* Leaves at various light intensity at 20°C (Plant were grown at different light transmittance rate, 24, July).

Disease occurence: Korea ginseng can grow until early August without shade roof if it is transplanted before new shoots emerge(1). However ginseng plants easily get diseases especially in leaves without shade, more severly depending on weather condition. Fig. 11 shows the relation between light intensity and leaf blight occurence under field condition(32). Occurence of leaf blight or anthracnose in each line tends to parallel with light intensity. Ginseng leaves were much severely infected by anthracnose spore inoculation under high light intensity(33). Spore may easily get into open stomata under higher light intensity. But effect of high temperature must not be ruled out until sole effect of light intensity on disease occurence is investigated.

Photosynthesis: Saturation light intensity and photosynthetic activity were shown in Table 3 (36–39). Saturation light intensity ranged from 4 Klux to 35 Klux. Most frequent value is 20 to 39 Klux that is equivalent to 16 to 25% of LTR. According to this value prevailing 3 to 8% of LTR seems to be far below of optimum. Photosynthetic activity was much less than maple tree which was reported as the lowest(34). From Table 3 it is well expected that saturation light intensity is higher in early growth stage of a year, in young age, at low temperature (Optimum temperature) and with high light intensity in previous growth.

Table 3. Saturated light intensity and photosynthetic activity of Panax ginseng.

Apparent (CO_2 mg/dm^2/hr)	Klux	°C	Years old	Date	Place to grow	Reference
5.8	10 (8%)	25	6	early Jun.	First line (sun leaf)	Kim (1964d)
5.0	4 (3%)	25	6	early Jun.	4th line (shade leaf)	Kim (1964d)
5.9	35	20	3	Jun. 20	3rd line	Lee et al. (1980)
5.5	35	20	3	Aug. 10	3rd line (pot)	Lee et al. (1980)
4.4	26	30	3	Jun. 20	3rd line	Lee et al. (1980)
4.0	26	30	3	Aug. 10	3rd line (pot)	Lee et al. (1980)
2.0	31	25	6	Aug. 20	3rd or 4th line	Park et al. (1979)
1.4	25	25	6	Jul. 29	2nd line (pot)	Lee et al. (1979)
14.4*	22	—	15	May 26	USSR	Grushiviskii (1957)
19.2*	22	—	4	May 26	Korea	Grushiviskii (1957)

* 0.8% CO_2

Most important factor seems to be temperature because the highest value of 35 Klux was at 20°C (Table 3). Transpiration characteristics as mentioned above also strongly suggests that temperature is an important factor compatible to light.

The oldest observation of Korea ginseng plant is described in ginseng song written by anonymous Korea(Koguryo BC 3–AD 668) quoted by Táo Hung-Ching(AD 502–549) in his book(34) as follow.

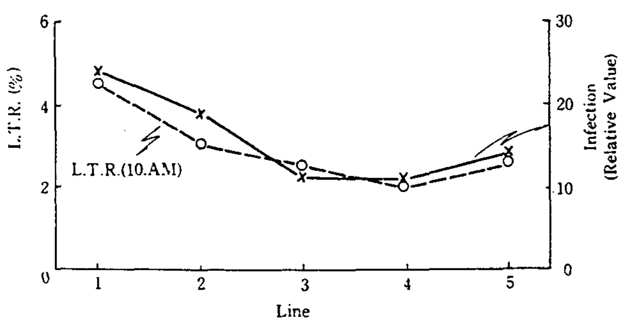

Fig. 11. Light intensity and infection of alternaria blight at each line in *Panax ginseng* (3-years old, Kim et al. 1979).

Ginseng Song

Three petioles and five leaves
you want to come seeing me
I'm against *YANG* but for *EUM*(Yin)
Please consult tillia tree.

The second line(背陽向陰) of original song was moved to third line in English version for rhyme. According to this song Korea ginseng is against Yang but for Eum(Yin). Yang means light(光) plus heat(熱) and Eum means light(光) plus cool(冷). Of course light in Eum may mostly be reflective or diffused indicating shade. Thus this line infers that Korea ginseng against warm light but for cool light.

Solar radiation carries radiant heat. Ginseng plants require light as other green plants do but dislike radiant heat or high temperature. Transpiration rate of Korea ginseng is very low and thus very sensitive to high temperature(31, 40).

Korea ginseng receives whole light early in the morning even under shade roof. The morning light of Morning Calm country is specially beneficial for Korea ginseng to provide the adaptogenic ingredients which make human being calm physically and mentally. Since morning light is cool the traditional shade roof receiving whole morning light seems to be very scientific and is well in accordance with the observation in the poem. Originally Yang and Eum are the principles of oriental philosophy and one of basic concept of herb medication. Even the adaptogenic theory is merely the version of one of Yin-Yang theory into mordern fashion easy to understand. The present national flag of Korea includes these principles. Yang and Eum do not limited to heat and cool and include number of other meanings.

Such a keen observation by an anonymous Korean could not be made unless one observes ginseng plant closely for a long period as in present cultivation. Koguryo(BC 3–AD 668) that was sometimes called Korea and thus the origin of the word Korea extended to Manchuria and present Korean peninsular. It covered most of habitat of P. ginseng as shown in Fig. 12. Still Kirin(Jilin in Fig. 12) remains as an active ginseng cultivation area. In Kirin number of historical monuments of old Korea such as General Tomb are left. Ginseng was not only the benevolence of nature in old Korea but also soybean was the benevolence of nature.

According to Pen-Tio-Kang-Moo ginseng culture seems to begin at three dynasty era (Korea, Sinla and Baikje). It is, however, interesting that Sinla ginseng was evaluated superior than that of Korea(43). Sinla was located in south of peninsula. Such old experience suggests that it is important to define unique environment for the best quality.

Characteristics of Korea ginseng was also described in Im-Weon-Sip-Ryuk-Ji that includes cultural method of ginseng(44). Characteristics were summerized in Fig. 13. On physiological response to light it reads that ginseng hates Yang and loves Eum. Yang concept was used here again. This observation suggests that damage of prolonged direct sun light on ginseng leaves is not light itself but radiant heat.

Radiant heat will increase leaf temperature. High air temperature will affect ginseng leaves as direct sun light(radiant heat) does. Thus photosynthesis was measured at various light intensity

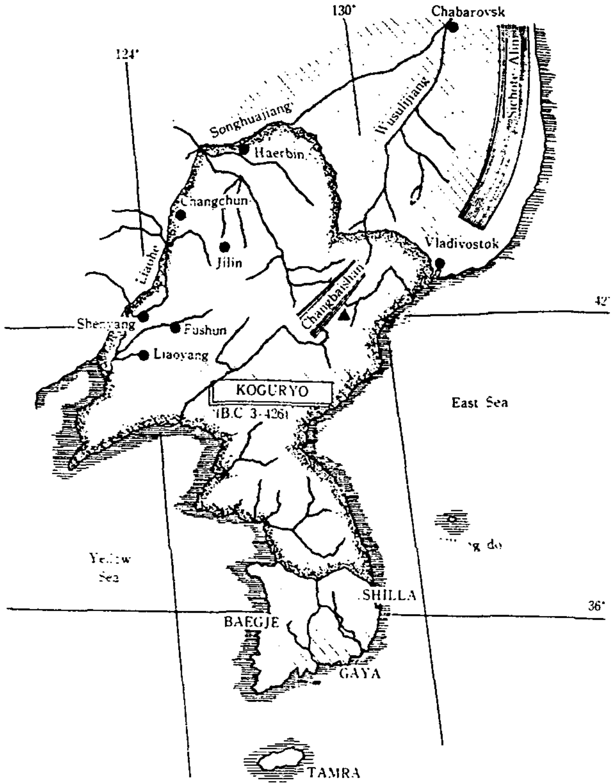

Fig. 12. *Panax ginseng* habitat and Korea (Koguryo).

Characteristics ⟶ Hate Yang, love Eum.
(蔘性) (惡陽喜陰)
Good Growth ⟶ With penetrated light, alternate Yang and Eum.
(滋長) (天光穿漏載陽載陰)
No Growth ⟶ Always with hot sun beam. Always without direct light.
(不得長) (烈日恒曝. 永無陽光)

Fig. 13. Characteristics of Korea ginseng described in Im-Weon-Ship-Ryuk-Ji(Seo Y. G. 1820).

and air temperature.

Saturation light intensity and photosynthetic activity at that point in different air temperatures of Panax leaves grown under various light intensity were shown in Table 4. In most cases saturation light intensity was 10 to 15 Klux. Since 15 Klux was the maximum light intensity tested saturation light intensity may be greater than 15 Klux. If whole sun light is 120 Klux 10 to 15 Klux is 8 to 13%. Thus present light intensity, 3 to 8% is too low. From 15 years field observation it was

Table 4. Saturation light intensity and apparent photosynthesis of Panax at different temperature.

Temp. (°C)		15		18		20		22		25		30		35	
	LTR (%)	SL	PS	SL	PS	SL	PS	SL	PS	SL	PS	SL	PS	SL	PS
Pg	5	10	3.56*	10	3.52	10	3.89	15	3.38	10	3.63	10	2.63	10	1.85
	15	15	3.90	15	4.24*	15	4.22	15	3.81	10	3.77	15	3.71	10	3.04
	30	10	4.70	10	4.86*	10	4.63	15	3.14	10	4.14	5	3.04	10	3.00
Px	5	15	3.77*	10	3.73	10	3.71	10	3.69	10	3.65	15	3.07	10	3.22
	15	10	3.66*	15	3.62	10	3.60	10	3.58	10	3.54	15	2.71	15	2.13
	30	10	3.62	10	3.58	10	4.46*	10	2.36	10	3.51	10	2.88	10	1.41
Pq	5	5	4.01	10	5.29*	10	4.47	15	4.70	5	3.88	5	3.05	5	3.75
	15	10	3.43*	10	3.39	10	3.38	10	3.36	10	3.32	10	2.33	5	0.92
	30	10	1.81	10	2.14*	15	1.78	15	1.77	10	1.75	10	1.72	10	0.84

LTR: Light transmittance rate at which Panax were grown. SL: Saturation light intensity (Klux), 15 Klux was maximum light intensity tested. PS: Apparent photosynthesis (mg $CO_2/dm^2/hr$). Underlined indicates maximum value at the same temperature and* :among temperature, Pg: P. ginseng var, atropurpureacaulo, PX: P. ginseng var, xanthocarpus, Pq: P. quinquefolius (late, July)

Table 5. Optimum temperature and apparent photosynthesis of Panax at various light intensity.

	LTR	2000 lux		5000 lux		10000 lux		15000 lux	
	(%)	OT	PS	OT	PS	OT	PS	OT	PS
Pg	5	20	0.77	25	2.87	20	3.89*	15	3.46
	15	20	1.28	18	2.83	25	3.77	18	4.24*
	30	18	2.11	15	3.84	18	4.86*	18	3.59
Px	5	20	1.59	15	3.00	18	3.73	15	3.77*
	15	15	1.22	18	2.82	15	3.66*	18	3.62
	30	18	1.49	18	2.99	20	4.46*	15	3.02
Pq	5	15	1.34	15	4.01	18	5.29*	22	4.70
	15	25	1.90	18	3.10	18	3.39*	18	3.39
	30	15	0.90	15	1.44	18	2.14*	18	1.79

LTR: light transmittance rate at which plant were grown. Underlined indicates maximum value at the same light intensity. OT: optimum temperature (°C), PS: apparent photosynthesis ($mgCO_2/dm^2/hr.$). Pg: P. ginseng var, atropurpureacaulo, Px: P. ginseng var, xanthocarpus. Pq: P. quinquefolius, (late July) *: Maximum among light intensity.

known that the longer the sunshine hours during crop season was the better the yield of ginseng (45).

Low saturation light may be attributed to high diffusive resistance of leaves. High diffusive resistance hinders not only carbon dioxide supply to chloroplast resulting in low photosynthesis but water movement not enough to cool down leaf temperature. By direct sunlight leaf temperature of Pg reached 42°C(30). Greater light intensity than saturation is not necessary but light saturation must be beneficial as long as there is nodamage caused by that light.

Saturation light intensity appears to be higher in Pg than in Pq. Korean ginseng showed certain trends of higher photosynthetic activity at higher temperature range and when grown under higher light intensity. American sheng was quite contrary to Pg and saturation light was 5 Klux in many cases above 25°C(Table 4). Similar results was reported for Pg(37). Saturation light intensity was higher(35 Klux) at lower temperature (20°C) than that(26 Klux) at higher temperature(30°C) for Korea ginseng (Table 3). Pq appears to be less tolerable to high light intensity. Maximum photosynthetic activity in the same temperature(underlined in Table 4) mostly occured in Pg grown under 30% LTR but in Pq and Px grown under 5% LTR. Maximum photosynthetic activity among temperatures (asterisk in Table 4) mostly occured below 18°C indicating that ginseng likes low temperature.

Optimum temperature and photosynthetic activity at that optimum temperature were shown

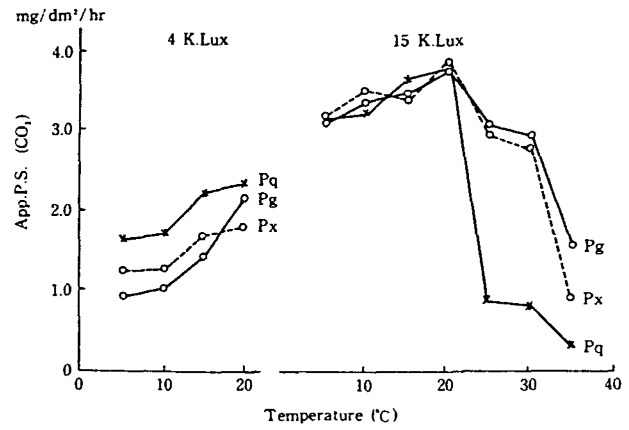

Fig. 14. Change of apparent photosynthesis of Panax at different temperature and light intensity (grown at 5% L.T.R., 25, Aug.).

in Table 5. Optimum temperature appears to be 15 to 18. Only three of 36 cases were 25°C, strongly suggesting that ginseng loves low temperature. Optimum temperature of photosynthesis was 15°C for 2 years old and 22°C for 6 years old (38). Optimum temperature of photosynthesis appears higher for Pg than for Pq indicating that Pg is more tolerable to higher temperature subsequently stronger sun light. Maximum photosyntheisis at the same light intensity occured mostly at 30% LTR in Pg but mostly at 5% LTR in Px and Pq(underlined in Table 5) as it was in relation to temperature(Table 4). Maximum photosynthetic activity among light intensity levels (asterisk in Table 5) mostly occured in 10 Klux.

In other investigation of photosynthesis in relation to temperature using detached leaves(Fig. 14) Pq showed greater photosynthesis especially in low temperature range under low light intensity but Pg was higher especially in high temperature range under high light intensity. This results are well in accordance with the facts mentioned above. Thus in the comparison with Pg to Pq Korea ginseng loves Yang, i.e. higher light intensity and heat(higher temperature) while American sheng loves Eum(Yin), lower light intensity and cool. Photosynthesis of Panax was very low(Table 4, 5, Fig. 14) except under high CO_2 concentration(in Table 3) and less than maple which was the lowest (34).

Light compensation point(light intensity) of Korea ginseng was shown in Table 6. It ranged 170–700 lux except particular case and was high in leaves grown under high light (36–38). It was also high at higher temperature probably due to higher respiration. Effect of temperature, light history on light compensation point were shown in Fig. 15. Light compensation point was much affected by temperature than that reported in Table 6. At 20°C light compensation point was higher in the leaves grown under low light intensity. But it was quite reverse at 30°C. This results seem to be contradictory to the assumption that leaves grown under high light intensity would be more tolerable to high light intensity.

Light compensation point was greater in Px than Pg and least in Pq suggesting that Pq may be well adapted to low light intensity. Light compensation point of Korea ginseng was reported as higher than that of evergreen broad leave trees

Table 6. Compensation point(lux) of P. ginseng

Compensation point (lux)	Temperature (°C)	Yrs.	Line	Date	Reference
700	25	6	1	May 18	Kim (1964d)
300	25	6	4	May 18	Kim (1964d)
500	25	6	1	Jun. 1, 24	Kim (1964d)
170	25	6	4	Jun. 1, 24	Kim (1964d)
400 < > 500	20	3	3	Jun. 20	Lee et al. (1980)
500 < > 600	30	3	3	Jun. 20	Lee et al. (1980)
16000*	25	2	Pot	Jul. 29	Park et al. (1979)

* After treated with the lower temperature (over 15°C) for 3 days than previous one.

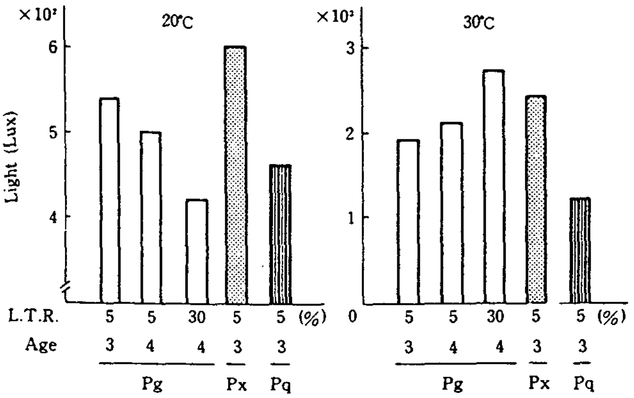

Fig. 15. Light compensation point (Lux) of Panax grown at different light intensity (26, Aug.).

(36) even though under which wild ginsengs were grown. High light compensation point of Px may be one of reasons that Px could not make the same yield as Pg could. Px could make better yield under higher light intensity.

Compensation point(Cp, CO_2 ppm) of Korea ginseng was reported as 175 above 30°C and it was considered so high that it was probable cause of slow growth(45). The relation among Cp, temperature and light intensity was shown in Fig. 16. Cp increased with the increase of light intensity and was much higher at 30°C than at 20°C. Increasing rate of Cp was also much greater at 30°C than at 20°C. Greater Cp than 110 ppm of Panax around optimum temperature(20°C) and optimum range of light intensity(4–10 Klux) is clearly higher than those of other plants(34).

Furthermore peculiar phenomenon is the increase of Cp with the increase of light intensity even below the saturation light intensity. This

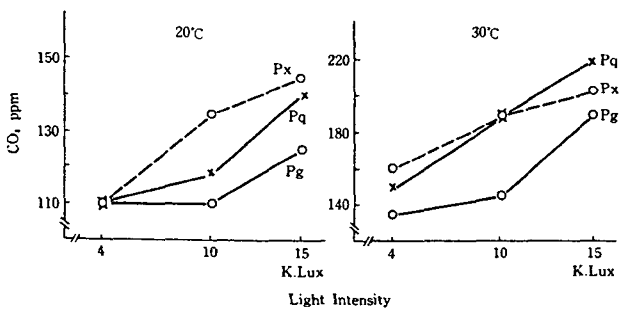

Fig. 16. Compensation point (CO_2 ppm) of Panax at different light intensity and temperature (3 yrs. 23, Aug.).

results suggests that photorespiration increases with light intensity in Panax. Photorespiration seems to be increase until saturation light intensity(34, 47). Compensation point is independent of light intensity above a relatively low intensity (47). But Cp of Panax increases even above saturation light intensity(Fig. 16).

There was almost no different in Cp at 20°C and 4 Klux among Panax species but above 4 Klux Pg showed least and Px greatest. Increasing rate of Cp was greater above 10 Klux for Pg and Pq, but below 10 Klux for Px. The fact that Pq showed greatest at 30°C and 15 Klux is well accordance with less tolerant characteristics of Pq to high light intensity and temperature as mentioned above.

Korea ginseng grown under high light intensity showed lower photosynthesis at low light intensity but higher photosynthesis at high light intensity in comparison with one grown low light intensity(Fig. 17). This result is well acordance with other report(34). Effect of high light intensity of previous growing environment on photosynthesis is much profund at high light intensity. Lower photosynthesis of high light leaves under low light intensity may be due to high photorespiration. Information of photorespiration can give certain explanation on effect of light intensity on compensation point and photosynthetic activity. But no data of photorespiration could be found.

Dark respiration was in decreasing order of Pq > Pg > Px at all temperature when grown

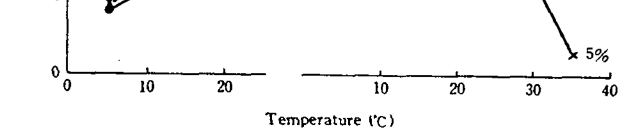

Fig. 17. Change of apparent photosynthesis of *P. ginseng* at different temperature and light intensity (grown at 5 or 30% L.T.R., 28, Aug.).

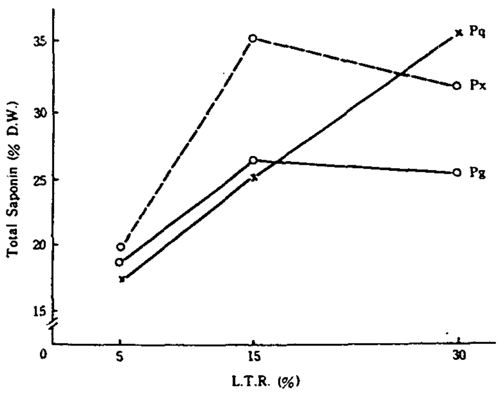

Fig. 18. Change of total saponin content of Panax Leaf grown at different light intensity.

at 5% light and Pg > Px > Pq when grown at 15% light. But under 30% light it was in order of Px > Pg > Pq below 22°C and Pq > Px > Pg above 25°C.

Pronounced photosynthesis under high light of leaves grown under high light intensity is probably due to greater stomatal conductance that can compensate the high diffusive resistance of leaves. The low saturation light intensity even at optimum temperature suggests that limiting factor of photosynthesis seems to be diffusive resistance in leaf tissue rather than poor leaf cooling system which might be more serious limiting factor under present field condition.

Effect of light quality on photosynthesis was hardly known. Red light was best and not different from natural sun light in yield (48). No studies were done on light quality. The diffusive light on the forest floor shows a high proportion of far red and near infra red, and also an increase in the proportion of green light relative to the blue and red (25). Ginseng plant might be thought more adaptive to light environment of forest floor. According to old experience(44), however, ginseng plants grow well with penetrated light and thus alternate Yang and Eum while they make no growth with hot sun beam always or without direct sun light always (Fig. 13). For the development of better shading material intensive research on light quality is needed.

Leaf saponin: The effect of light on ginseng quality is not known. Panacene and alkaloids in root increased with decrease of light intensity(17). Quality of Korea ginseng specially red ginseng root depends much on size, shape(number of lateral roots, balance between length and diameter and between tap and lateral root size), intactness, color and feeling of skin, and color, homogenity and compactness of inside. Recently analytically oriented scientists tend to and try to evaluate ginseng quality as saponin content. However saponin can not be a only quality criterion simply because small roots which contain much saponin are eliminated for best quality ginseng, and leaves which contain much higher content of saponin are thrown away from time inmemorial. Thus for the use of saponin as criteria the ratio of saponin fractions, i.e. Panaxadiol and triol was proposed as quality criteria(49). Since saponin is one of quality criteria that is ease to use the change of leaf saponin content was investigated. Experience is long and science is short as long as ginseng use or efficacy is concerned. Analytical knowledge should learn wisdom from long experience as it was in ginseng production. Total saponin content was greatest when grown at 15% LTR and slightly decreased above 15% in Korea ginseng while it linearly increased until 30% LTR in American sheng(Fig. 18). This results indicates great difference between Pg and Pq as in the case of carotenoids (Fig. 4). The effect of light on root saponin is now under investigation. Since there is no information about the relationship between leaf and root saponin no explanation could be made only by the variation of leaf saponin.

High pressure liquid chromatogram of Panax leaves grown under various light intensities were shown in Fig. 19. In Korea ginseng leaf grown under 5% light ginsenoside Rb_3 peak was absent and small Rh_1 peak was seen. In the leaf grown under 30% light Rh_1 peak is greater and Rb_3 peak is absent too. Rh_1 was reported only in root of Pg(50). Rg_1 and Rg_2 decreased but Rd increased. HPLC pattern of Px is quite similar to that of Pg. In American sheng Rb_3 peak appeared but Rh_1 peak is absent. Rg_1, Rg_2 and Rd peaks followed those of Pg.

Leaf saponin is qualitatively different between Korea ginseng and American sheng. Gin-

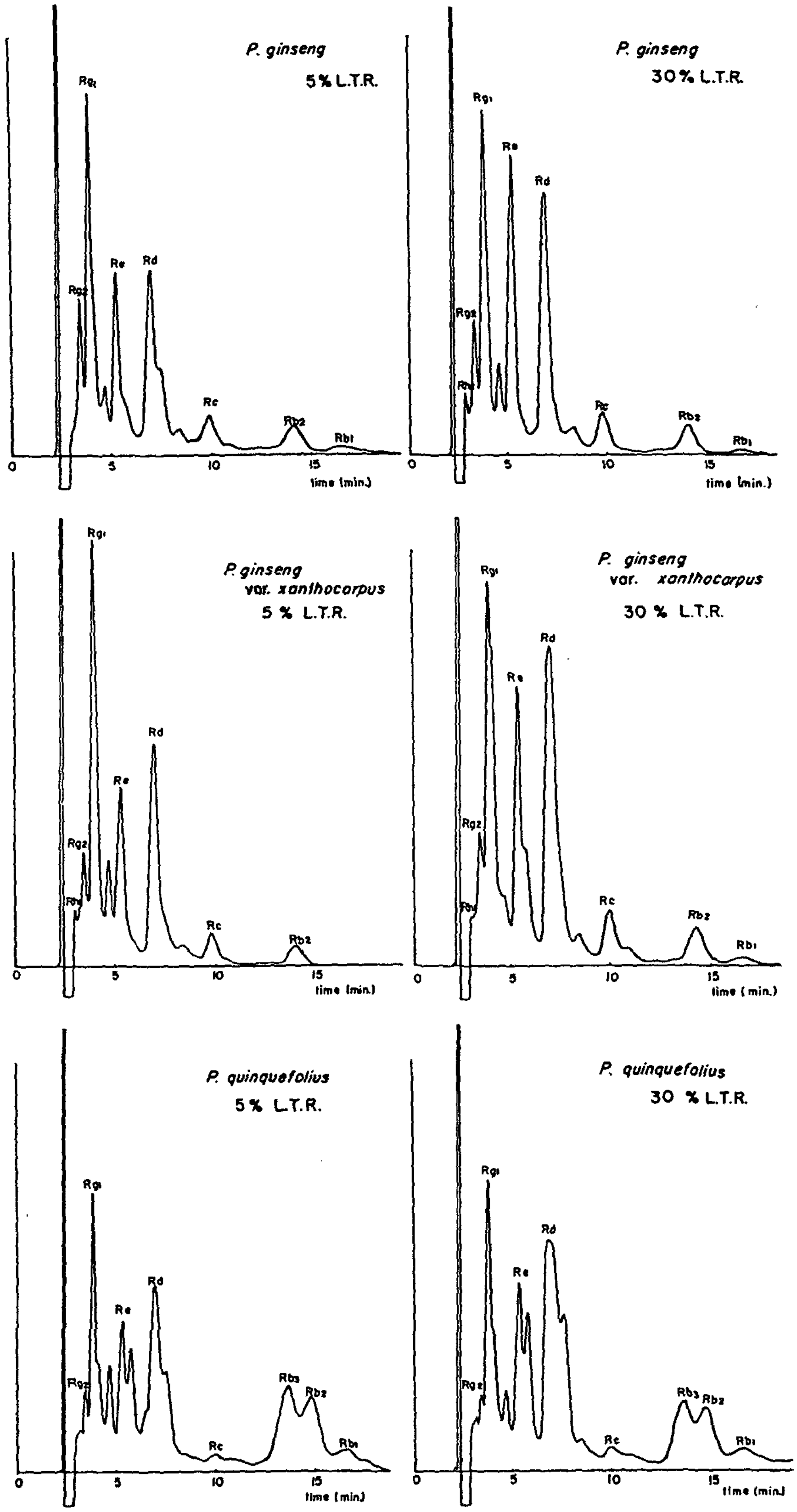

Fig. 19. High pressure liquid chromatogram of ginsenosides in Panax leaves grown at various light intensity. (3 yr. old, 11, Aug.)

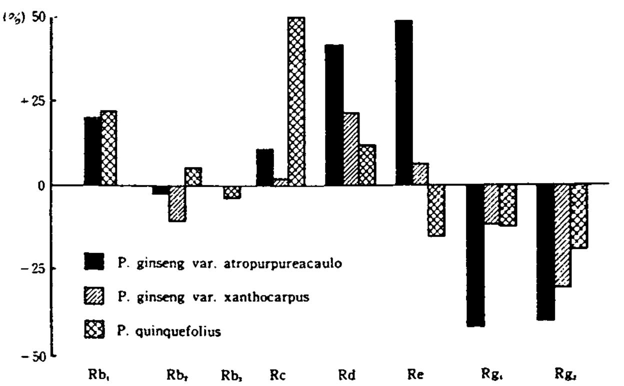

Fig. 20. Increase or decrease of each leaf ginsenoside in Panax grown under 15% light (Control: 5% Light).

senoside Rb_3 have been isolated and identified in the leaves of P. pseudoginseng subsp. himalaicus (Hymalayan Panax) and in Pg root(50) but it was not found in the leaves of P. quinquefolius(49) and P. ginseng(11). But in the present study relatively high amount of ginsenoside Rb_3(13 to 20% of total saponin) was found in the leaves of American sheng.

The change of each leaf ginsenoside with the increase of light intensity from 5% LTR to 15% was shown in Fig. 20. Rg_2 and Rg_1 decreased and Rc and Rd increased in Pg and Pq, Re increased but Rb_2 decreased in Pg quite contrary to Pq. Px followed Pg. In general diol saponin(PD) increases and triol saponin(PT) decreases by increasing light intensity. Thus PT/PD was above unity in Pg and Px but below unity in Pq in every case(Fig. 21). Though PT/PD of Pg and Px decreased by the increase of light intensity it never reached below unity and was still far above that of Pq. PT/PD increased when light increased from 15% to 30% only in Pg.

The relation among physiological characteristics, cultural environment and efficacy of Panax are shown in Fig. 22. According to Eum(Yin)-yang theory Panaxatriol belongs to Yang principle since it is stimulative and Panaxadiol(sedative) to Eum. Under the high light intensity, that is, Yang environment Yang principle(PT) decreases but Eum pirnciple(PD) increases. Korea ginseng being physiologically Yang characteristics (tolerable to highlight intensity and high temperature) are cultured under Eum environment(low light intensity) and used for Yang efficacy (to build up energy) while American sheng of Eum characteristics(weak to high light intensity and high temperature) are grown under Yang environment(high light intensity) and used for Eum efficacy(to cool down heat). It said that Korea ginseng has long been used to build up energy(stimulative) mostly during winter but American sheng has been long to cool down(sedative) during summer in Hong Kong. Quality should be considered when light intensity will be changed for better yield since light intensity affects quality of ginseng.

Photoperiodism: Korea ginseng begins to blossom in late May of 3 years old. Flowering date is not different among lines under shade.

Some plants make flower very rarely at 2 years old. Reports on photoperiodism of Korea ginseng is hardly to find. Since differentiation for flower bud is accomplished two years before(52) study on photoperiodism seems to be somewhat difficult.

Korea ginseng has flower wrapped with leaves under ground before emergence. Korea ginseng when transfered to warm room in early spring from field blossoms in early April. With vinyl tunnel Korea ginseng emerges 14 days earlier and blossoms about 20 days earlier than control(53). American sheng grown in Korea showed similar time of flowering and ripening to those in north America. The light quality under the shade is also unknown.

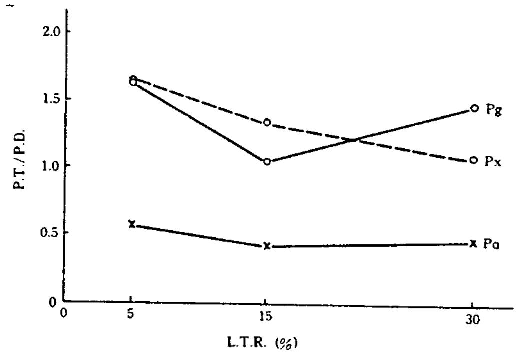

Fig. 21. Change of PT/PD value of Panax leaf grown at different light intensity (PT: triol saponin, PD: diol saponin)

Panax	Physiological Characteristics		Growth Condition		Use Efficacy
Pg	Yang (陽)	⟹	Eum (陰)	⟹	Yang (陽)
Pq	Eum (陰)	⟹	Yang (陽)	⟹	Eum (陰)

Fig. 22. Comparison of Panax in relation to physiological characteristics and efficacy.

Nutrient uptake: The effect of light regime in relation to nutrient uptake is not well known. Nitrogen content decreased with the increase of light intensity but phosphorus and potassium increased. The maximum rate of uptake and content of P and K was observed at 50% shading but N uptake was greatest at 70–75% shading(54). In other field investigation(55) the content of N. P. K of leaves and stem tend to greater at first line(high light) than at 3rd line(low light). But in petiole nitrogen content tends to follow that of leaves while P and K are not consistent. In root the content of N. P. K was clearly high in 3rd line than in first line.

Acknowledgement: I should like to express my thanks to Dr. Hyo-Won Bae president of Korea Ginseng Research Institute for encouraging me and to Symposium Committee to invite me for presentation. I also gratefully acknowledge the efforts of my colleague researchers in Physiology Laboratory for the preparation of this presentation.

Summary

Physiological response of Panax ginseng var. atropurpureacaulo (purple stem variety, Pg) to light was reviewed through old literatures and recent experiments. Canopy structure, growth, pigment leaf anatomy, disease occurence, transpiration, photosynthesis (PS), leaf saponin, photoperiodism and nutrient uptake were concerned. P. ginseng var, xanthocarpus(Yellow berry variety, Px) and Panax quinquefolius(Pq) were compared with Pg if possible. Under thatch roof where all cool morning light reach stem, petioles, leaves are arranged for maximum harvest of light. With the increase of light intensity stem length, leaf size, leaf area ratio, chlorophyll and carotenoids decreased while number of stem per plant, relative growth rate, net assimilation rate, leaf thickness specific leaf weight, stomata frequency, stomata index, stomatal conductance(aperture) and chlorophyll a/chl. b ratio increased. Absorption rate of nitrogen, phosphorus and potassium increased but content in root decreased with increase of light. Leaf blight, anthracnose and defoliation increased with increase of light. Transpiration increased with increase of light intensity and in leaves grown under higher light intensity. There was no distinguished compact palisade cells in leaves. Mesophyll cells tended to compact under high light intensity. Helical tracheids frequently appeared in Pq leaves. Many large starch granules were observed in chloroplast of leaves grown under 15% light in Pg.Light saturation of PS ranged from 5 to 35 Klux and tended to be high in early season and in old age, and low above optimum temperature which appeared 15 to 20°C. Photosynthesis of leaves grown under 30% light was smaller at 4 Klux but greater at 15 Klux than that of leaves grown at 5% light. Light compensation point was around 500 lux at 20°C but around 2 Klux at 30°C. Compensation point (Cp) increased with increase of light and ranged from 110 to 150 at 20°C but from 140 to 220 at 20°C with 4 to 15 Klux indicating occurence of light and temperature-dependent high photorespiration. Characteristics of Korea ginseng to hate high temperature was well in accordance with an observation 2000 years ago. Korea ginseng showed lower Cp and appeared to be more tolerant to high light intensity and temperature than American sheng although the latter showed greater PS, stomata frequency and conductance, chlorophyll and carotenoids. Px showed lower PS than Pg probably due to higher Cp. total leaf saponin was higher in leaves grown under high light. Ratio of triol saponin and diol saponin(PT/PD) decreased with increase of growing light intensity mainly due to decrease of ginsenoside Rg, and increase of ginsenoside Rd. Leaves of Pg and Px had Rh_1 but no Rb_3 which was only found in Pq leaves as much as 20% and decreased with increase of growing light intensity. Re increased in Pg and Px but

decreased in Pq with increase of light. PT/PD in leaf ranged 1.0–1.5 in Pg and Px but around 0.5 in Pq. Korea ginseng has Yang characteristics (tolerant to high light and temperature), cultured under Eum(shade) condition and long been used for Yang efficacy(to build up energy) while Pq was quite contrary. Traditional low light intensity(3–8%) for Korea ginseng culture appeared to be strongly related to historical unique quality. Limiting factors of photosynthesis(around 4mg $CO_2/dm^2/hr$) of Korea ginseng might be low diffusive resistance of leaves causing CO_2 depletion and poor leaf cooling system. Optimum light intensity for yield increase of Korea ginseng appears to be 15% rather than preveiling 8% with the same quality although there seems no limitation of light intensity as long as temperature ranges within optimum. Effect of light quality and photoperiodism was not well known. Experiences are long but scientific knowledge is short for production as well as quality assessment of ginseng. Recent scientific knowledge of ginseng should learn wisdom from the old experiences.

Chairman: Now the time is open to discussion.

Chang, W.C.: Thank you Dr. Park. I am very exciting about your research. Have you done some work about using the higher concentration? American ginseng or Korean ginseng? Some friends who treat the higher concentration can get more tolerance for the light intensity. A lot of friends treat the plants with the high concentration and hope to get a higher photosynthetic activity. Have you done some work about this?

Park: This year, we start intensive study of photosynthesis. We measured the photosynthetic activity with the high concentration of CO_2 but I didn't look through yet all the data.

Chang, W.C.: May I have one more question? In your abstract you talk about you still don't know about photoperiod of Panax ginseng. You mean you don't know whether long or short day plant for flowering?

Park: Yes, there is no report on photoperiod of ginseng, but I think it is very difficult because ginseng is very peculiar. This flower buds are all initiated before two years ago. Ginseng has unique characteristics. You know that the buds or new buds are already formed two years before. Physiologically they compensate the weather conditions during the two years. That is biologically very benificial for long living. When we keep the roots worm in the laboratory they make flower right after emergence. It is very difficult to know about photoperiod because it is already initiated two years ago.

References

1. Imamura, T. 1939. Ginseng History Vol. 6. Micellaneous. P. 440 (Japanese)
2. Kuribayashi, T. and Ohashi, H. 1971. Physiological and ecological studies in Panax ginseng. V. Effects of light intensity and soil PH on gowth. Shoyakugaky Zasshi 25, 110–6 (Japanese)
3. Mackinney, G. 1941. Absorpation of light by chlorophyll solutions. J. Biol. Chem. 140:315–22
4. Official Methods of the A.O.A.C. 1975. 12th ed. P. 821.
5. Sampson, J. 1961. A method of replicating dry or moist surfaces for examination by light microscopy. Nature 191:932–3.
6. Ishihara, K., Nishihara, T. and Ogura, T. 1971. The relationship between environmental factors and behaviour of stomata in the rice plant. 1. On the measurement of stomatal aperture. J. Crop. Sci. Sco. Jap. 40:491–500 (Japanese)
7. Berlyn, G.P. and Miksche, J. P. 1976. Botanical microtechnique and cytochemistry. The Iowa State University Press, Ames. Iowa.
8. Kim, W. K. 1973. Ultrastructural and cytochemical studies on the main root in Panax ginseng C.A. Meyer. Science and Technology 14:71–109 (Korean)
9. Dawes, C. J. 1971. Biological Techniques in electron microscopy. Barnes & Noble, Inc. New York.
10. Namba, T., Yoshizaki, M., Tomimori T., Kobashi, K., Mitsui, K. and Hase, J. 1974. Fundamental studies on the evaluation of the crude drugs III. Chemical and biochemical evaluation of ginseng and related crude drugs. Yakugaku Zasshi 94:252–260 (Japanese)
11. Hong, S. K., Park, E. K., Lee, C. Y. and Kim, M.U. 1979. High performance liquid chromatographic determination of ginseng saponin.

Yakhak Hoeji 23:181-186 (Korean)
12. Vorobjeva, P.P. 1960. Light effects on growth and some anatomyphysiological characteristics of ginseng. J. Materials of studying on ginseng and limonnik. 4:64-86 (Russian). Also in Kuribayashi, T. and Ohashi, H. 1971. Michurin Biological Research 7: 8-18 (Japanese)
13. Kim, J. H. 1964a. Physiological and ecological studies on the growth of ginseng plants (Panax ginseng) II. Growth habits and an analysis of the seasonal growth. Seoul Univ. J. Biol. Agr. Ser. B. 15:68-80.
14. Kim, J. H. 1946b. Factors affecting the received light intensity of ginseng plants (Panax ginseng). Nat. Acad. Korea. J. Natur. Sci. Ser. 5:1-17.
15. Hong, S. K. 1974. Cultivation of ginseng. Korean Ginseng Sci. Symp. (Seoul) pp. 37-54 (Korean)
16. Miyazawa, Y. 1975. Technique of ginseng culture. Agric & Hort. 50:117-122 (Japanese)
17. Yang, Y. Y. 1974. The effect of different shading of mulching on yield of root and quality in Panax ginseng. Proc. Internat. Ginseng Symp. The central Research Inst. Office of Monopoly. Korea.
18. Veninga, L. 1973. Ginseng Book. Big Trees Press
19. Williams, L. and Duke, J. A. 1978. Growing ginseng. USDA.
20. Kim, D. C. 1973. Ginseng cultivation, Ilhan Toseo Publishing Co., Seoul (Korean)
21. Park, H., Ohh, S. H. and Lee, C. H. 1980. Occurence pattern of yield and missing plant of Panax ginseng in lines under field condition. J. Korean Soc. Crop Sci. 25:76-81 (Korean)
22. Kim, J. H. 1962. Physiological and ecological studies of growth of sheng plant (Panax ginseng) I. Environmental and productive structures. Kongju Teachers College Nonmunjip 1:149-160 (Korean)
23. Hong, S. K. and Ohh, S. H. 1976. Studies on multistem ginseng. Res. Rep. 833-848. Central Res. Inst. Office of Monopoly (Korean)
24. Kim, J. H. 1964c. Physiological and ecological studies on the growth of ginseng plants (Panax ginseng). III. An analysis of the perennial growth and the growth attributes under varying light intensities. Seoul Univ. J. Biol. Agr. Ser. B. 15:81-93.
25. Boardman N. K. 1977. Comparative photosynthesis of sun and shade plants. Ann. Rev. Plant physiol. 28:355-377.
26. Takahama, U. 1979. Stimulation of lipid peroxidation and carotenoid bleaching by deuterium oxide in illuminated chloroplast fragments: Participation of singlet molecular oxygen in reaction. Plant Cell Physiol. 20:213-218.
27. Takahasi, N. and Osumi T. 1940. On the inheritance of the colour of stem and fruit in Panax ginseng C.A. Meyer. Jap. Jour. Genet. 16:273-276 (Japanese)
28. Park, H. and An J. S. 1980. Studies on factors affecting stomatal frequency and conductance of Panax ginseng leaf. Korean Biol. Sci. Asso. Supplement. B-12.
29. Kim, Y. T., Lee, J. C. add Cheon, S. K. 1979. Studies on stomatal aperture and transpiration of Panax ginseng leaves. Ginseng Res. Rep. Korea Ginseng Res. Inst. 575-589 (Korean)
30. Ahn, H. Y., Lee, Stadelmann, O.Y. and Kim, J. H. 1978. Transpiration and stomatal parameters in leaves of Panax ginseng. Korean Biol. Sci. Asso. B-29.
31. Park, H., Yoon, T. H. and Bae, H. Y. 1979. Characteristics in wilting and transpiration of Panax ginseng leaves. J. Korean Soc. Sci. Fert. 12:77-82. (Korean)
32. Kim, Y. T., Kim, H. J. and Kim, H. M. 1979. Prevention trials against leaf blight. Ginseng Res. Rep. 395-408. Korea Ginseng Res. Inst.
33. Chung, H. S. and Bae, H. W. 1979. Ginseng anthracnose in Korea. Factors affecting primary inoculum, growth of the pathogen, disease development and control. Korean J. Pl. Prot. 18:35-41.
34. Zelitch, I. 1971. Photosynthesis, photorespiration and plant productivity. Academic press. New York.
35. Tao Hung Ching 502-549, Myong-Ui-Byeol-Rok (Chinese)
36. Kim, J. H. 1964d. Physiological and ecological studies on the growth of ginseng plants (Panax ginseng) V. On the photosynthesis, respiration and dry matter production. J. Konju Teachers College 2:149-146.
37. Lee, J. C., Cheon, S. K., Kim, Y. T., Lee, C. H. and Park, H. 1980. Effects of temperature and light intensity on photosynthesis and root growth. J. Korean Soc. Crop. Sci. 25 (in press, Korean)
38. Park, H., Lee, C. H., Bae, H. Y. and Hong Y. P. 1979. Effects of light intensity and temperature on photosynthesis and respiration of Panax ginseng leaves. J. Korean Soc. Soil Sci. Fert. 12:49-53. (Korean)
39. Grushviskii V. and Novichkova, L. M. 1957. Photosynthesis in ginseng. Bot. Zh., 42:751-6 (Russian)

40. Park, H. 1980. Physiological response of Panax ginseng to temperature II. Leaf physiology, soil temperature, air temperature growth of pathogene. Korea J. Ginseng Sci. 4:104–120.
41. Rhee, W.S. and Rhee, S.R. 1968. Standard History Atlas Gyohagsa, Seoul.
42. Britanica Allas. 1979. Encyclopedia Britanica Inc.
43. Ryuk Woo. 760. Da Gyeong (Tea book, Tang Dinasty)
44. Seo Yu Geo 1820. Im-Weon-Sip-Ryug-Ji. (Chinese)
45. Imamura, T. 1936. Ginseng History Vol. 5 Culture of ginseng.
46. Lee, J.H., Park, H., Ryu, K.J. and An, J.S. 1979. Studies on dry matter production and metabolism. Ginseng Research Report. 173-203. Korea Ginseng Research Institute.
47. Canvin, D.T. 1979. Photorespiration: Comparison between C_3 and C_4 plants. In Photosynthesis II. Encyclopedia of plant physiology. Vol. 6. 368–96. Springer-Verlag.
48. Osumi, T. In the lecture note "Ginseng plants and their cultural environment" by Jwang, J.K. (Korean)
49. Han, B. W. 1974. Chemical components of Korean ginseng. Korean ginseng Symposium. 81–111.
50. Yahara, S., Taniyatsu, S., Kasai, R. and Tanaka. O. 1979. Saponin in airial part of Panax species: On the relation between components and taxanomy especially by Himalayan ginseng. Abstracts of Korea Ginseng Seminar. Hiroshima Japan (Nov. 28–29) P. 12–14.
51. Lui, J. H. and Staba, E. J. 1980. The ginsenosides of various ginseng plants and selected products. J. Natural Products. 43:340–346.
52. Gurushiviskii, I. V. 1962. Panax ginseng (its biological aspect) Japanese version by Hukazawa, M.
53. Park, H., Kim, K. S. and Bae, H. Y. 1979. Effects of gibberellin and kinetin on bud dormancy breaking and growth of Korea ginseng root (Panax ginseng C.A. Meyer). Proceedings of 6th Annual Meeting of Plant Growth Regulator Working Group. 210–217. Las Vegas. U.S.A. (Aug. 20–24)
54. Pechenitsina, A. M. 1960. The effect of the intensity of the light on the content and intake of the basic elements of nutrition in ginseng plants. Abst. Korea Ginseng Studies (1687–1975). P. 29. Ginseng Biol. 003. The Research Inst. Office of Monopoly. Korea
55. Kim, Y. T., Kim, J. M. and Moon, H. O. 1979. Comparative study of violet stem variant and yellow berry variant. Ginseng Res. Rep. 533–551. Korea Ginseng Res. Inst.