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Varietal Difference of Dry Matter Production and Photosynthetic of Middle and Lower Leaves in Soybean

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ABSTRACT: This research was conducted to compare the dry matter production and the yield productivity among nine soybean cultivars by measuring the photosynthetic ability of the middle and lower leaves at the flowering and the seed development stages. The leaf greenness (SPAD value) were ranged as 32~42 at the flowering stage. Also, They were ranged as 25~40 and 38~51 at the fifth leaf and the seventh leaf, respectively. The photosynthetic ability at the flowering and the seed development stage showed significant differences among soybean cultivars, and the photosynthetic ability at the seed development stage showed higher difference among cultivars than the flowering stage. The variation of the photosynthetic ability at the flowering and the seed development stage also was significant among cultivars. The light saturation point at the flowering stage was about 1500 μmol $m^{-2}s^{-1}$ PAR, and the seed development stage was about 1000 μmol $m^{-2}s^{-1}$ PAR. The photosynthesis showed the high negative correlation with the leaf area and the positive correlation with the leaf area ratio. Also, photosynthesis at seed development stage showed positive correlation with grain yields but there was not significant between photosynthesis and yields at flowering stage.

Key words : Soybean, Leaf greenness, Photosynthetic ability, Middle and Lower Leaves, graln yields.

Researches on photosynthesis and dry matter production of soybeans had been achieved based on the population structure, the light-interception characteristics, the photosynthesis of population, and the photosynthetic ability of leaf (Asanome and Ikeda, 1998; Chun and Kim, 1992; Kokubun *et al.* 1988; Sagawa, 1997, 1998). Through out these researches, various factors affecting the photosynthesis of leaf were proved theoretically including the plant type that have light-interception characteristics to get high population photosynthesis (Dornhoff and Shibles, 1970).

Amount of the photosynthesis of individual leaf does not increase further as the luminous intensity reaches to the light saturation point. The amount of the photosynthesis in community, however, increases in high luminous intensity.

That was considered to be that leaves at the high position reach to the light saturation point easily by the direct light, but the amount of the photosynthesis of leaves at middle and lower position increases due to the light interception by high positioned leaves, consequently, the light interception made leaves difficult to reach the light saturation point (Sagawa, 1998). Also, there was a report stated that the yield was increased by augmenting the amount of photosynthesis of leaves using reflected light or supplemental lighting to heighten their light utilization efficiency (Sagawa, 1997). But, there are difficulties to apply the reflected light and supplemental lighting to actual cultivation.

Yields of soybeans closely related with the ability of the population photosynthesis (Ford *et al.*, 1983). There was a report stated that cultivars with high photosynthetic ability at middle and lower leaves shows relatively high yield, and high yield cultivars keep higher photosynthetic ability and chlorophyll content than the other cultivars (Ma *et al.*, 1995; Sagawa, 1998).

Therefore, this research was carried out to investigate the ability of photosynthesis in middle and lower leaves of soybean at flowering and at seed development stage among nine soybean cultivars cultivated in Korea and evaluated the difference of yields among cultivars.

MATERIALS AND METHODS

This experiment carried out at farm affiliated to Collage of Agriculture, Chungnam National University in Korea. Nine soybean cultivars classified with the flowering stage were used in this experiment. Two cultivars (cv. Keunolkong, and cv. Danwonkong) were used as early maturing cultivars. Five cultivars (cv. Tawonkong, cv. Duyoukong, cv. Eunhakong, cv. Geumgangkong and cv. Bokwangkong) were used as medium-maturing cultivars. Two cultivars (cv. Hannamkong and cv. Hwangkeumkong) were used as late maturing cultivars.

Seeds were sowed with the planting density of 60×15 cm at May 30, 2000. The cultivated area of experimental plots was about 9.6 m^2 per cultivar. This study was conducted ran-

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domized block design with three replications. The amount of applied fertilizer was N;3 g, P_2O_5;10 g, and K_2O; 10 g per m^2 with all basal fertilizations, The photosynthesis of middle and lower leaves was measured using portable photosynthesis instrument measuring device (Li-cor 6400, U. S. A.) at flowering (R1 by Fehr *et al.* 1971) and seed development stages (R6).

Measurements were taken from the central leaflet of 5th and the 7th leaf in main stem from 9 : 30 in the morning to 3 : 30 in the afternoon. Six replications of measurements per each cultivar were conducted.

Flowering stage of the early maturing cultivars, the medium-maturing cultivars, and the late maturing cultivars was 4^{th}~10^{th}, 11^{th}~15^{th}, and 16^{th}~21^{st} day of July, respectively. Seed development stage of the early maturing cultivars, the medium-maturing cultivars, and the late maturing cultivars was 2^{nd}~6^{th}, 7^{th}~11^{th}, and 12^{th}~16^{th} day of August, respectively.

The light intensity used to measure the photosynthesis was in the range of 0~2000 *u*mol m^{-2} s^{-1} (Li-6400 LTD). The CO_2 concentration was 330~370 ppm and the flow rate of the air was 500 mL min^{-1}. Also, the chlorophyll content was measured using chlorophyll instrument (SPAD 502, Minolta, Japan) with the photosynthesis measurement.

RESULTS

Photosynthesis and chlorophyll content

The photosynthetic ability of the 5th and 7th leaf at flowering and seed development stage was shown in Table 1. The photosynthetic ability of soybean leaves at the flowering and seed development stage had significance among soybean cultivars.

Yeunhakong showed the highest Photosynthesis ability of 22.7 *u*mol CO_2 m^{-2} s^{-1}, and Hannamkong showed the lowest photosynthesis ability of 14.0 *u*mol CO_2 m^{-2} s^{-1} at flowering stage.

The photosynthetic ability at the seed development stage, Yeunhakong was the highest by 19.3 *u*mol CO_2 m^{-2} s^{-1} and Bokwangkong was the lowest by 7.6 *u*mol CO_2 m^{-2} s^{-1}. Also, the photosynthesis differences between the flowering and the seed development stages, the biggest difference appeared on Hwangkeumkong and smallest appeared on Duyukong.

On the other hand, the photosynthesis ability in each soybean cultivars due to the light intensity at the flowering and at seed development stages was shown in Fig. 1. The photosynthesis ability increased as the light intensity increased. In general, the light saturation point appeared at the light intensity over 1500 μmol $m^{-2}s^{-1}$ PAR (photosynthetically active radiation) at the flowering stage and 1000 μmol $m^{-2}s^{-1}$ PAR at the seed development stage.

But, the light intensity that reached the light saturation

Table 1. Photosynthetic ability (CO_2 μmol m^{-2} s^{-1}) of 9 soybean cultivars in the 5th and 7th positional leaves at flower stage and seed development stage.

Cultivars	Flower stage (A)	Seed development stage (B)	A-B
Keunolkong	21.8ab♪	13.4abc	8.4
Danwonkong	18.1abc	13.0abc	5.1
Tawonkong	20.7abc	13.9abc	6.8
Duyoukong	19.9ac	17.1ab	2.7
Geumgangkong	18.2abc	9.8bc	8.4
Eunhakong	22.7a	19.3a	3.4
Bokwangkong	15.8bcd	7.6c	8.2
Hwangkeumkong	19.2abc	9.2bc	10.0
Hannamkong	15.0cd	9.7bc	5.3
mean	18.5	12.8	5.7

♪ Means followed by different letters are significantly different according th DMRT (p<0.05).

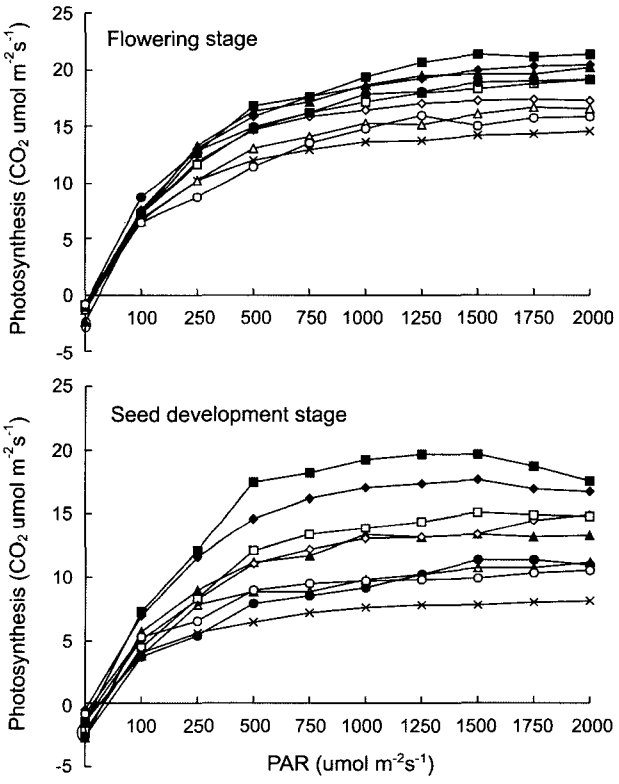

Fig. 1. Change of photosynthetic ability with light intensity of 0~2000 PAR in low leave positions of 9 soybean cultivars. ; Keunolkong, ▲ ; Tawonkong, ◇ ; Danwonkong, □ ; Duyoukong, ◆ ; Geumgangkong, △ ; Eunhakong, ■ ; Bokwangkong, ● ; Hwangkeumkong, ○ ; Hannamkong.

point was over 700 μmol $m^{-2}s^{-1}$ PAR in Hannamkong and Bokwangkong, over 1000 μmol $m^{-2}s^{-1}$ PAR in Geumgangkong, over 1250 μmol $m^{-2}s^{-1}$ PAR in Danwonkong, Keunolkong, Eunhakong, Hwangkeumkong, Duyoukong, and Tawonkong at flowering stage

The leaf greenness of the middle and lower leaves in soybean cultivars at the flowering and seed development stage was shown in figure 2. The leaf greenness ranged as 32~42 SPAD at the flowering stage. Yeunhakong showed high leaf greenness and Keunolkong and Tawonkong showed comparatively low leaf greenness.

The leaf greenness at the seed development stage showed clear difference compare to the flowering stage among soybean cultivars. The leaf greenness ranged as 25~40 SPAD and 38~51 SPAD at the fifth leaf and the seventh leaf, respectively. Among cultivars, Duyoukong and Eunhakong showed relatively high leaf greenness compare to Keunolkong, Tawonkong and Hannamkong which showed low leaf greenness.

And, the leaf greenness at the fifth and seventh leaf showed difference among soybean cultivars. Hwangkeumkong showed the highest difference and Duyoukong and Eunhakong showed less difference of the leaf greenness respect to the leaf position.

Yield, leaf area, and dry matter

Dry weight of soybean cultivars at the flowering and seed development stage was shown in Table 2. The dry matter weight was classified into leaf and stem. There was significant difference in dry matters of leaf and stem among cultivars at the flowering and seed development stage.

Also, the change of the dry weight at the flowering and seed development stage was at most in Yeunhakong and Hwangkeumkong as 23.8 g and 23.6 g, respectively, and Keunolkong showed the lowest change of the dry weight as

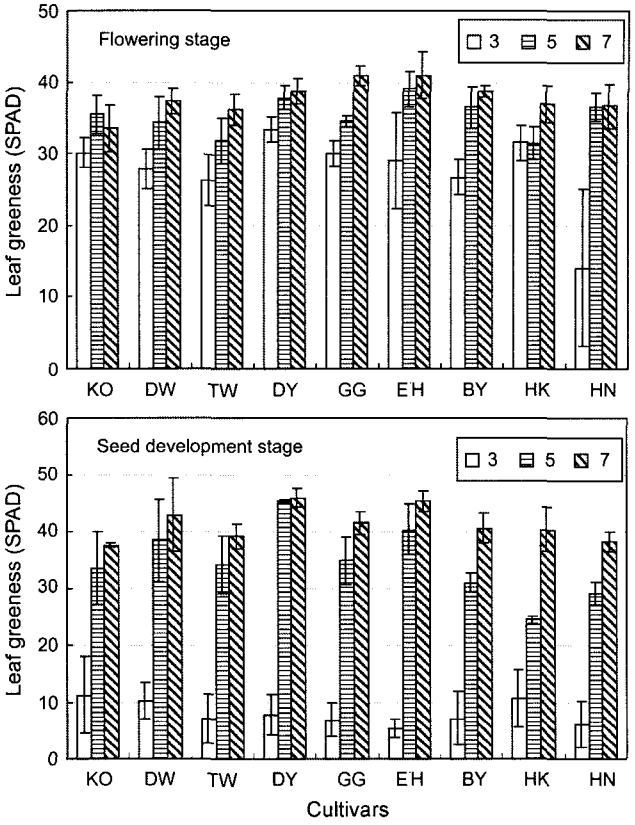

Fig. 2. Leaf greenness of low leaf position in 9 soybean cultivars at flower and seed development stage. KO; Keunolkong, DW; Danwonkong, DW ; Tawonkong, DY; Duyoukong, GG; Geumgangkong, EH; Eunhakong, BK; Bokwang-kong, HK; Hwangkeumkong, HN; Hannamkong. Barsimdicated standard enor.

Table 2. Difference of dry weight (g $plant^{-1}$) in 9 soybean cultivars at flowering and seed development stage.

Cultivars	Leaf			Stem			Total		
	F. S.* (A)	S.D.S** (B)	B-C	F.S. (A)	S.D.S (B)	B-C	F. S. (A)	S.D.S(B)	B-C
Keunolkong	6.8cd	9.6abcd	2.8	5.8def	9.9cd	4.1	12.6bcde	19.5de	6.9
Danwonkong	2.9e	6.8d	3.9	3.0f	9.4cd	6.4	5.9f	16.2e	10.3
Tawonkong	3.0e	10.1abcd	7.1	2.9f	14.0bc	11.1	5.9f	24.1bcd	18.2
Duyoukong	3.4de	9.1bcd	5.7	3.5ef	15.4bc	11.9	6.9f	24.5bcd	17.6
Geumgangkong	4.2cde	10.8abcd	6.6	4.9def	17.5b	12.6	9.1def	28.3bc	19.2
Eunhakong	3.6de	11.7abcd	8.1	3.8def	19.5b	15.7	7.4ef	31.2bc	23.8
Bokwangkong	6.5cd	15.1ab	8.6	10.2ab	24.3a	14.1	16.7b	39.4a	22.9
Hwangkeumkong	3.6de	14.2abc	10.6	3.1f	16.1bc	13.0	6.7f	30.3bc	23.6
Hannamkong	11.1a	13.0abcd	1.9	13.8a	22.0a	8.2	24.9a	35.0ab	11.1
mean	5.0	11.2	6.1	5.7	16.5	10.8	10.7	27.7	17.0

*, ** ; marks of flower and seed development stage, respectively.
♪ Means followed by different letters are significantly different according th DMRT ($p<0.05$).

6.9 g.

In the case of the leaf area, Hannamkong, Bokwangkong and Keunolkong were high at the flowering stage, and Hannamkong, Hwangkeumkong and Bokwangkong were high at the seed development stages. The change of the leaf area at the flowering and the seed development stages, Hwangkeumkong showed the highest change by 2,208 cm^2, and Eunhakong, Bokwangkong, Tawonkong, Geumgangkong and Duyoukong showed next high leaf area change in order.

The leaf area of Hannamkong, however, decreases or the degree of the increase was less compare to other cultivars (Table 3). The leaf area ratio (leaf area/shoot dry weight) was relatively high at the flowering stage in Keunolkong, Tawonkong, Duyoukong, and Hannamkong. Hwangkeumkong, Keunolkong, Tawonkong, and Hannamkong showed high leaf area ratio at the seed development stage.

Hwangkeumkong showed the lowest change of the leaf area ratio at the flowering and the seed development stage by 3.0. Duyoukong and Geumgangkong showed the comparatively high leaf area ratio change compare to other cultivars. Also, Tawonkong and Hannamkong showed comparatively many seed numbers among cultivars. Duyoukong showed the highest seed yield per unit area (m^2), and Bokwangkong showed the lowest seed yield.

DICUSSION

The photosynthetic ability of the middle and lower leaves showed decreasing tendency as developed from the seed development stage to the flowering stage. In all soybean cultivars, significant photosynthetic ability was appeared at the flowering and the seed development stage.

Generally, the photosynthetic ability of middle and lower leaves has an intimate relationship with the light interception character of the leaf, and the early maturing cultivars has less LAI (leaf area index) and the size of individual leaf area is small compare to the late maturing cultivars (Sagawa, 1998). So, the early maturing cultivars have a good light interception character at the middle and lower leaves. In this experiment, in general, Keunolkong which was the early maturing cultivar showed higher photosynthetic ability than that of the late maturing cultivars.

There were many reports stated that the photosynthetic ability has negative correlation with the leaf area and has positive correlation with SLA (specific leaf area) and the content of the chlorophyll (Sagawa, 1997). Results obtained from this research, the photosynthesis showed the high negative correlation with the leaf area and the positive correlation with the leaf area ratio (Fig 3a, b). Also, photosynthesis at seed development stage showed positive correlation with yields but there was not significant between photosynthesis and yields at flowering stage (Fig. 3c, d). Therefore, The photosynthetic ability of the leaves and yield showed no correlation with the photosynthetic ability at the flowering stage, but showed positive correlation with the photosynthetic ability at the seed development stage (Kukubun *et al.*, 1988). Some existing reports, meanwhile, stated that there was correlation between the photosynthesis and the yield (Dornhoff & Shibles, 1970; Buttery & Buzzell, 1981) and some reports stated that there was no correlation between the photosynthesis and the yield (Ford *et al.*, 1983; Kukubun, 1988). These researches measured the photosynthetic ability with flourishing photosynthesis ability leaves.

Table 3. Difference of leaf area, leaf area ratio, pod number and grain yield among 9 soybean cultivars at flowering and seed development stage.

Cultivars	Leaf area (cm_2 $plant^{-1}$)			LAR (Shoot D.W. LA^{-1})			Pod no. ($plant^{-1}$)	Grain yield ($g\ m^{-2}$)
	F. S.* (A)	S.D.S** (B)	B-A	F.S. (A)	S.D.S (B)	A-B		
Keunolkong	2,058cdef	2,474bc	416	163.3a	126.9a	36.4	32.8d	217.8a
Danwonkong	715g	1,666c	951	121.2bc	102.8b	18.4	43.4cd	198.0a
Tawonkong	993fg	2,866bc	1,873	168.3a	118.9ab	49.4	82.0a	185.4b
Duyoukong	1,126defg	2,565bc	1,439	163.2a	104.7b	58.5	54.3cd	252.5a
Geumgangkong	1,426cdefg	2,898bc	1,472	156.7a	102.4b	54.3	58.8c	200.2a
Eunhakong	1,091efg	3,567ab	2,476	147.4ab	114.3ab	33.1	34.9cd	219.0ab
Bokwangkong	2,194bcde	4,131a	1,937	131.4b	104.8b	26.6	48.0cd	170.8ab
Hwangkeumkong	913fg	3,121bc	2,208	136.3b	136.0a	3.0	73.1bc	209.5a
Hannamkong	2,910a	4,030a	1,120	157.0a	115.1ab	41.9	85.9a	196.9ab
Mean	1,492	3,035	1,543	149.4	114.0	35.4	57.0	205.6

*, ** ; marks of flower and seed development stage, respectively.
♪ Means followed by different letters are significantly different according th DMRT ($p<0.05$).

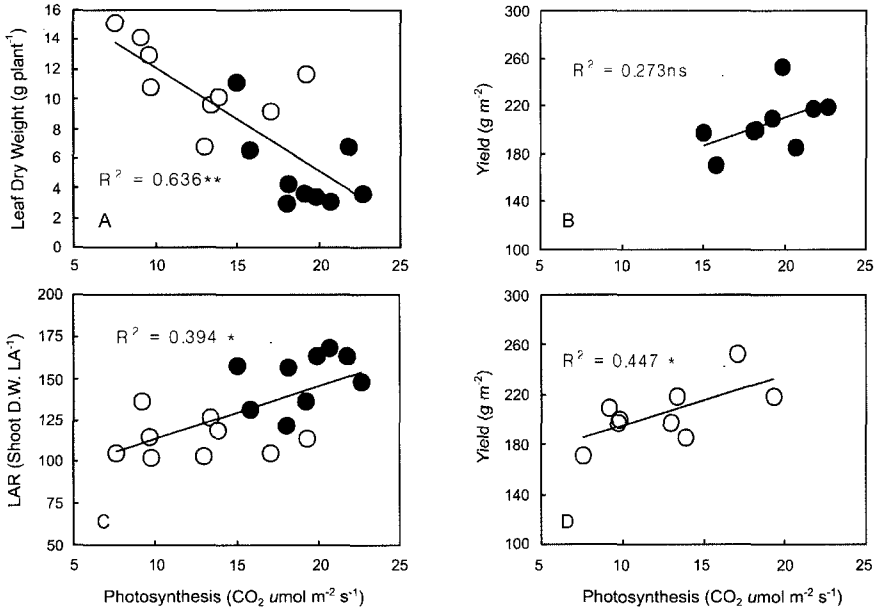

Fig. 3. Relationship between leaf dry weight (A), LAR(B), yields (C, D) and photosynthesis of of 9 soybean cultivars at flowering (●) and seed development (○) stage. . ns ; not significant, * & ** ; significant at 0.05% and 0.01%, respectively.

However, the results obtained from this research coincided with results by Sagawa (1998) which stated that the yield highly correlated with the photosynthetic ability of the middle and lower leaves at the pod formation and the seed development stage.

The photosynthetic ability of the middle and lower leaves in soybeans could be influenced greatly by the light interception from high positioned leaves spread perfectly.

Even though cultivars which have large dry weight of leaf, the cultivars, which has narrow petiole angle of high positioned leaves, could be favorable because it allowed higher light incident and intensity of radiation to the middle and lower leaves. Wofford and Allen (1982) reported that development of new cultivars could be breed cultivars which had smaller leaf size and higher light inception efficiency plant type since the leaf blade angle of soybeans had significant difference among cultivars

The condition of the high yield soybean cultivars could keep the high crop growth rate (CGR) at the flowering and the pod formation stage by early ensuring of the leaf area index (LAI), and have high growth increment and good light inception efficiency.

Usually, even though the cultivars with high growth increment have low photosynthetic ability at the lower and middle leaves, the cultivars with high growth increment and with high light transmissibility in internal parts of community could be a cultivar which has a high photosynthetic ability in middle and lower leaves as well as whole population and expect to have high yield.

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