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Changes of Chemical Composition during Seedling Development in Soybean

Rak Chun Seong*, Kyu Hoon Choi*, and Harry C. Minor**

ABSTRACT

Seedling establishment of soybean [*Glycine max* (L.) Merrill] is an important factor for soybean production in the field. The objective of this study was to determine the distribution of chemical composition in the emerging organs during seedling development in soybeans. Three soybean cultivars (Hill, Paldalkong, and Jangyeobkong) were planted at the Research Farm of College of Natural Resources, Korea University, on May 26, June 5, and June 14. Protein, oil, sugar, and starch contents were measured in each organ at each developing stage. Mean dry weight of three soybean cultivars decreased until VE stage and increased after this stage. Protein content of whole seedling did not change significantly during the seedling growth stage, but the amount in cotyledons markedly decreased with each growth stage increment. About 88% of the cotyledon protein was translocated to the other parts of the seedling at the V2 stage. Oil content of cotyledons sharply decreased until the V1 stage. Sugar content of the seedling was not detected at VE stage and starch content of seedlings increased slightly at VE and VC stages. For the changes of each metabolic component, the amount for whole plants decreased until the V1 stage and started to increase after this stage. The results of this study provide evidence for the breakdown of carbohydrates and oil at the initial stage of seedling growth.

Key word : soybean [*Glycine max*(L.) Merrill], protein content, oil content, sugar content, starch content.

Seed germination and seedling growth of crops in the field are two of the most important factors for canopy establishment. Its improvement can be achieved by the sufficient digestion of seed reserves and the translocation of digested material to the emerging organs and continuous seedling growth.

Loomis (1945) proposed a theory about transport mechanism of corn seed reserves and assimilates. The dry weight of seedlings was decreased slightly at an early stage of seedling growth, but increased after this time. The soybean cotyledons function as reserve storage for protein, oil, sugar, and starch. During the early stage of germination, protein synthesis occurred in the embryonic organ of the seed. Total nitrogen content of cotyledon decreased and the contents of the radicle and hypocotyl increased (Mayer & Poljakoff-Mayber, 1982; Skorto & Chmielewska, 1966). Oil, a major energy source of the soybean seed, in the cotyledons decreased markedly during seedling growth (Brown et al., 1962; Menetrez et al. 1988; Park & Polacco, 1989; Shin, 1974; Singh et al., 1968; Yosida & Kajimoto 1981). Cotyledons of soybean seed have been reported as a major energy source during the germination and seedling growth (Bewley & Black, 1978; Murray, 1984).

To obtain basic information about translocation of seed reserves, it is important to visualize the energy balance of emerging organs by measuring quantitative changes of seed reserves in each seedling part during the germination and seedling growth. The objective of this study was to determine the distribution of chemical compositions in the emerging organs during seedling development in soybeans.

MATERIALS AND METHODS

Three soybean [*Glycine max* (L.) Merrill] cultivars, 'Hill', 'Paldalkong', and 'Jangyeobkong' were planted at the Research Farm of College of Natural Resources, Korea University, on May 26, June 5, and June 14. One to four hundred seeds were planted in washed sandy soil using plastic box (55×35×15 cm) with holes. A completely randomized design was used with three replications per planting. Each seed bed was watered fully to eliminate drought stress. The temperature during experimental period from May 26 to July 6 ranged from 11.8℃ to a maximum of 33.0℃. Samples were taken at each developing stage (Table 1) and separated to roots, cotyledons, stems, and unifoliolate and trifoliolate leaves. Each sample was dried at 70℃ oven for 48 hours and was using a Udy cyclon mill (0.5 mm screen). Nitrogen content was measured by boric acid modification of the Micro-Kjeldahl method, and multiplied factor 6.25 to obtain the protein content (Association of Official Analytical Chemists; 1995). Oil content was determined by the Soxhlet method. Sugar and starch contents were determined using the Anthrone method. Collected data were analyzed using a SAS package (Appendix 1).

RESULTS AND DISCUSSION

The mean dry weight of three soybean cultivars de-

* Dept. of Agronomy, College of Natural Resources, Korea University, Seoul 136-701, Korea.
** Dept. of Agronomy, College of Agriculture, University of Missouri-Columbia, Columbia, MO 65211, U.S.A.
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Table 1. Number of days required from one stage to the next of the vegetative stages in three soybean cultivars.

Stage	Average number of days	Range in number of days	Number of seeds or plants	Description
Seed	0	0	100	Seed.
Germination	1	1	100	1 day after imbibition.
VE (Emergence)	6	5~6	300	Cotyledons above the soil surface.
VC (Cotyledon)	3	2~5	400	Unifoliolate leaves unrolled sufficiently so the leaf edges are not touching.
V1 (First node)	7	6~8	400	Fully developed leaves at unifoliolate nodes.
V2 (Second node)	6	5~9	400	Fully developed trifoliolate leaf at node above the unifoliolate nodes.

Table 2. The change of dry weight of each plant part during seedling development of three soybean cultivars.

Vegetative stage	Cultivar	Dry weight (g/100 seedlings)							
		Seed	Seedcoat	Root + hypocotyl	Cotyledon	Stem + epicotyl	Unifoliolate leaf	Trifoliolate leaf	Total
Seed	Hill	11.57							11.57
	Paldalkong	13.41							13.41
	Jangyeobkong	23.19							23.19
	Mean	16.06							16.06
Germ.	Hill	10.75	0.88						11.63
	Paldalkong	13.02	1.11						14.13
	Jangyeobkong	21.15	1.33						22.48
	Mean	14.97	1.11						16.08
VE	Hill			2.28	7.54				9.82
	Paldalkong			2.42	8.49				10.91
	Jangyeobkong			3.68	15.62				19.30
	Mean			2.79	10.55				13.34
VC	Hill			3.57	5.17	1.23			9.97
	Paldalkong			3.84	6.00	1.14			10.98
	Jangyeobkong			6.31	12.54	1.57			20.42
	Mean			4.57	7.90	1.31			13.78
V1	Hill			5.81	2.38	2.42	3.30		13.91
	Paldalkong			6.46	3.48	2.18	3.45		15.57
	Jangyeobkong			8.90	6.27	3.45	5.51		24.13
	Mean			7.06	4.04	2.68	4.09		17.87
V2	Hill			8.50	1.76	4.57	4.06	3.22	22.11
	Paldalkong			9.16	2.64	3.42	4.07	3.25	22.54
	Jangyeobkong			11.51	4.40	5.91	6.25	3.75	31.82
	Mean			9.72	2.93	4.63	4.79	3.41	25.48

creased by about 10% as compared with the original seed weight until the VE stage but increased after this stage (Table 2). It has been reported that significant physiological changes occurr during seed germination and seedling development such as the loss of dry matter by respiration, the digestion and mobilization of seed reserves to axis growth, and dry matter increase by photosynthesis of the emerging leaves (Bewley & Black, 1978; Mayer & Poljakoff-Mayber, 1982; Murray, 1984).

Quantitative change of total protein content of whole seedling did not occur during the seedling growth stage, but its amount in cotyledons markedly decreased with seedling development (Table 3). About 88% of the cotyledon protein was translocated to other parts of seedling at the V2 stage, indicating that the nitrogen source for seedling growth was mostly the nitrogen in the cotyledon. This was consistent with the results of Mayer & Poljakoff-Mayber (1982), and Skorto & Chmielewska (1966).

The oil content of cotyledons decreased sharply until the V1 stage and only about 7% was left as compared to the oil content of seed (Table 4). Cotyledon oil of soybean seed was the major energy source for germination and early seedling growth, and seemed to be very

Table 3. Change of protein content of each plant part during seedling development of three soybean cultivars.

Vegetative stage	Cultivar	Protein content (g/100 seedlings)						
		Seed	Root + hypocotyl	Cotyledon	Stem + epicotyl	Unifoliolate leaf	Trifoliolate leaf	Total
Seed	Hill	4.11(35.53)†						4.11(35.53)
	Paldalkong	5.47(40.84)						5.47(40.84)
	Jangyeobkong	8.99(38.76)						8.99(38.76)
	Mean	6.19(38.38)						6.19(38.38)
Germ.	Hill	4.17(38.76)						4.17(38.76)
	Paldalkong	5.95(45.74)						5.95(45.74)
	Jangyeobkong	8.59(40.64)						8.59(40.64)
	Mean	6.24(41.71)						6.24(41.71)
VE	Hill		0.84(36.83)	2.98(39.34)				3.82(38.90)
	Paldalkong		1.15(47.41)	4.00(47.10)				5.15(47.20)
	Jangyeobkong		1.53(41.52)	7.78(44.13)				9.31(43.71)
	Mean		1.17(41.92)	4.92(43.59)				6.09(43.47)
VC	Hill		1.29(36.05)	1.88(36.37)	0.53(43.03)			3.70(37.11)
	Paldalkong		1.66(43.34)	3.01(50.17)	0.53(46.47)			5.20(47.36)
	Jangyeobkong		2.50(39.70)	5.39(42.95)	0.73(46.52)			8.62(42.21)
	Mean		1.82(39.70)	3.43(43.16)	0.59(45.34)			5.84(42.38)
V1	Hill		1.31(22.56)	0.52(21.99)	0.76(31.55)	1.23(37.20)		3.82(27.46)
	Paldalkong		1.72(26.57)	1.35(38.86)	0.83(38.14)	1.37(39.86)		5.27(33.85)
	Jangyeobkong		2.73(30.64)	2.37(37.82)	1.33(38.71)	2.16(39.28)		8.59(35.60)
	Mean		1.92(26.59)	1.41(32.89)	0.97(36.13)	1.59(38.78)		5.89(32.96)
V2	Hill		1.15(13.55)	0.19(11.16)	0.79(17.46)	1.01(25.01)	0.99(30.74)	4.13(18.68)
	Paldalkong		1.61(17.56)	0.57(21.68)	0.90(26.47)	1.25(30.64)	1.18(36.26)	5.51(24.45)
	Jangyeobkong		2.67(23.24)	1.00(22.67)	1.87(31.57)	2.16(34.49)	1.48(39.49)	9.18(28.85)
	Mean		1.81(18.12)	0.59(18.50)	1.19(25.17)	1.47(30.05)	1.22(35.50)	6.28(24.65)

† ( ) : Percentage of dry weight.

Table 4. Change of oil content of each plant part during seedling development of three soybean cultivars.

Vegetative stage	Cultivar	Oil content (g/100 seedlings)						
		Seed	Root + hypocotyl	Cotyledon	Stem + epicotyl	Unifoliolate leaf	Trifoliolate leaf	Total
Seed	Hill	2.46(21.29)†						2.46(21.29)
	Paldalkong	2.57(19.16)						2.57(19.16)
	Jangyeobkong	4.95(21.35)						4.95(21.35)
	Mean	3.33(20.60)						3.33(20.60)
Germ.	Hill	2.53(23.57)						2.53(23.57)
	Paldalkong	2.72(20.88)						2.72(20.88)
	Jangyeobkong	4.87(23.03)						4.87(23.03)
	Mean	3.37(22.49)						3.37(22.49)
VE	Hill		0.05(2.20)	1.65(21.92)				1.70(17.31)
	Paldalkong		0.04(1.75)	1.42(16.68)				1.46(13.38)
	Jangyeobkong		0.08(2.07)	3.56(20.18)				3.64(17.09)
	Mean		0.06(2.01)	2.21(19.59)				2.27(16.20)
VC	Hill		0.05(1.28)	0.73(14.19)	0.05(3.81)			0.93(9.33)
	Paldalkong		0.05(1.25)	0.57(9.43)	0.03(2.86)			0.65(5.92)
	Jangyeobkong		0.09(1.44)	1.81(14.47)	0.05(3.12)			1.95(9.55)
	Mean		0.06(1.32)	1.04(12.70)	0.04(3.26)			1.14(8.27)
V1	Hill		0.05(0.92)	0.15(6.48)	0.04(1.72)	0.13(3.95)		0.41(2.95)
	Paldalkong		0.09(1.32)	0.17(4.79)	0.04(1.76)	0.17(3.92)		0.44(2.83)
	Jangyeobkong		0.10(1.15)	0.38(6.09)	0.07(2.11)	0.26(4.67)		0.81(3.36)
	Mean		0.08(1.13)	0.23(5.79)	0.05(1.86)	0.18(4.18)		0.54(3.02)
V2	Hill		0.09(1.04)	0.09(5.39)	0.07(1.49)	0.15(3.67)	0.12(3.60)	0.52(2.35)
	Paldalkong		0.11(1.22)	0.11(4.06)	0.06(1.63)	0.11(2.61)	0.10(3.05)	0.49(2.17)
	Jangyeobkong		0.10(0.83)	0.21(4.83)	0.09(1.48)	0.21(3.38)	0.14(3.64)	0.75(2.36)
	Mean		0.10(1.03)	0.14(4.76)	0.07(1.53)	0.16(3.22)	0.12(3.43)	0.59(2.32)

† ( ) : Percentage of dry weight.

Table 5. Change of sugar content of each plant part during seedling development of three soybean cultivars.

Vegetative stage	Cultivar	Sugar content (g/100 seedlings)						
		Seed	Root + hypocotyl	Cotyledon	Stem + epicotyl	Unifoliolate leaf	Trifoliolate leaf	Total
Seed	Hill	1.28(11.10)†						1.28(11.10)
	Paldalkong	1.22(9.08)						1.22(9.08)
	Jangyeobkong	2.38(10.25)						2.38(10.25)
	Mean	1.63(10.14)						1.63(10.14)
Germ.	Hill	1.28(11.90)						1.28(11.90)
	Paldalkong	1.10(8.48)						1.10(8.48)
	Jangyeobkong	2.24(10.57)						2.24(10.57)
	Mean	1.54(10.32)						1.54(10.32)
VE	Hill		0.06(2.63)	0.14(1.92)				0.20(2.04)
	Paldalkong		0.04(1.70)	0.20(2.40)				0.24(2.20)
	Jangyeobkong		0.09(2.45)	0.42(2.39)				0.51(2.39)
	Mean		0.06(6.78)	0.25(2.24)				0.31(2.21)
VC	Hill		0.07(1.99)	0.19(3.59)	0.02(1.98)			0.28(2.81)
	Paldalkong		0.06(1.45)	0.23(3.76)	0.03(2.36)			0.32(2.91)
	Jangyeobkong		0.11(1.82)	0.48(3.85)	0.04(2.26)			0.63(3.09)
	Mean		0.08(1.75)	0.30(3.73)	0.03(2.20)			0.41(2.98)
V1	Hill		0.07(1.29)	0.11(4.43)	0.03(1.55)	0.09(2.66)		0.30(2.16)
	Paldalkong		0.09(1.43)	0.12(3.37)	0.04(1.68)	0.07(1.97)		0.32(2.06)
	Jangyeobkong		0.11(1.21)	0.17(2.71)	0.05(1.55)	0.18(3.33)		0.51(2.11)
	Mean		0.09(1.31)	0.13(3.50)	0.04(1.46)	0.11(7.96)		0.37(2.07)
V2	Hill		0.19(2.29)	0.05(2.95)	0.13(2.89)	0.15(3.75)	0.15(4.59)	0.67(3.03)
	Paldalkong		0.24(2.65)	0.09(3.34)	0.10(2.89)	0.13(3.16)	0.09(2.72)	0.65(2.88)
	Jangyeobkong		0.19(1.66)	0.13(2.95)	0.11(1.79)	0.17(2.78)	0.11(2.88)	0.71(2.23)
	Mean		0.21(2.20)	0.09(3.08)	0.11(2.52)	0.15(3.23)	0.12(3.40)	0.68(2.67)

† ( ) : Percentage of dry weight.

Table 6. Change of starch content of each plant part during seedling development of three soybean cultivars.

Vegetative stage	Cultivar	*Starch content (g/100 seedlings)*						
		Seed	Root + hypocotyl	Cotyledon	Stem + epicotyl	Unifoliolate leaf	Trifoliolate leaf	Total
Seed	Hill	0.35(3.05)†						0.35(3.05)
	Paldalkong	0.42(3.15)						0.42(3.15)
	Jangyeobkong	0.81(3.50)						0.81(3.50)
	Mean	0.53(3.23)						0.53(3.23)
Germ.	Hill	0.46(4.28)						0.46(4.28)
	Paldalkong	0.26(1.99)						0.26(1.99)
	Jangyeobkong	0.74(3.48)						0.74(3.48)
	Mean	0.49(3.25)						0.49(3.25)
VE	Hill		0.18(7.79)	0.47(6.25)				0.65(6.62)
	Paldalkong		0.15(6.08)	0.48(5.63)				0.63(5.77)
	Jangyeobkong		0.24(6.65)	1.01(5.73)				1.25(5.87)
	Mean		0.19(6.84)	0.65(5.87)				0.84(6.00)
VC	Hill		0.14(3.90)	0.45(8.70)	0.05(3.90)			0.64(6.42)
	Paldalkong		0.14(3.53)	0.46(7.65)	0.03(2.54)			0.63(5.74)
	Jangyeobkong		0.24(3.87)	0.92(7.35)	0.05(3.04)			1.21(5.93)
	Mean		0.17(3.77)	0.61(7.90)	0.04(3.16)			0.82(5.95)
V1	Hill		0.17(2.88)	0.14(6.03)	0.07(3.00)	0.06(1.70)		0.44(3.16)
	Paldalkong		0.14(2.18)	0.15(4.40)	0.07(3.02)	0.09(2.58)		0.45(2.89)
	Jangyeobkong		0.29(3.07)	0.14(4.60)	0.09(2.70)	0.09(2.50)		0.79(3.27)
	Mean		0.19(2.71)	0.19(5.01)	0.08(2.91)	0.10(2.26)		0.56(3.13)
V2	Hill		0.26(3.07)	0.10(5.85)	0.22(4.79)	0.24(5.85)	0.23(7.12)	1.05(4.75)
	Paldalkong		0.23(2.53)	0.12(4.70)	0.14(4.13)	0.26(6.34)	0.23(7.23)	0.98(4.35)
	Jangyeobkong		0.33(2.89)	0.28(6.35)	0.20(3.34)	0.39(6.20)	0.28(7.50)	1.48(4.65)
	Mean		0.27(2.83)	0.17(5.63)	0.19(4.09)	0.30(6.13)	0.25(7.28)	1.18(4.63)

† ( ) : Percentage of dry weight.

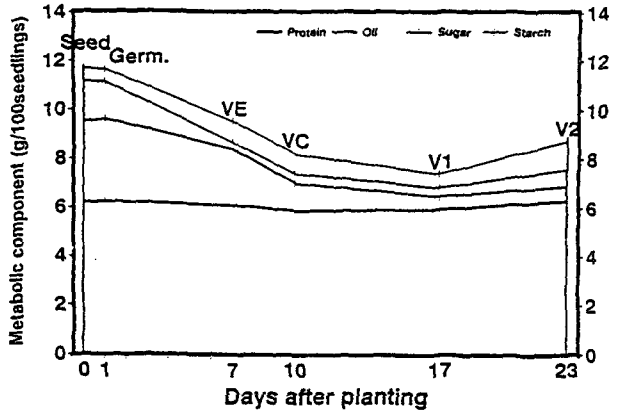

Fig. 1. Change of each metabolic component during the seedling growth of three soybean cultivars.

important until the V1 stage as reported by many reseachers (Brown et al., 1962; Menetrez et al., 1988; Park & Polacco, 1989; Shin, 1974; Singh et al., 1968; Yosida & Kajimoto, 1981).

Seed sugar was quickly used for germination and seedling emergence. The sugar content of the seed nearly disappeared at the VE stage and after this period its amount in other parts increased slightly (Table 5). However, the starch content of seedlings increased at the VE and VC stages, and decreased at the V1 stage (Table 6). In the other parts of the seedling except cotyledons, starch content was higher at the V2 stage. This increase may be due to the carbon assimilation in unifoliolate leaves emerged at the VC stage (Abrahamsen & Sudia, 1966; Hsu et al., 1973; Loomis, 1945; Newton et al., 1980).

The metabolic components in whole soybean seedlings such as protein, oil, sugar, and starch was lower until the V1 stage and then increased after this stage (Fig. 1) (Seong et al., 1997). Therefore the role of soybean cotyledons as the nutrient supplier for germination and seedling growth seemed to be very important until the V1 stage. In addition, our results showed the loss of carbohydrates and oil rather than protein in the seeds and cotyledons at an initial stage of seedling growth.

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Appendix. Analysis of variance of dependent variables in soybean seedlings by cultivars, stages, and component parts.

Dependent variable	Source	DF	Sum of square	Mean square	F value
Dry weight	Cultivars	2	430.68	215.34	9.70**
	Stages	5	1176.84	235.37	13.40**
	Parts	6	2221.45	370.24	35.15**
Protein content	Cultivars	2	86.41	43.20	11.24**
	Stages	5	363.86	72.77	37.99**
	Parts	6	365.93	60.99	31.86**
Oil content	Cultivars	2	9.29	4.64	3.10*
	Stages	5	159.43	31.89	71.79**
	Parts	6	161.58	26.93	62.36**
Sugar content	Cultivars	2	0.80	0.40	1.47ns
	Stages	5	22.16	4.43	100.37**
	Parts	6	22.29	3.71	86.04**
Starch content	Cultivars	2	0.68	0.34	8.02**
	Stages	5	1.39	0.28	7.73**
	Parts	6	1.79	0.30	9.30**

*, ** : Significant at the 0.05 and 0.01 levels of error probability, respectively.
ns : Not significant.