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Growth and Yield Responses of Soybean Cultivars to Drought Stress at Early Growth Stage

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콩 생육초기 수분 장애에 따른 생육 및 수량 반응의 품종간 차이

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ABSTRACT : Water deficit stress during early soybean[*Glycine max* (L.) Merrill] growth stage is the most important environmental factor limiting productivity. Eight soybean genotypes were grown in replicated pot under well-watered(control: near 0 bar) and drought(−5 and −10 bars) conditions. Soybean plants were subject to drought stress for 20 days at 10 days after seed emergence. Significant genotypic variation was observed for leaf area(LA) and total dry weight (TDW). At the end of water stress, LA and TDW of Hwanggeumkong and Paldalkong, which had large LA in the non-stressed control, were more sensitive to water stress than those of the other cultivars, while those of Suwon 93 with small LA were insensitive. Leaf proline and abscisic acid(ABA) contents increased after water stress. However, changes in proline and ABA contents were not consistently related to the changes in LA as affected by water stress. As the soil water potential decreased, the yield reduction of Hodgson 78 showing large decrease in LA and TDW in response to water deficit was severe when compared to that of Baegunkong with small decrease in LA and TDW. Relatively greater yield stability and higher average yield across soil water potential were observed in Baegunkong. Of specific interest was the small reduction in yield of Paldalkong in spite of its significant decrease in LA and TDW.

Key words : Soybean, Water deficit, Drought, ABA, Proline.

Drought stress is one of major abiotic constraints to the production of soybean and many other crops. It is responsible for low and unstable crop yield. Thus identification of soybean genotypes showing a relatively small yield reduction when exposed to drought has been a long-term goal of soybean crop improvement programs. As the assessment of drought tolerance is highly complex, indirect selection of components of drought tolerance could be an effective way to increase the efficiency of selection for drought tolerance. The various traits including proline and ABA accumulation in response to drought stress have been shown to be associated with drought tolerance.

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Proline accumulation under stress has been reported in soybean (Fukutoku and Yamada, 1981; Singh and Gupta, 1983; Waldren et al., 1974) and many other crops, including Bermudagrass(Barnett and Naylor, 1966), sorghum(Blum and Ebercon, 1976; Waldren et al., 1974), potato(Levy, 1983), cotton(McMichael and Eldmore, 1977), Ladino clover (Routley, 1966), barley(Singh et al., 1972; 1973). However, the physiological basis of the relationship between drought tolerance and proline accumulation is unclear, although genotypic variation is considerable under drought stress. This is probably due to the difficulty in measuring proline content at the same moment and at the equal water potential. The possible function of proline was described by Aspinall and Paleg(1981). Proline may contribute to osmotic adjustment, protect various enzymes from desiccation and heat stress, or help to protect membranes from disruptions by extreme temperatures. According to Blum(1988), proline seemed to be closely associated with other types of stress as well.

The plant hormone ABA has been also implicated in drought tolerance. Since the report by Little and Eidt(1968) that ABA was involved in leaf transpiration, much more research have revealed that low transpiration rate was due to the stomatal closure by ABA(Ackerson, 1980; Horton, 1971; Jones and Mansfield, 1972; Mittelheuser et al., 1971). Leaf ABA contents tend to increase in response to water deficit. Larque-Saavedra and Wain(1974, 1976) reported that high ABA accumulation was observed in drought tolerant genotypes of corn. In contrast, Quarrie and Jones(1979) reported the low ABA concentration in drought tolerant spring wheat. Unfortunately, as a whole the association of ABA accumulation with drought tolerance is still conflicting and difficult to interpret(Blum, 1988). Much more evaluation is needed properly before the use of proline or ABA contents in drought tolerance screening.

Crop has been exposed to the intermittent or transient drought of varying duration and intensity during crop growth. In Korea, drought occurs commonly at an early growth stage of soybean. In the present paper, we examine the physiological responses in growth and yield of eight soybean genotypes grown under well-watered(control:near 0 bar) and water deficit (−5 and −10 bar) condition at an early growth stage in the pot. Temporal changes in leaf proline and ABA concentration in response to drought stress were also compared among soybean genotype to evaluate the association with drought tolerance.

MATERIALS AND METHODS

Five recommended soybean cultivars from Korea including Paldalkong(PDK), Jangbaegkong(JBK), Baegunkong(BUK), Namcheonkong(NCK), and Hwanggeumkong(H-GK) were used. In addition, two elite lines Suwon 93(SW 93) and Suwon 119(SW 119), and one foreign cultivar, Hodgson 78(HOD) were selected for this study. These eight soybean genotypes, diverse in seed weight (12.3 to 26.2g/100 seeds) and maturity, were grown in plastic pot(90cm in diameter and 33cm in depth) under well-watered and drought treatments. Each pot was filled with sandy loam with 14.9% clay, 13.7% organic matter, and 5.6 soil pH. Twelve plants were grown in each pot with a spacing density of 40×15cm.

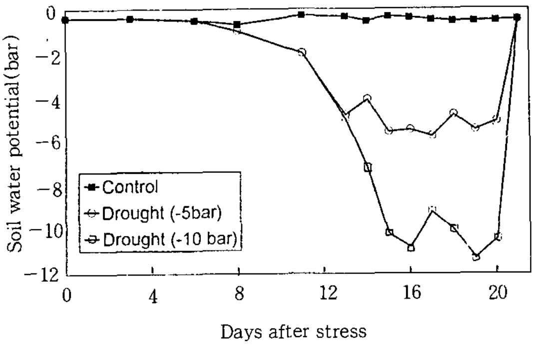

Fig. 1. Changes in soil water potential during drought treatment.

In the well-watered treatment(control), pots were irrigated to maintain −0.5bar of soil water potential. In the drought treatment, drought was initiated at an early growth stage, i.e., when plants were 10days after seed emergence by adjusting water supply for 20days to reach −5bar and −10bar of soil water potential. During the drought treatment, soil water potential was monitored with gypsum block placed 10cm deep in the center of each pot(Fig. 1). It took 13 and 15 days after cessation of water supply in the pot to reach −5bar and −10 bar of soil water potential. At the end of drought treatment, plants were sampled to measure leaf area and dry weight of each plant part. Also, proline and ABA concentrations were determined in the leaves.

Leaf proline concentration was measured according to the rapid determination method by Bates(1973). Approximately 2g of leaf sample was ground in 30ml of aqueous sulfosalicylic acid, and extracted for 24hrs at 4℃ in the dark. After filteration with Whatman No. 2, 2ml ninhydrin solution(1.25g ninhydrin, 30ml glacial acetic acid, and 20ml of 6M phosphoric acid) and 2ml glacial acetic acid, and boiled for 1hr. The reaction was halted by placing on the ice and added with 4ml toluene. The absorbance at 520nm was measured in toluene layer.

The ABA was extracted as described previously(Saunders, 1978) and determined according to the radioimmunoassay(RIA) based on monoclonal antibody(Weiler, 1986). About 5g of fresh leaf were extracted in 50 ml of 80% methanol for 24 hrs at 4℃ in the dark. Water-soluble fraction was re-extracted two times with ethyl acetate and one time with 3% $NaHCO_3$. Finally ethyl acetate layer was concentrated in vacuum at 37℃, and dissolved in 5ml methanol. After removal of organic solution with N_2 gas, 0.1ml methanol extract was incubated for 90 min at 4℃ in the dark after adding RIA incubation mixture [phosphate buffered saline:bovine serum : ^{3}H-ABA = 5:1:1(V/V)] and 0.1ml antibody for ABA. The mixture was added with 0.7ml ammonium sulfate, and incubated for 30min in the dark. After centrifugation, supernatant was discarded. The remnant was again mixed with 1ml ammonium sulfate to remove unbound ^{3}H-ABA. Radioactivity was determined with liquid scintillation counter(Beckman LS 5801).

RESULTS AND DISCUSSION

Drought-stress effects on soybean growth and yield depend primarily on the duration, intensity, and timing of drought as well as their genotypic variation. At the end of 20days after drought stress, soybean genotype×soil water potential treatment interactions were significant($P<0.01$) for all growth characters such as stem length, stem diameter, leaf area, leaf dry weight, and total dry weight(Table 1). This indicated that genotypic variations in these growth charac-

Table 1. Genotypic difference in growth characters after drought treatment for 20 days at 10 days after seed emergence

Water potential	Genotype	Stem length (cm)	Stem diameter (mm)	Leaf area (cm^2/plant)	Leaf dry weight (g/plant)	Total dry weight (g/plant)
Control	Hodgson 78	37.6	3.3	539	1.5	2.8
	Paldalkong	32.6	3.7	726	1.7	3.3
	Jangbaegkong	43.3	3.3	568	1.4	2.9
	Baegunkong	40.5	3.2	624	1.4	2.9
	Suwon 93	39.0	3.5	521	1.3	2.6
	Suwon 119	40.6	3.9	693	1.8	3.6
	Namcheonkong	40.0	3.2	650	1.5	2.9
	Hwanggeumkong	43.2	3.5	932	2.1	4.2
−5 bar	Hodgson 78	13.5	2.3	118	0.4	0.8
	Paldalkong	13.9	2.5	130	0.4	0.8
	Jangbaegkong	17.6	2.4	126	0.5	0.9
	Baegunkong	14.8	2.4	131	0.5	0.8
	Suwon 93	13.1	2.6	140	0.5	0.9
	Suwon 119	17.7	2.7	156	0.6	1.0
	Namcheonkong	18.2	2.0	140	0.5	0.9
	Hwanggeumkong	14.7	2.3	148	0.6	1.0
−10bar	Hodgson 78	9.3	1.9	74	0.3	0.5
	Paldalkong	8.6	2.2	91	0.3	0.5
	Jangbaegkong	13.5	2.2	120	0.5	0.8
	Baegunkong	12.0	2.3	104	0.4	0.6
	Suwon 93	8.4	1.9	71	0.3	0.5
	Suwon 119	11.8	2.1	97	0.4	0.7
	Namcheonkong	14.1	1.8	104	0.4	0.6
	Hwanggeumkong	12.1	1.8	103	0.4	0.6
F-test	Water(W)	49.1^{**}	504.8^{**}	3819^{**}	950.0^{**}	1423.0^{**}
	Genotype(G)	40.3^{**}	10.9^{**}	34^{**}	8.3^{**}	11.2^{**}
	W * G	6.9^{**}	3.4^{**}	26^{**}	5.9^{**}	7.7^{**}
LSD$_{.05}$	Water(W)	1.00	0.15	23.5	0.10	0.17
	Genotype(G)	0.62	0.09	14.4	0.06	0.11
	W * G	1.07	0.16	24.9	0.10	0.19

ters were not consistent across the soil water potential. Retarded leaf growth seems to be a critical parameter for estimating drought injury of plants. Hwanggeumkong and Paldalkong with large LA showed significant reduction in LA and TDW than the other cultivars. Also, Suwon 93 which had small leaf area compared to other cultivars was insensitive to drought stress for LA and TDW change.

Proline and ABA have been intensively studied to understand the implication in drought tolerance. However, it is not clear yet how proline and ABA accumulations in response to drought stress are related drought tolerance on a physiological basis. Remarkable accumulation in leaf proline and ABA was observed after drought stress

Table 2. Changes in leaf proline and ABA content at the end of 20 day drought treatment

Genotype	Soil water potential			Mean
	Control	−5 bar	−10 bar	
	Leaf proline content (ug/g fresh weight)			
Hodgson 78	16	359	1,003	459.3^{b+}
Paldalkong	10	400	1,044	484.7^{b}
Jangbaegkong	23	486	916	475.0^{b}
Baegunkong	15	482	909	468.7^{b}
Suwon 93	15	450	1,009	491.3^{b}
Suwon 119	15	254	1,017	428.7^{b}
Namcheonkong	15	491	1,321	609.0^{a}
Hwanggeumkong	16	360	913	429.7^{b}
Mean	15.6^{c}	410.3^{b}	$1,017.5^{a}$	480.8
	Leaf ABA content (ng/g fresh weight)			
Hodgson 78	89.5	269.0	287.6	215.4^{c}
Paldalkong	104.8	281.1	317.9	234.6^{bc}
Jangbaegkong	119.1	358.4	372.4	283.3^{a}
Baegunkong	123.5	322.7	364.2	270.1^{a}
Suwon 93	130.1	284.8	411.9	275.6^{a}
Suwon 119	97.9	283.6	324.4	235.3^{bc}
Namcheonkong	80.4	193.6	207.6	160.5^{d}
Hwanggeumkong	157.1	278.6	332.5	256.1^{ab}
Mean	112.8^{c}	284.0^{b}	327.3^{a}	241.3

[+] Within traits, means (column or row) not followed by the same letter are significantly different at $p \leq 0.05$ based on LSD.

(Table 2). Averaged across soybean genotypes, when plants were grown at −5 bar and −10 bar, 26 and 65 times higher proline concentrations were obeserved when compared to the non-stressed control, and 2.5 and 2.9 times higher ABA were accumulated, respectively. Proline and ABA accumulations in response to drought stress are a good agreement with other studies(Fukutoku and Yamada, 1981; Singh and Gupta, 1983; Waldren et al., 1974; Larque-Saavedra and Wain, 1974, 1976). Unfortunately, our works shows that change in proline and ABA contents was not consistently related to the changes in LA which was thought to be a sensitive parameter to drought stress as revealed in Table 1. This indicated that the association of ABA and proline contents with drought tolerance could not be explained properly in this study.

Intensity of drought stress influences the yield of soybean significantly. Fig. 2. represents the relationship between mean yield across soil water potential and slope. The slope, which was approximated in the regression equation on the basis of yield change in response to soil water potential, indicates the yield sensitivity to water deficit stress. As the soil water potential decreased, the yield reduction of Hodgson 78 which showed large decrease in LA and TDW, was greater than that of Baegunkong with small decrease in LA and TDW. Baegunkong showed comparatively greater yield stability and higher average yield across soil water potential when compared to the other soybean

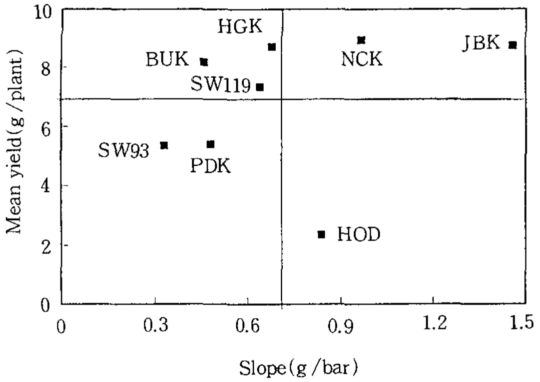

Fig. 2. Relationship between potential yield and yield response to drought.

genotypes(Fig. 2). There was an exceptional case in Paldalkong which showed more slight reduction in yield than the other genotypes though the decrease of Paldalkong in LA and TDW were large. The yields of Jangbaegkong and Namcheonkong, which have high yields under non-stressed control, decreased significantly when they were subject to drought stress treatment. However, those soybean genotypes were able to maintain relatively higher yields under drought stress than the other genotypes.

Large variations in yield response of soybean genotypes to drought stress at an early growth stage were observed in this study. Paldalkong showed the small reduction in yield in spite of its significant decrease in LA and TDW after drought stress when compared to any other genotypes (Table 1 and Fig. 2). This is partly due to the genotypic difference in recovery pattern after drought stress. More importantly, early drought stress in this study had a large interval between the release of drought and final harvest which could cause large genotypic variation in recovery pattern. Related to that, recovery pattern along with recovery duration must be considered to explain the association between genotypic sensitivity to drought and yield potential.

摘 要

생육초기의 수분부족 장애에 대한 콩의 생리적 및 작물학적인 여러 형질들의 반응양상과 콩 품종들의 한발저항성을 구명하기 위하여 황금콩 등 8 품종을 공시하고 생육초기반응에 대해서 토양 수분장력을 −0.3, −5 및 −10bar로 달리하여 폿트를 이용한 토양재배를 하였던 바 그 주요 결과를 요약하면 다음과 같다.

1. 생육초기 20일간의 토양수분 부족장애시는 모든 생육지표에서 생육을 감소시켰는데 특히 엽면적과 지상부건물중의 감소가 뚜렷하였다. 토양수분 부족장애에 의한 생육감소의 품종간 차이는 절대엽면적이 큰 황금콩의 감소율이 높고, 엽면적이 작은 수원 93호가 감소율이 제일 작았다.
2. 엽중 proline 및 ABA 함량은 20일간의 토양수분 부족장애로 인해 현저히 증가하였는데, proline은 무처리구에 비해 −5 bar에서 26배 내외, −10 bar에서 65배 내외 증가되었고 ABA는 각각 2.5 배 및 2.9배 정도 증가되었는데, 품종들의 엽면적감소율 순위와 proline 또는 ABA 함량의 증가순위와는 일치하지 않았다.
3. 콩 생육초기 20일간 토양수분 부족장애 처리후 생육량 감소 정도와 수량의 무처리구 대비 백분율을 기준으로 품종을 구분하여 보면, 백운콩은 엽면적과 총건물중의 감소율이 작으면서 수량 감소율도 작은 품종이었으며, 팔달콩은 엽면적과 총건물중의 감소율은 크나 수량 감소율은 작은 품종이었고, Hodgson 78은 어느 형질이나 감소율이 큰 품종이었다.
4. 토양수분 부족장애가 없을 경우 수량이 높았던 장백콩과 남천콩은 토양 수분 부족장애로 인해 수량 감소율은 컸지만 수분부족 장애시에도 타 품종들에 비해 수량이 높았다.

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