

Application of Non-photochemical Quenching on Screening of Osmotic Tolerance in Soybean Plants

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Non-photochemical quenching (*NPQ*) values for utilizing them to detect osmotic tolerance in plants were examined with two different soybean cultivars, an osmotic tolerant soybean (Shinpaldalkong 2) and a control soybean (Taekwangkong). Two different stresses were applied to the cultivars as the restricted irrigations of 200 and 50 ml water pot⁻¹ d⁻¹ for 5 days for a control and a drought stress, respectively, and a sodium chloride solution of 200 mmol for 6 days for a salt stress. The intact leaves of the two cultivars after treatment were used to measure chlorophyll fluorescence parameters, maximum efficiencies of photosystem II photochemistry (F_v/F_m), efficiencies of photosystem II photochemistry (Φ_{PSII}), CO₂ assimilation rate (P_N), and *NPQ*. Leaf water potentials of the two cultivars decreased from -0.2 to -0.8 MPa by a drought treatment and from -0.7 to -1.7 MPa by a salt treatment. Leaf water content of Shinpaldalkong 2 after a salt treatment was less decreased than that of Taekwangkong. F_v/F_m values of both cultivars were not changed, while Φ_{PSII} and P_N were decreased proportionally to leaf water potential decrease. The response of *NPQ* was occurred in Shinpaldalkong 2 under the drought and salt stresses. With Taekwangkong cultivar, only drought stress referred *NPQ* response. The cultivar differences on chlorophyll fluorescence parameters were found in the relationships between Φ_{PSII} and P_N , and between *NPQ* and Φ_{PSII} . Although the positive relationships between Φ_{PSII} and P_N were established on all treatments of both cultivars, the decreasing rate of Φ_{PSII} to P_N was smaller in Shinpaldalkong 2 than Taekwangkong. The *NPQ* was increased according to the decrease of Φ_{PSII} by osmotic treatments in Shinpaldalkong 2. The complementary relationships between *NPQ* and Φ_{PSII} were well maintained at all treatments in Shinpaldalkong 2, while these relationships were lost at a salt treatment in Taekwangkong. Taken together, the results suggest that analysis of complementary relationships between Φ_{PSII} and *NPQ* could be more valuable and applicable for determining osmotic tolerance than single analysis of each parameter such as F_v/F_m , Φ_{PSII} and *NPQ*.

Key words: Non-photochemical quenching, Chlorophyll fluorescence, Osmotic stress, Soybean.

Abbreviations

Chl - chlorophyll;

F_0 - minimum fluorescence;

F_m - measured maximum fluorescence;

F_v - variable fluorescence;

F_m^0 - maximum fluorescence of light-adapted leaves;

F_s - steady-state fluorescence;

F_0^0 - minimum fluorescence of light-adapted leaves;

F_v/F_m - maximum quantum efficiency of PSII photochemistry;

Φ_{PSII} - quantum efficiency of PSII photochemistry;

$(F_m^0 - F_s) / F_m^0$; *NPQ* - non-photochemical quenching;

P_N - CO₂ assimilation rate;

PS II - photosystem II.

Introduction

Chlorophyll fluorescence of intact leaf exposure to natural light conditions is always emitted and the emission rate is rapidly changed by the environmental conditions, such as light, temperature, water and nutritional state for adjust the stabilization of its photosynthetic metabolism. Therefore, chlorophyll fluorescence techniques have been widely used to understand the photochemical mechanisms of photosynthesis and detect the disorders of photosynthesis by environmental stress in intact plants (Baker and Rosenqvist, 2004; Wingler *et al.* 2004).

In experimental conditions, the specific chlorophyll fluorescence kinetics could be induced by control of lightening source and time after dark adaptation of leaf. Then we could measure and calculate the various chlorophyll fluorescence parameters (Maxwell and Johnson 2000). Among them, the efficiency of photosystem II (PSII) photochemistry or PSII operating efficiency, symbolized by Φ_{PSII} , F^p_q/F^r_m , or $\Delta F/F^r_m$ is one of the widely used parameter. It has been used to estimate the quantum yield and the down-regulation of PSII photochemistry in stressful plant since it is directly related to the CO₂ assimilation rate of the leaf (Gentry *et al.* 1989). But in the field experiments, the positive relationships between Φ_{PSII} and CO₂ assimilation rate are easily broken because the electron sinks for photochemical quenching are changed competitively from CO₂ assimilate reaction to the other alternative mechanisms such as photorespiration, nitrogen metabolism and electron donation to oxygen under natural stressful environments combined with one more stressor (Cornic and Fresneau 2002; Noctor *et al.* 2002).

Non-photochemical quenching, termed by *NPQ*, has been elucidated as a protective function of photosystems against photo-inducible damage (Chaves *et al.* 2002; Holt *et al.* 2004; Štroch *et al.* 2004). It is now well known that the excessive light energy produced in photosystems under unfavorable conditions can induce formation of reactive oxygen species (ROS) that could damage to cell components (Niyogi 1999). The biochemical mechanism of *NPQ* involves de-excitation of the singlet excited state of chlorophyll via interaction with the carotenoid, zeaxanthin in the light-harvesting antenna of photosystem II, thereby minimizing the deteriorious effects of high light via thermal dissipation of excess excitation energy (Demmig-Adams and Adams 1996; Niyogi *et al.* 2005).

The complementary relationships between Φ_{PSII} and *NPQ* on a wide range of growth conditions have been researched (Laisk *et al.* 1997; Melkonian *et al.* 2004). Gilmore (1997) suggested that *NPQ* is regulated in a complementary relationship as to keep the lifetime of excited states in PSII constant. Under severe stress conditions, however, a loss of complementary between *NPQ* and Φ_{PSII} may occur and can lead the formation of ROS and photo oxidative damage.

Photosynthetic responses and defense mechanisms of drought stressful plant have been researched by two main streams, stomatal limitation (Cornic 2000; Medrano *et al.* 2002) and non-stomatal limitations, which are metabolic impairments (Lawlor 2002). And it has been documented that stomatal closure is the earliest response and the dominant limitation to photosynthesis at mild to moderate drought. However, progressive down-regulation or inhibition of metabolic processes becomes the dominant limitation at severe drought (Flexas and Medrano 2002; Flexas *et al.* 2006).

On the mild and moderate drought conditions, the down-regulation of PSII predicted by Φ_{PSII} could occur slightly and the heat dissipation by *NPQ* could be gradually increased (Biehler *et al.* 1997; Lu and Zhang 1999; Osório *et al.* 2006; Praxedes *et al.* 2006). The reasons of no occurrence of large scale down-regulation of PSII from mild to moderate stress have been suggested on the cooperative operation of alternative electron sinks like as the *NPQ*, photorespiration (Foyer and Noctor 2000; Noctor *et al.* 2002), and the Mehler reaction (Asada 1999; Niyogi 2000; Ort and Baker 2002). However, when stress is severe, the decreases of Φ_{PSII} would occur distinctly (Souza *et al.* 2004; Miyashita *et al.* 2005; Correia *et al.* 2006; Lauriano *et al.* 2006). On the agricultural applications of fluorescence techniques, structural function index reflects the fraction of *NPQ* (SFI) as selection criteria in groundnut (Clavel *et al.* 2006) and the steady state chlorophyll fluorescence (F_s) as a useful tool for deciding irrigation time (Medrano *et al.* 2002) were suggested.

Salt stress, which is another serious abiotic stress in crop plants, showed very similar apparent symptoms with drought stress in early stage of stress (Bartels and Sunkar 2005). Munns (2002) documented that initial plant responses occurred within a few days under salty conditions came from the changes of cell water relations like as the responses of drought stress, and salt specific

effects of salty conditions were expected after a few days later. Therefore, chlorophyll fluorescence responses in salt stressed plants showed the similar patterns with those of drought stressed plants (Belkhdja *et al.* 1999; Muranaka *et al.* 2002; Kao *et al.* 2003; Netondo *et al.* 2004; Backhausen *et al.* 2005; Jiang *et al.* 2006; Stepien and Klobus 2006). Also salt tolerant cultivars or species showed stability in chlorophyll fluorescence under salt stress conditions in comparison with susceptible plants (Kao *et al.* 2003; Lee *et al.* 2004; Morant-Manceau *et al.* 2004; Demiral and Turkan 2006; S. M'rah *et al.* 2006; Yang *et al.* 2006).

In the previous experiment for screening environmental stress tolerant soybean cultivars breed in Korea, we found that Shinpaldalkong 2 is more drought tolerance than Taekwangkong on the apparent growth characteristics and the responses of chlorophyll fluorescence parameters. Therefore, the purposes of this experiment are to closely search the chlorophyll fluorescence parameter for screening tolerant cultivar and to find how different responses of photochemical and non-photochemical quenching in tolerant soybean occur under moderate osmotic stress conditions. The reasons for using two different stressors, drought and salt, as osmotic treatments were that (1) the control of moderate drought condition in pot would not easy by withholding or restriction of watering because plant wilting instantly accelerated around the wilting point, (2) drought treatment by restricted water supply could induce a mild osmotic stressful condition, and (3) salt treatments could induce the moderate osmotic stressful condition within a few days without salt specific effects (Munns 2002).

Materials and methods

Plant. Two soybean cultivars, Shinpaldalkong 2 (an osmotic-tolerant) and Taekwangkong (a control), distributed from National Institute of Crop Science, RDA, Korea were planted in 1.5L plastic pot with soil mixtures of loam : sand : horticultural bed soil of 1 : 1 : 1 by volume. The sowing was done 4 seeds per pot and 2 plants per pot were thinned at 2 weeks after sowing. The soybean plants were grown at greenhouse of Department of Plant Resources, Hankyong National University with ambient temperature and humidity condition. Before drought and salt treatments were done, water supplied every 2 times per day, 10 am and 4 pm, without water stress. Four weeks

old soybean plants with four nodes and fully developed trifoliolate on the third node were treated with drought and salt stress. Drought stress was done by the restricted irrigation with 2 levels, 50 (drought plant) and 200 ml pot⁻¹ day⁻¹ (control plant) for 5 days. Salt treatment was imposed by soaking of NaCl solution with 200 mmol at bottom part of pot for 6 days. The salt solutions were refreshed everyday.

For measurements of leaf water content, leaf water potential and chlorophyll a and b, and carotenoids content, leaf samples were collected at fully developed trifoliolate with 3 replications. The leaf water content was determined by dry method in 75 °C for 2 days. The leaf water potential was measured by dew point and wet bulb methods using a HR-33T dew point microvoltmeter with C-52 sample chamber (Wescor, US) in the same leaf of water content determination. The chlorophyll was extracted in 80% chilled acetone and quantified spectrophotometrically. Chlorophyll a, b and carotenoids were determined at wavelength 663 nm, 648 nm, and 470 nm, respectively, following Lichtenthaler (1987).

The CO₂ assimilation rate and chlorophyll fluorescence were analyzed at the same intact leaf, fully developed middle leaf of trifoliolate. The CO₂ assimilation rate was measured using portable CO₂ analyzer (LCi, ADC, UK) under light intensity of 500 μmol s⁻¹ m⁻² of halogen light condition. The chlorophyll fluorescence was analyzed using a chlorophyll fluorescence imaging analyzer (FluorCam 700 MF imaging fluorometer, Brno, Czech Republic) with modulated fluorescence mode. Minimum fluorescence (F_0) was measured on dark-adapted leaves for 30 min by exposing to actinic light of orange LED with 200 μmol s⁻¹ m⁻² and 0.8 s pulse of saturating halogen light 2,500 μmol s⁻¹ m⁻² was applied to measure maximum fluorescence (F_m). For induction of fluorescence kinetics under light conditions, saturating light of 0.8 s were applied 5 times every 15 sec under actinic light condition. After illumination, maximum fluorescence of light-adapted leaves (F_m'), steady-state fluorescence (F_s) and minimum fluorescence of light-adapted leaves (F_0') were recorded. The following equations were used for calculating photosynthetic parameters: Maximum quantum efficiency of PSII photochemistry, $F_v/F_m = (F_m - F_0) / F_m$; Quantum efficiency of PSII photochemistry, $\Phi_{PSII} = (F_m' - F_s) / F_m'$ (Gentry *et al.* 1989); non-photochemical quenching, $NPQ = (F_m / F_m') - 1$ (Bilger and Björkman 1990).

Results

In drought treatments for 5 days, leaf water potentials recorded the ranges of -0.3 to -0.6 MPa in Shinpaldalkong 2, and -0.2 to -0.8 MPa in Taekwangkong (Fig. 1). Those of salt treatment referred a markedly decrease of leaf water potentials from about -0.7 to -1.7 MPa for 6 days in both cultivars. However, there was no difference between two cultivars on leaf water potential by two osmotic treatments. On the other hand, the leaf water content was different between cultivars by salt treatment (Fig. 2). Leaf water content was more decreased in Taekwangkong from 81.6 to 77.1% than in Shinpaldalkong 2 from 81.0 to 78.2% by salt treatment. Therefore, the decreasing rate of leaf water content to leaf water potential in salt stressful condition was smaller in Shinpaldalkong 2 than Taekwangkong. The apparent withering symptom of leaves

was found only in Taekwangkong at the 6th day after salt treatment (Result not shown here).

The chlorophyll a and b contents were increased by drought and decreased by salt treatment in both cultivars (Fig. 3). The ratios of chlorophyll a to b in both cultivars were lower slightly by salt treatment compared with those of control and drought treatment without cultivar difference. Carotenoids contents and the ratios of carotenoids to chlorophylls were also lower by salt treatment in both cultivars. On the comparison of cultivar, Shipaldalkong 2 showed smaller changes of chlorophyll, carotenoids contents and their ratios than Taekwangkong by two osmotic treatments.

The CO₂ assimilation rates (P_N) were decreased steeply under salt treatment on the below -1.0 MPa of water potential in both cultivars (Fig. 4-A, B). However, Shinpaldalkong 2 showed the tendency of high CO₂ assimilate rates than Taekwangkong on the entire ranges

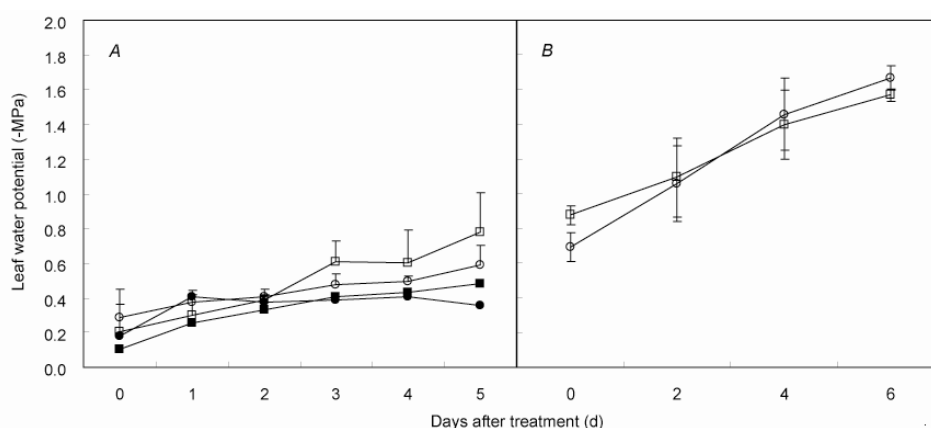


Fig. 1. Changes of leaf water potentials of two soybean cultivars, Shinpaldalkong 2 (circle) and Taekwangkong (square) of (A) control (closed) and drought (open); and (B) salt treatment. Bars represent SE ($n = 3$).

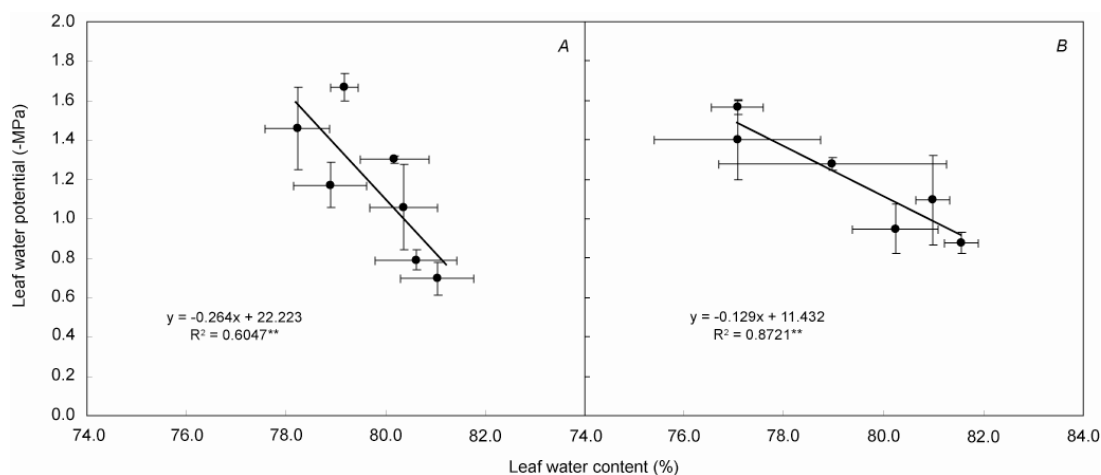


Fig. 2. Relationships between leaf water content and leaf water potential of two soybean cultivars, Shinpaldalkong 2 (A) and Taekwangkong (B), of salt treatment. Bars represent SE ($n = 3$).

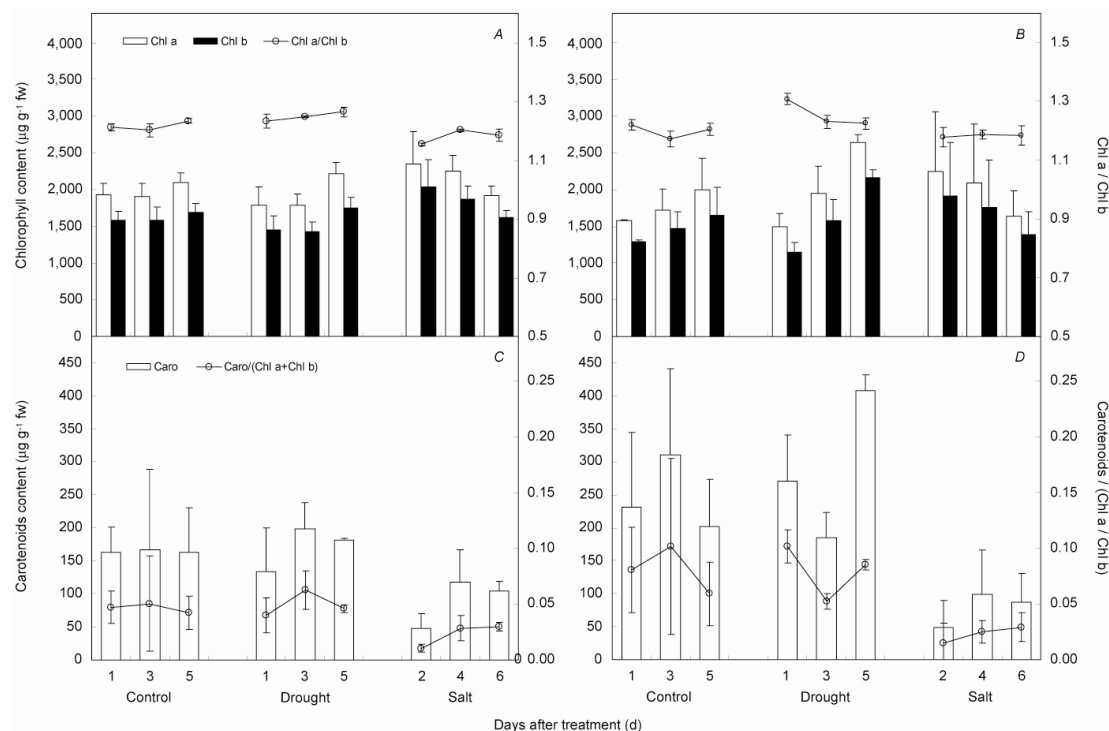


Fig. 3. Changes of chlorophyll a and b content, and the ratio of chlorophyll a to b (A,B), and carotenoids content and the ratio of carotenoids to chlorophyll a+b (C,D) of two soybean cultivars, Shinpaldalkong 2 (A,C) and Taekwangkong (B,D), with control, drought and salt treatment. Bars represent SE ($n = 3$).

of water potential. The F_v/F_m values, maximum quantum efficiency of PSII photochemistry, of two cultivars were so stable on the entire ranges of water potential that the decreasing could not occur even at late periods of salt treatment around -1.5 MPa of water potential (Fig.4-C, D). The Φ_{PSII} values, quantum efficiency of PSII photochemistry, of two cultivars showed slight decreasing on the below -1.0 MPa of water potential (Fig.4-E, F), which was smaller than the decrease of PN. There were found no significant differences between cultivars on F_v/F_m , Φ_{PSII} and P_N by osmotic treatments. The NPQ , non-photochemical quenching, of Shinpaldalkong 2 was shown the range from about 0.2 to 0.8, while those of Taekwangkong were distributed widely from 0.2 to 1.2 under drought treatment (Fig.4-G, H). Under salt treatment on the below of -1.0 MPa water potential, however, the increasing of NPQ was occurred only in Shinpaldalkong 2 except Taekwangkong.

The cultivar differences of chlorophyll fluorescence parameters were found clearly in the relationships between Φ_{PSII} and P_N and between NPQ and Φ_{PSII} . The positive relationships between P_N and Φ_{PSII} were revealed under all osmotic treatments in both cultivars (Fig. 5). However, the decreasing rate of Φ_{PSII} to P_N was higher in Taekwangkong than Shinpaldalkong 2. The negative or

complementary relationships between Φ_{PSII} and NPQ were established at all treatments except salt treatment of Taekwangkong (Fig. 6). Especially, all measured NPQ values in Shinpaldalkong 2 were aligned well on the complementary relationships between Φ_{PSII} and NPQ regardless of stressors. In Taekwangkong, however, the NPQ of salt treatment showed the deviation from the complementary relationships of control and drought treatment.

Discussion

As osmotic stresses cause a visual symptom of withering on soybean leaves, it has been suggested that an analysis of chlorophyll fluorescence parameters determines photosynthetic metabolism disorders prior to visible symptoms under stressful condition (Baker and Rosenqvist 2004) and it may provide an easy, fast detection method for plants suffering osmotic stresses. The relationships between leaf water potential and water content under salt treatment (Fig. 1 and 2) confirmed that Shinpaldalkong 2 was an osmotic stress tolerant cultivar. It is likely for Shinpaldalkong 2 to possess high ability of water holding and/or solute accumulation within cells

under osmotic stress compared to a non-tolerant cultivar. Analyses of chlorophylls and carotenoids showed that different cultivars responded differently against the osmotic stresses (Fig. 3). The content of carotenoids and the ratio of carotenoids to chlorophylls were less affected in Sinpaldalkong 2 than in Taekwangkong by salt treatments. These results indicate that carotenoids meta-

bolisms in Shinpaldalkong 2 were more stable than those in Taekwangkong under the osmotic stresses (Jung 2004; Demiral and Turkan 2006; M'rah *et al.* 2006). The carotenoids, especially Zeaxanthin, involved in *NPQ* mechanism have been well documented (Demmig-Adams and Adams 1996; Havaux 1998; Niyogi *et al.* 2005; Demmig-Adams and Adams 2006).

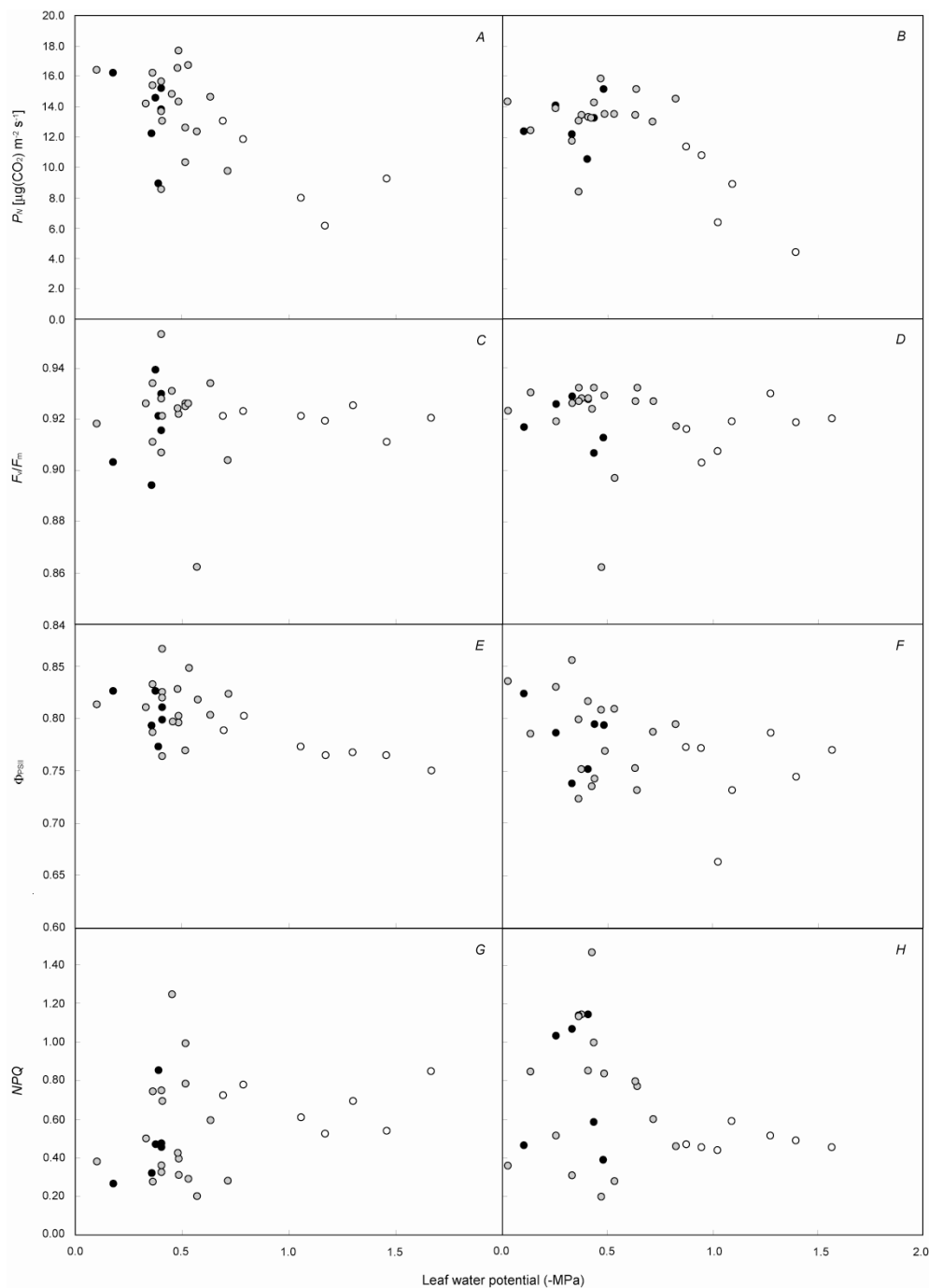


Fig. 4. Relationships between leaf water potential and CO_2 assimilation rate (P_N) (A,B) and maximum quantum efficiency of PSII photochemistry (F_v/F_m) (C,D) and quantum efficiency of PSII photochemistry (Φ_{PSII}) (E,F) and non-photochemical quenching (NPQ) (G,H) of two soybean cultivars, Shinpaldalkong 2 (A,C,E,G) and Taekwangkong (B,D,F,H), with control (closed), drought (gray) and salt treatment (open).

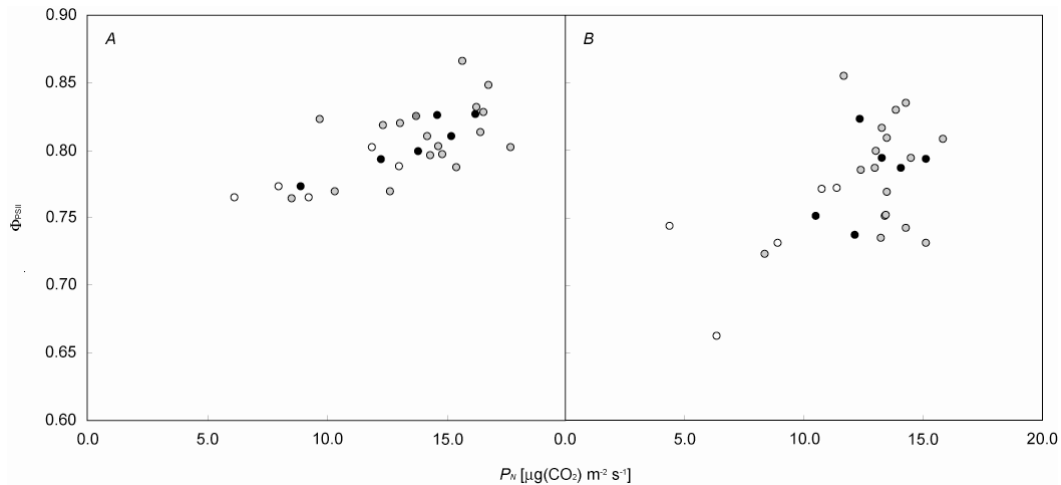


Fig. 5. Relationships between CO_2 assimilation rate (P_n) and quantum efficiency of PSII photochemistry (Φ_{PSII}) of two soybean cultivars, Shinpaldalkong 2 (A) and Taekwangkong (B), with control (closed), drought (gray) and salt treatment (open).

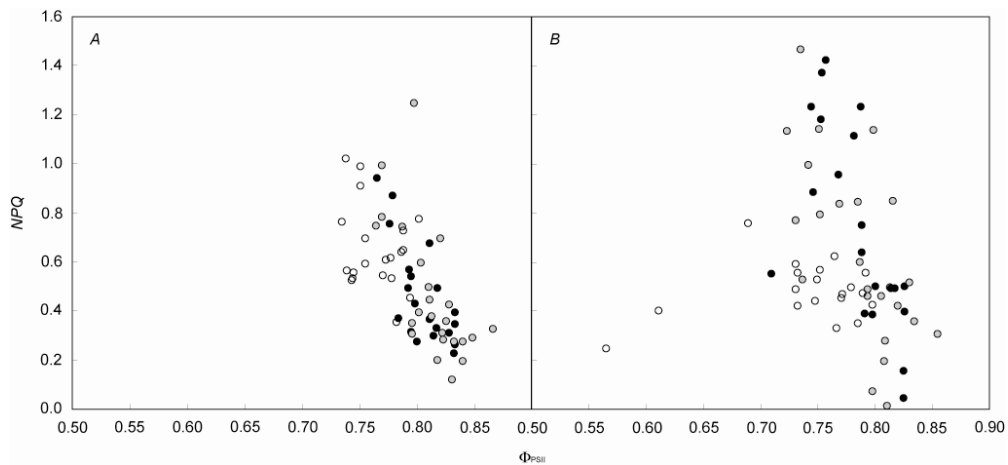


Fig. 6. Relationships between quantum efficiency of PSII photochemistry (Φ_{PSII}) and non-photochemical quenching (NPQ) of two soybean cultivars, Shinpaldalkong 2 (A) and Taekwangkong (B), with control (closed), drought (gray) and salt treatment (open).

The single analysis of chlorophyll fluorescence parameters does not give a clue to screen cultivars in relation to osmotic stress (Fig. 4). The F_v/F_m and Φ_{PSII} values showed no significant difference between cultivars in relation to moderate osmotic stress (Kao, *et al.* 2003; Kocheva *et al.* 2004; Souza *et al.* 2004; Miyashta *et al.* 2005; Yang *et al.* 2006).

The stability of PSII photochemical reactions under osmotic stressful conditions have been resulted from the cooperative operations of alternative electron sinks like as NPQ, photorespiration (Foyer and Noctor 2000; Noctor *et al.* 2002), and the Mehler reaction in case of the block of CO_2 assimilation (Asada 1999; Cornic and Fresneau 2002; Niyogi 2000; Ort and Baker 2002; Lawson *et al.* 2002). In our experiments, the down-regulation of PSII in soybean

plants occurred below -1.0MPa of leaf water potential (Fig. 4). This result is similar to the previous results including sunflower (Correia *et al.* 2005), wheat (Lu and Zhang 1999; Muranaka *et al.* 2002), barley (Belkhdja *et al.* 1999; Jiang *et al.* 2006), sorghum (Netondo *et al.* 2004), kidney bean (Miyashta *et al.* 2005), cowpea (Souza *et al.* 2004), tomato (Biehler *et al.* 1997), potato (Backhausen *et al.* 2005), cucumber (Stepień and Klobus 2006), nectarine tree (Osório *et al.* 2006) and coffee (Praxedes *et al.* 2005).

The cultivar difference in the relationships between Φ_{PSII} to CO_2 assimilation rate was detected (Fig. 5). The smaller variation range of Φ_{PSII} to leaf water potential (Fig. 4) and the less decrease in Φ_{PSII} to CO_2 assimilation rate in Shinpaldalkong 2 (Fig. 5) indicates that the down-

regulation of PSII mechanism was more stable, resistant in Shinpaldalkong 2 than Taekwangkong against osmotic stress (Maury *et al.* 1996; Colom and Vazzana 2003; Kao *et al.* 2003; Lee *et al.* 2004; M'rah *et al.* 2006; Yang *et al.* 2006). Although it would be required an additional determination for CO₂ assimilation rate, our results demonstrated that the relationships between Φ_{PSII} and CO₂ assimilation rate could be as an available parameter on screening of osmotic stress-tolerant ability in plants.

According to the decrease of Φ_{PSII} by osmotic treatments, the *NPQ* was increased complementarily in both cultivars (Fig. 6). Our *NPQ* data showed very interesting results that *NPQ* of Taekwangkong was increased only at control and drought treatment except salt treatment. In the case of Shinpaldalkong 2, however, the *NPQ* was also increased at salt treatment (Fig. 4). Therefore, it indicates that the heat dissipation of excessive light energy is operated normally in the osmotic-resistant cultivar under moderate osmotic stress (Biehler *et al.* 1997; Belkhdja *et al.* 1999; Jung 2004; Netondo *et al.* 2004; Backhausen *et al.* 2005; Clavel *et al.* 2006; Stepień and Klobus 2006; Yang *et al.* 2006).

Response with *NPQ* between different cultivars and the complementary relationship between Φ_{PSII} and *NPQ* were different between stress tolerant and non-tolerant cultivar (Fig. 6). Laisk *et al.* (1997) suggested that relationship between the yields of photochemical (ϕ_{PSII}) and total non-photochemical processes (ϕ_{NPQ}) was both linear and complementary under a wide range of growth conditions except severe stress, and the sum of ϕ_{NPQ} and ϕ_{PSII} was constant (≈ 0.8). Melkonian *et al.* (2004) were also demonstrated the complementary relationship ϕ_{PSII} and ϕ_{NPQ} in chilling treated bean (*Phaseolus vulgaris*). However, the complementary relationship between ϕ_{NPQ} and ϕ_{PSII} could be lost under severe stress conditions (Gilmore 1997; Laisk *et al.* 1997). Although our Φ_{PSII} and *NPQ* values were not recalculated to ϕ_{PSII} and ϕ_{NPQ} , the complementary relationships between Φ_{PSII} and *NPQ* in two soybean cultivars is similar to the result reported by Melkonian *et al.* (2004). The relationships have been well maintained regardless of stressors in Shinpaldalkong 2, not in the non-tolerant cultivar under salt treatment.

In conclusion, our results suggest that analysis of complementary relationship between Φ_{PSII} and *NPQ* could be more valuable and applicable for screening osmotic tolerance in soybean plant under the osmotic stressful

condition than single analysis of each chlorophyll fluorescence parameter, F_v/F_m , Φ_{PSII} and *NPQ*.

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콩의 삼투 저항성 검정에 있어서 Non-photochemical quenching의 적용

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한발과 염 스트레스에 대한 콩의 저항성 검정에 있어서 Non-photochemical quenching (NPQ)을 적용하기 위하여, 저항성 콩 (신팔달콩 2호)와 대조구 콩 (태광콩)을 이용하여 제한적 관수 (50 m/pot/day)와 염 (200 mmol NaCl) 처리를 한 후, 엽록소 형광반응의 변수, maximum efficiencies of photosystem II photochemistry (F_v/F_m), efficiencies of photosystem II photochemistry (Φ_{PSII}), NPQ와 CO₂ 동화율 (P_N)을 측정하였다. 콩 두 품종의 엽 수분포텐셜은 한발처리에서 -0.2 MPa에서 -0.8 MPa로, 염처리에서는 -0.7 MPa에서 -1.7 MPa로 감소하였다. 염처리에서 엽 수분함량의 감소는 신팔달콩 2호에서 적었다. 두 품종 모두 엽의 수분포텐셜이 감소함에 따라 F_v/F_m 은 변화가 없었으며, Φ_{PSII} 와 P_N 는 감소하였다. NPQ의 경우, 신팔달콩 2호는 한발과 염처리에 모두에서 반응이 나타난 반면, 태광콩에서는 한발처리에서만 나타났다. 두 품종의 모든 처리에서 Φ_{PSII} 와 P_N 간에 정의 상관 관계를 보였으나, P_N 의 감소에 대한 Φ_{PSII} 의 감소 정도가 신팔달콩 2호에서 적었다. 또한 삼투처리에 따른 Φ_{PSII} 의 감소와 NPQ의 증가는 신팔달콩 2호에서만 나타나 Φ_{PSII} 와 NPQ 간의 부의 관계가 유지된 반면, 태광콩에서는 염처리에서 이들간의 연관성이 없었다. 따라서 본 연구는 삼투 저항성의 검정에 있어서 엽록소 형광반응의 단일변수(F_v/F_m , Φ_{PSII} , 및 NPQ)의 이용보다 Φ_{PSII} 와 NPQ의 상호관계 분석이 더 유효한 것을 제시하였다.

중심어 : Non-photochemical quenching, 엽록소 형광, 삼투스트레스, 콩