Effects of Water Stress by PEG on Growth and Physiological Traits in Rice Seedlings

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ABSTRACT : This study was conducted to evaluate the drought tolerance of Japonica and Indica rice cultivars during germinating and seedling stages by using the polyethylene glycol (PEG) solution. Each 5 cultivars of Japonica and Indica were cultured from 14 days after seeding (DAS) to 21 DAS using the PEG solution in a moderate water potential (-0.63 MPa). The lengths of radicle and plumule during the germinating stage were inhibitied by the PEG treatment to about 50% and 85%, respectively. The application of PEG to the seedling of two rice types caused to inhibit the plant height and leaf age about 23% and 10%, respectively. Shoot and root dry weights by PEG treatment were inhibited more severely in Japonica than those in Indica. The difference on delaying of leaf area expansion between both rice types was not found with treatment of PEG, while the leaf color was increased in both Japonica and Indica by 19.9% and 9.2%, respectively. The average photosynthetic ability was inhibited more in Japonica to 36.0% than did Indica to 27.9%. The stomatal conductance was severely affected by PEG treatment, and the degree was varied in both rice types, ranged with 80~85% in Japonica and 29.3~81.6% in Indica. These results indicate there is little relationship between seed germination and seedling growth under the stress of low water potential.

Keywords : drought, growth, polyethylene glycol, rice, low water potential.

Drought stress or insufficient water supply is one of most important limiting factors in world rice production. In Korea, most of rice has been cultivated in paddy field. Drought injury was sometimes occurred during the seedling stage of rice particularly in dry direct seeding culture due to low soil water potential. Recently, upland rice cultivation without an adequate irrigation system has been increased in southern area of Korea as a following crop of onion and garlic. The improvement of drought resistance for the high yielding rice cultivars for upland or insufficient water supply areas is a priority goal of rice breeders since upland rice relies exclusively on rainfall and has generally had low yielding (Fukai and Cooper, 1996; Price *et al.*, 1997).

In studies of plant responses to water deficit, low water potential is often imposed by the reducing the supply of water into the soil or other solid media in which a plant is growing. Seeding in dry soil often results in poor seedling stands or slower seedling development (Ahmad *et al.*, 1987; Lee *et al.*, 1993). Often, the lack of moisture could be continued after the seeds were germinated, and the seedlings are injured by dehydration, such as emergence is prolonged and seed reserves might be depleted before the shoot reaches the soil surface (Guedira *et al.*, 1997). Low soil water potential might also reduce the photosynthetic rate by the closure of stomata on leaf (Brix, 1962).

Screening for drought tolerance in hydrophonic culture at seedling stage may lead to effective rice breeding. Many experiments have been used osmotica such as PEG, mannitol, sorbitol or inorganic salts, in solution culture to impose low water potential (Hohl and Schopfer, 1991; Termaat and Munns 1986). Among them, the PEG which can not penetrate the cell wall pores is often used to impose low water potentials in solution culture (Verslues *et al.* 1998). Studies with rice (Hasio *et al.*, 1984; Lu and Neumann, 1999) and soybean (Itube-Ormaetxe *et al.*, 1998) show that PEG stress mimics water stress and may be an useful tool for screening of drought tolerance cultivars and for examining on mechanic basis of plant responses to water stress.

The objective of this study was to ascertain the effect of PEG treatment on seedling growth and to evaluate the drought tolerance of rice cultivars among Japonica and Indica and their relationships between the germinating and seedling stages.

MATERIALS AND METHODS

In a preliminary experiment, the plumule and radicle length of most rice cultivars were severely inhibited in a 19.5% PEG solution (-0.86 MPa in water potential), while the largest cultivar difference was observed in a 15.0% solu-

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tion of PEG solution (-0.63 MPa). Therefore, we used 15.0% PEG (mw. 1500; Aldrich Chemical Co.) to evaluate growth and physiological traits of rice in this study. Also, as the result of the preliminary experiment, five cultivars of Japonica and Indica showing the various damaged degree in the length of radicle and plumule were selected among 20 Japonica and 9 Indica cultivars tested.

PEG stress at germinating stage

Ten seeds of each cultivar placed in a petridish (ϕ9 cm) which filled with 5 ml of PEG dissolved solution to impose low water potential. And the planted seeds were cultured for 4 days in an incubator under 30°C air temperature. At 4 days after seeding, lengths of the radicle and plumule were determined.

PEG stress at seedling stage

The pregerminated seeds of each cultivar planted on nylon mesh attached 10 holes of styron forme which covered on the plastic container (L × W × H; 40 cm × 30 cm × 20 cm). The container was filled with Yoshida's nutrient solution (Yoshida *et al.*, 1976) upto nylon mesh so that seeds were suspended slight above the solution. The pH of solution was adjusted to 4.5 from seeding to 14 DAS, thereafter it was maintained to about 5.0 using the HCl and NaOH solution. The plants were grown under controlled air temperature conditions (day/night: 29/21°C) in a phytotron room at International Rice Research Institute (IRRI). The seedlings cultured for two weeks without PEG were transferred to dissolved PEG solution and cultured for another week. Thereafter, the cultured plants in PEG solution were transferred in water culturing solution for rehabilitation and cultured for one week (until 28 DAS) to compare the differences on recovery degrees among the cultivars. For the measurement the plant sampling were done at 21 DAS (end of PEG treatment for one week) and at 28 DAS (rehabilitation for one week). Upon recording the plant height and leaf age of 20 plants, the leaf color was measured by a chlorophyll meter (SPAD 502, Minolta, Japan) and then leaf area was also measured with the detached leaf blades using an automatic leaf area meter (Li-Cor, USA). The dry weight of shoot and root were examined after drying for 48 hours at 70°C. The photosynthetic rate and stomatal conductance were determined on fully developed top leaf by a CO_2 measuring machine(LI-6400, Li-Cor, USA).

RESULTS AND DISCUSSION

Radicle and plumule effects by PEG

At the germinating stage of rice, average radicle and plumule lengths were longer in Indica in both the control and the PEG treatment than those in Japonica, showing that their lengths were much shorter with treatment of PEG compared to those of the control.

It seems that PEG treatment would reduce the length of radicle and plumule. The plumule length of all cultivars was clearly shorter than did the radicle length. The average inhi-

Table 1. Cultivar differences on radicle and plumule lengths as stressed by PEG for 4 days at germinating stage of rice.

Cultivar	Radicle length			Plumule length		
	Control	PEG treatment	Inhibition rate†	Control	PEG treatment	Inhibition rate
	-----mm-------		%	-------mm------		%
Japonica						
Iksan 438	48.9 ± 9.9	34.1 ± 8.6	30.3	19.1 ± 3.8	4.5 ± 1.1	76.4
Hwasambyeo	57.0 ± 8.3	29.5 ± 3.8	48.2	16.3 ± 0.7	2.9 ± 0.7	82.2
Daeanbyeo	43.1 ± 6.3	24.0 ± 4.3	44.3	15.3 ± 1.2	2.3 ± 0.4	85.0
Geumnambyeo	29.9 ± 2.9	12.4 ± 1.7	58.5	11.7 ± 0.9	1.3 ± 0.2	88.9
Sangnambatbyeo	40.8 ± 10.4	6.9 ± 1.0	83.1	9.8 ± 3.4	0.9 ± 0.2	91.8
Average	43.9	21.4	52.9	14.4	2.4	84.9
Indica						
Ifugao Rice	81.4 ± 10.1	57.7 ± 4.1	29.1	38.6 ± 4.1	7.7 ± 1.0	80.1
NSG 19	68.0 ± 4.2	28.3 ± 5.2	58.4	41.8 ± 6.1	5.6 ± 2.5	86.6
KDML 105	49.2 ± 3.2	22.0 ± 6.0	55.3	26.7 ± 3.4	2.1 ± 1.4	92.1
IR 20	47.7 ± 5.2	22.5 ± 2.1	52.8	23.7 ± 2.9	3.8 ± 0.4	84.0
IR 52	47.4 ± 8.1	25.3 ± 8.0	46.6	23.3 ± 2.0	3.0 ± 1.4	87.1
Average	58.7	31.2	48.4	30.8	4.4	86.0

†Inhibition rate (%)=(Control-After PEG treatment (or After rehabilitation))/Control × 100

bition of radicle length by PEG treatment was slightly higher in Japonica (52.9%) than that in Indica (48.4%), but the inhibition rate of plumule length was similar between both rice types. Among the Japonica, the highest growth inhibition of both radicle and plumule lengths were in Sangnambatbyeo of an upland cultivar, especially on radicle.

Growth and physiological effects by PEG at seedling stage

Effects of PEG and rehabilitation treatments on plant length and leaf age were shown in Table 2. Both of average inhibition rates after PEG and rehabilitation treatments in plant height were similar in both rice types. In the Japonica type cultivars, the plant height was inhibited the highest in Sangnambatbyeo and the lowest in Hwasambyeo with treatment of PEG, while the recovery degree due to rehabilitation treatment was the highest in Daeanbyeo. On the other hand, all cultivars of Indica responded similarly to the PEG and the rehabilitation treatments with respect to plant height.

The inhibitory effect in leaf age by PEG treatment was relatively lower than those of other growth parameters, such that the ratio of leaf age on PEG treated plants versus the control was ranged in 3.317.5 % in Japonica and in 8.713.1 % in indica. According to rehabilitation treatment, most of rice cultivars, except for Hwasambyeo of the Japonica, and Ifugao rice, NSG 19 and IR 20 of the indica, were recovered like those of their control.

In the Japonica type, the inhibitory degree on shoot dry weight by PEG treatment was the highest on Sangnambatbyeo and the lowest on Iksan 438, while in the Indica, it was the highest on IR 20 and lowest on IR 52. The recovery degree on shoot dry weight by rehabilitation compared to the control was about 15% in the Japonica caltivars, except for Sangnambatbyeo (26.0%), and about less than 10% in the Indica cultivars, except NSG 19 (22.0%). Therefore, the inhibitory degrees on shoot dry weight by PEG treatment and the recovery degree were higher in Kaponica than in those Indica.

As shown in Table 3, the root growth in dry weight by PEG treatment was inhibited more in Japonica (45.1%) than in Indica (31.1%), the severest on Hwasambyeo (67.3%) in Japonica. In the Indica type cultivars, the inhibitory degree was relatively higher on NSG 19 and IR 20, while lower on KDML 105 and Ifugao. The recovery degree was severely low on Sangnambatbyeo in Japonica, and NSG 19 in Indica. The recovery degree on both dry weight of shoot and root showed above 100% in some cultivars compared to the control, because their tillering was accelerated by rehabilitation treatments. Yoshida and Hasegawa (1982) reported that the recovery of drought stressed plants was lower in upland cultivar than that in paddy cultivar, which was not consistent with their drought tolerance. In this study, an upland cultivar, Sangnambatbyeo, was also shown to be severely injured by PEG treatment and it's recovery degree was also lower than other cultivars. The inhibition rates on shoot and root dry weight after both PEG and rehabilitation treatments were higher in Indica than in Japonica.

These differences between two rice types were similar to the result by Choi and Park (1980) who reported that the recovery degree in leaf number of water stressed plants by rewatering was higher in Indica than that in Japonica. And Oka and Rho (1957) also reported that the drought tolerance was stronger in Indica than in Japonica.

Average leaf area of both rice types was inhibited similarly to about 46%. The inhibition on leaf area was less in Hwasambyeo and Iksan 438 in the Japonica than KDML 105 and IR 20 in the Indica (Table 4). The recovery degree was higher in Daeanbyeo and Kuemnambeyo in Japonica. In the Indica, the IR 20 and IR 52 were recovered similar to the control, but others were inhibited up to 22% 36% compared to the control.

The chlorophyll content measured with the SPAD meter was increased by PEG treatment, and its content was higher in Japonica that in Indica (Table 4). After the rehabilitation treatment, the chlorophyll content of the Japonica cultivar between the PEG treatment and was similar, while the Indica cultivars had a lower chlorophyll content in the PEG treatment than those in the control.

The effects on photosynthetic rate and stomatal conductance of rice plant with both the PEG and the rehabilitation treatments were shown in Table 5. The average photosynthetic rate was inhibited more with treatment of PEG in Japonica (36.0%) than that in Indica (27.9%). The inhibition degree was the highest in Iksan 438(46.8%), but the lowest in Hwasambyeo (25.0%) in the Japonica, while in the Indica, it was the highest in NSG 19 (39.8%), but the lowest in IR 52(11.8%). After the rehabilitation treatment, the photosynthetic rate of Daeanbyeo and Sangnambatbyeo in the Japonica was higher compared to that of the control, but it of Hwasambyeo was inhibited to about 25.7% compared to the control. On the other hand, the photosynthetic rate of the Indica cultivars after recovery showed a trend to increase, except for IR 20 to be inhibited to about 9.9%. Its average recovery degree was higher in Indica than that in Japonica.

Average stomatal conductance in the unstressed plant was slightly higher in Japonica than in Indica, but this result was not consistent with the rasearch result of Maruyama and Tajima (1990), who reported that the leaf conductance at maturing stage was higher in Indica and Indica-Japonica hybrid than in Japonica. The stomatal conductance was severely affected by PEG treatment, and the degree was var-

Table 2. Difference of plant length and leaf age as stressed by PEG treatment and their recovery degree after rehabilitation in japonica and indica cultivars.

Cultivar	Plant height						Leaf age					
	Cont.	After PEG treat.[†]	In.[‡]	Cont.	After rehabil. treat.[§]	In.	Cont.	After PEG treat.	In.	Cont.	After recovery	In.
Japonica	------cm------		%	-----cm------		%	-----cm-----		%	-----cm-----		%
Iksan 438	41.8 ± 2.9	34.6 ± 1.5	17.2	46.6 ± 4.6	37.8 ± 4.6	18.9	6.1 ± 0.1	5.8 ± 0.1	4.9	7.0 ± 0.1	6.9 ± 0.7	1.4
Hwasambyeo	41.4 ± 1.5	34.8 ± 1.1	15.9	48.9 ± 1.2	40.3 ± 2.4	17.6	6.1 ± 0.1	5.9 ± 0.1	3.3	7.4 ± 0.5	6.7 ± 0.4	9.5
Daeanbyeo	45.3 ± 15.7	34.0 ± 1.0	24.9	50.5 ± 1.2	36.0 ± 1.2	28.7	6.6 ± 0.5	5.8 ± 0.4	12.1	7.6 ± 0.5	7.6 ± 0.1	0
Geumnambyeo	47.5 ± 1.0	35.8 ± 1.6	24.6	54.2 ± 1.5	44.9 ± 3.5	17.2	6.3 ± 0.6	5.2 ± 0.1	17.5	7.0 ± 0.4	6.9 ± 0.1	1.4
Sangnambatbyeo	51.3 ± 2.3	35.4 ± 1.5	31.0	60.4 ± 2.1	44.1 ± 6.9	27.0	6.0 ± 0.0	5.4 ± 0.2	10.0	6.9 ± 0.1	6.8 ± 0.3	1.4
Average	45.5	34.9	23.3	52.1	40.6	22.1	6.2	5.6	9.7	7.2	7.0	2.8
Indica												
Ifugao Rice	61.2 ± 1.5	45.6 ± 2.2	25.5	73.6 ± 3.4	57.5 ± 4.6	21.9	6.6 ± 0.1	5.9 ± 0.1	10.6	7.6 ± 0.2	7.6 ± 0.4	0
NSG 19	61.0 ± 2.1	47.0 ± 1.6	23.0	72.9 ± 1.1	59.5 ± 2.4	18.4	6.9 ± 0.1	6.0 ± 0.1	13.0	7.7 ± 0.2	7.7 ± 0.3	0
KDML105	55.5 ± 1.7	43.3 ± 1.8	22.0	70.7 ± 1.6	56.3 ± 6.5	20.4	6.7 ± 0.1	6.1 ± 0.2	9.0	7.4 ± 0.3	7.1 ± 0.1	4.1
IR 20	31.9 ± 0.7	25.7 ± 1.1	19.4	36.6 ± 1.0	28.1 ± 2.4	23.2	6.1 ± 0.1	5.3 ± 0.1	13.1	6.6 ± 0.3	6.6 ± 0.1	0
IR 52	46.7 ± 1.0	35.4 ± 2.0	24.2	53.9 ± 2.7	41.9 ± 2.5	22.3	6.9 ± 0.9	6.3 ± 0.5	8.7	7.7 ± 0.2	7.4 ± 0.1	3.9
Average	51.3	39.4	23.2	61.5	48.7	20.8	6.6	5.9	10.6	7.4	7.3	1.4

[†]The plants were imposed by PEG dissolved solution (15.0%) from 14 DAS to 21 DAS.
[‡]Inhibition rate (%)=(Control-After PEG treatment (or After rehabilitation))/Control × 100
[§]The investigation of recovery degree by rehabilitation treatment was done at 7 days (28 DAS) after removing the stressed plants to hydroponic solution without PEG.

Table 3. Difference in dry weights of shoot and root stressed by PEG treatment and their recovery after rehabilitation treatment in japonica and indica cultivars.

Cultivar	Shoot dry weight						Root dry weight					
	Cont.	After PEG Treat.	In.[†]	Cont.	After recovery	In.	Cont.	After PEG Treat.	In.	Cont.	After recovery	In.
Japonica	----g/3plants----		%	----g/3plants----		%	----g/3plants----		%	----g/3plants----		%
Iksan 438	0.38 ± 0.13	0.25 ± 0.08	32.9	0.65 ± 0.19	0.55 ± 0.36	15.4	0.10 ± 0.07	0.06 ± 0.04	37.3	0.13 ± 0.07	0.15 ± 0.08	-14.4
Hwasambyeo	0.39 ± 0.07	0.25 ± 0.06	35.1	0.57 ± 0.10	0.48 ± 0.06	14.7	0.17 ± 0.09	0.06 ± 0.03	67.3	0.12 ± 0.03	0.09 ± 0.05	26.9
Daeanbyeo	0.45 ± 0.09	0.24 ± 0.08	46.5	0.62 ± 0.08	0.54 ± 0.26	12.7	0.10 ± 0.06	0.07 ± 0.03	27.7	0.10 ± 0.04	0.11 ± 0.06	-7.9
Geumnambyeo	0.32 ± 0.05	0.16 ± 0.04	49.8	0.61 ± 0.07	0.52 ± 0.07	14.3	0.06 ± 0.04	0.04 ± 0.04	34.5	0.08 ± 0.02	0.12 ± 0.03	39.3
Sangnambatbyeo	0.42 ± 0.09	0.18 ± 0.04	57.1	0.63 ± 0.08	0.46 ± 0.06	26.0	0.13 ± 0.06	0.08 ± 0.05	40.3	0.21 ± 0.02	0.10 ± 0.06	53.2
Average	0.39	0.218	44.4	0.61	0.512	16.6	0.113	0.062	45.1	0.128	0.112	12.5
Indica												
Ifugao Rice	0.59 ± 0.03	0.33 ± 0.14	43.3	0.93 ± 0.13	0.85 ± 0.08	8.6	0.16 ± 0.03	0.13 ± 0.01	16.0	0.30 ± 0.09	0.28 ± 0.07	7.3
NSG 19	0.66 ± 0.15	0.38 ± 0.12	42.8	1.07 ± 0.12	0.83 ± 0.41	22.0	0.18 ± 0.05	0.10 ± 0.02	46.7	0.30 ± 0.10	0.21 ± 0.13	19.2
KDML 105	0.41 ± 0.15	0.33 ± 0.17	18.3	0.78 ± 0.08	0.79 ± 0.05	-1.8	0.11 ± 0.01	0.10 ± 0.01	15.9	0.16 ± 0.03	0.28 ± 0.05	-44.6
IR 20	0.19 ± 0.03	0.09 ± 0.04	53.2	0.30 ± 0.05	0.29 ± 0.10	4.0	0.02 ± 0.02	0.01 ± 0.01	45.5	0.06 ± 0.04	0.07 ± 0.03	-26.3
IR 52	0.56 ± 0.07	0.35 ± 0.22	37.5	0.78 ± 0.07	0.79 ± 0.23	-1.4	0.19 ± 0.03	0.12 ± 0.06	35.5	0.28 ± 0.05	0.23 ± 0.07	15.1
Average	0.479	0.295	38.4	0.772	0.712	7.8	0.132	0.091	31.1	0.218	0.204	6.4

[†]Inhibition rate (%)=(Control-After PEG treatment (or After rehabilitation))/Control × 100

Table 4. Differences of leaf area and leaf color as stressed by PEG treatment and their recovery after rehabilitation treatment in between Japonica and Indica cultivars.

Cultivar	Leaf area						Leaf color					
	Cont.	After PEG Treat.†	In.†	Cont.	After recovery	In.	Cont.	After PEG Treat.	In.	Cont.	After recovery	In.
Japonica	---cm^3/3plants---		%	----/3plants---		%	----SPAD----		%	----SPAD----		%
Iksan 438	51.9 ± 19.6	36.3 ± 3.7	30.2	96.8 ± 25.0	70.4 ± 33.3	27.3	25.3 + 1.3	32.7 ± 2.1	-29.2	30.9 ± 3.4	35.0 ± 4.7	-13.3
Hwasambyeo	45.4 ± 16.9	37.5 ± 17.0	17.4	100.0 ± 9.2	71.5 ± 6.0	28.5	28.0 ± 2.7	34.6 ± 1.3	-23.6	36.0 ± 0.7	29.4 ± 2.5	18.3
Daeanbyeo	74.7 ± 13.1	35.3 ± 3.5	52.8	115.1 ± 12.1	90.0 ± 16.9	21.8	26.3 ± 2.5	31.0 ± 1.5	-17.9	31.6 ± 0.8	34.6 ± 0.7	-9.5
Geumnambyeo	45.4 ± 9.9	20.7 ± 5.0	54.5	103.0 ± 9.8	80.5 ± 11.2	21.9	28.6 ± 1.1	29.8 ± 4.5	-4.2	30.9 ± 2.2	27.8 ± 1.6	10.0
Sangnambatbyeo	92.3 ± 9.3	36.3 ± 8.6	60.6	143.1 ± 13.0	98.2 ± 17.2	31.4	24.9 ± 0.9	31.3 ± 0.9	-25.7	30.1 ± 1.7	30.1 ± 3.8	0
Average	62.0	33.20	46.4	111.6	82.09	26.4	26.6	31.9	-19.9	31.9	31.4	1.6
Indica												
Ifugao Rice	62.4 ± 4.1	35.1 ± 13.7	43.7	135.6 ± 20.0	106 ± 44.8	21.9	24.5 ± 1.9	28.5 ± 2.9	-16.3	30.3 ± 0.9	24.7 ± 3.2	18.5
NSG 19	108.2 ± 24.6	40.3 ± 7.3	62.8	183.1 ± 47.9	117.3 ± 18.2	36.0	28.4 ± 0.4	30.4 ± 2.4	-7.0	32.1 ± 0.4	26.2 ± 2.5	18.4
KDML 105	52.6 ± 9.7	37.4 ± 4.2	29.0	134.7 ± 11.6	101.7 ± 29.1	24.5	27.2 ± 1.8	29.4 ± 1.3	-8.1	32.2 ± 1.0	30.0 ± 2.0	6.8
IR 20	36.5 ± 2.7	24.81 ± 1.5	32.0	70.5 ± 4.4	70.9 ± 32.9	-1.0	29.4 ± 0.5	32.8 ± 0.4	-11.6	33.5 ± 0.5	29.6 ± 2.6	11.6
IR 52	80.9 ± 14.9	46.3 ± 19.0	42.8	142.9 ± 9.4	144.9 ± 52.5	-1.0	31.4 ± 2.0	32.8 ± 0.4	-4.5	35.2 ± 0.3	30.5 ± 0.3	13.4
Average	68.1	36.8	46.0	133.4	108.1	18.9	28.2	30.8	-9.2	32.7	28.2	13.8

†Inhibition rate (%)=(Control-After PEG treatment (or After rehabilitation))/Control × 100

Table 5. Difference of photosynthetic rate and stomatal conductance as stressed by PEG treatment and their recovery after rehabilitation treatment in Japonica and Indica type cultivars.

Cultivar	Photosynthetic rate						Stomatal conductance					
	Cont.	After PEG treat.	In.†	Cont.	After recovery	In.	Cont.	After PEG treat.	In.	Cont.	After recovery	In.
Japonica	μ mol m^{-1} s^{-1}		%	μ mol m^{-1} s^{-1}		%	cm S^{-1}		%	cm S^{-1}		%
Iksan 438	15.6 ± 3.8	8.3 ± 0.5	46.8	27.1 ± 1.6	23.3 ± 2.8	14.0	1.60 ± 0.29	0.24 ± 0.02	85.0	0.71 ± 0.04	0.99 ± 0.03	-39.4
Hwasambyeo	11.2 ± 1.4	8.4 ± 1.6	25.0	28.0 ± 0.7	20.8 ± 2.2	25.7	1.46 ± 0.06	0.22 ± 0.05	84.9	0.83 ± 0.05	0.83 ± 0.05	0
Daeanbyeo	14.5 ± 0.6	8.7 ± 1.1	40.0	22.4 ± 0.1	25.6 ± 4.6	-14.0	1.46 ± 0.05	0.20 ± 0.02	86.3	0.64 ± 0.02	0.93 ± 0.11	-45.3
Geumnambyeo	13.6 ± 3.5	9.6 ± 0.9	29.4	23.2 ± 0.5	22.1 ± 0.7	4.7	1.35 ± 0.22	0.27 ± 0.04	80.0	0.64 ± 0.03	0.74 ± 0.02	-15.6
Sangnambatbyeo	14.8 ± 0.5	9.6 ± 1.1	35.1	18.8 ± 0.1	19.9 ± 0.9	-6.0	1.48 ± 0.24	0.25 ± 0.04	83.1	0.63 ± 0.03	0.80 ± 0.14	-27.0
Mean	13.9	8.9	36.0	23.9	22.3	10.8	1.47	0.24	83.7	0.69	0.86	-24.6
Indica												
Ifugao Rice	17.3 ± 0.5	13.0 ± 0.6	24.9	25.0 ± 0.4	25.6 ± 1.9	-2.0	1.44 ± 0.14	0.30 ± 0.01	79.2	0.72 ± 0.02	0.93 ± 0.09	-29.2
NSG 19	18.6 ± 3.2	11.2 ± 0.9	39.8	24.9 ± 0.5	26.6 ± 3.4	-7.0	1.41 ± 0.11	0.26 ± 0.04	81.6	0.77 ± 0.06	0.91 ± 0.08	-18.2
KDML 105	16.8 ± 2.2	10.5 ± 1.2	37.5	23.5 ± 1.6	25.6 ± 0.5	-9.0	1.18 ± 0.32	0.22 ± 0.04	81.4	0.66 ± 0.03	0.84 ± 0.06	-27.3
IR 20	16.7 ± 2.5	12.1 ± 2.4	27.5	22.2 ± 0.6	20.0 ± 2.1	9.9	1.08 ± 0.29	0.41 ± 0.15	60.0	0.89 ± 0.05	0.74 ± 0.12	16.9
IR 52	20.3 ± 2.1	17.9 ± 2.8	11.8	23.6 ± 0.1	24.0 ± 3.9	-2.0	1.40 ± 0.14	0.99 ± 0.74	29.3	1.25 ± 0.46	0.77 ± 0.15	38.4
Mean	17.9	12.9	27.9	23.8	24.4	-3.0	1.30	0.44	66.2	0.86	0.84	2.3

†Inhibition rate (%)=(Control-After PEG treatment (or After rehabilitation))/Control × 100

Table 6. Correlation coefficients of growth and physiological traits between germinating stage and seedling stage.

	Inhibition rate by PEG at seedling stage							
	Plant height	Leaf age	Shoot dry weight	Root dry weight	Leaf area	Leaf color	Photosynthetic rate	Stomatal conductance
Inhibition rate by PEG at germinating stage								
Radicle length	0.529	0.320	0.405	0.245	0.462	0.119	0.040	0.059
Plumule length	0.570	0.445	0.046	0.181	0.407	0.533	0.115	0.120

ied on both rice types, ranged with 80.0~86.3% in Japonica and 29.3~81.6% in Indica. After rehabilitation treatment, the stomatal conductance was recovered in all cultivars of Japonica, but not in IR 20 and IR 52 of Indica.

Relationship between PEG strees at germination and seedling stage

Finally, the correlation coefficients between the inhibition rate of radicle and plumule length by treatment of PEG just after germination and those of growth and physiological traits from 14 DAS to 21 DAS were shown in Table 6. The positive relationships were shown in all cases of relationship, although the significance of the relationship was not found at 5% level. However, the radicle and plumule lengths showed the relation coefficients in relation with plant length, leaf age and leaf area than other factors. The correlation coefficients of radicle and plumule length at germinating stage showed a lower related trend to the physiological traits (i.e., photosynthetic rate and stomatal conductance) than did the growth traits. These results indicate a little relationship between germination of seeds and growth of seedlings under the stress of low water potential, which is similar with the case of wheat (Blum *et al.*, 1980). In order to establish an effective screening system to develop the drought tolerance cultivars at seedling stage, more study would be needed with respect to the growth and physiological relationships on drought tolerance of rice plant between seedling stage and mature growth stage.

REFERENCES

Ahmad, S., T. Kobata, and S. Takami. 1987. Leaf death and alteration of internal water relations in rice (*Oryza sativa* L.) in response to water deficits in the seedling stage. *Jpn. J. Crop Sci.* 56(4):582-588.

Blum, A., B. Sinmena, and O. Ziv. 1980. An evaluation of seed and seedling drought tolerance screening in wheat. *Euphytica* 29:727-736.

Brix, H. 1962. The effect of water stress on the rates of photosynthesis and respiration in tomato plants and liblolly pine seedling. *Physiol plant.* 15:10-20.

Choi, S. J., and R. K. Park. 1980. Varietal difference in ecological and morphological characteristics affecting tolerance. *Korean J. Soc. Crop Sci.* 25:10-16.

Fukai, S. and M. Cooper. 1996. Stress physiology in relation to breeding for drought resistance: A case study of rice. *In* Physiology of Stress Tolerance in Rice. Singh et al. (eds). NDUAT-IRRI. pp.123-149.

Guedira, M., J. P. Shroyer, M. B. Kirkam, and G. M. Paulsen. 1997. Wheat coleoptile and root growth and seedling survival after dehydration and rehydration. *Agron. J.* 89: 822-826.

Hohl, M. and P. Schopfer. 1991. Water relations of growing maize coleoptiles. Comparison between mannitol and polyethylene glycol 600 as external osmotica for adjusting turgor pressure. *Plant Physiol.* 95:716-722.

Hasio, T. C., J. C. O'Toole, E. B. Yambao, and N. C. Turner. 1984. Influence of osmotic adjustment on leaf rolling and tissue death in rice. *Plant Physiol.* 75:338-341.

Iturbe-Ormaetxe, I., P. R. Escuredo, C. Arrese-Igor, and M. Becana. 1998. Oxidative damage in pea plants exposed to water deficit or paraquat. *Plant Physiol.* 116:173-181.

Lee, S. S., J. H. Back, T. J. Kim, and S. B. Hong. 1993. Seedling emergence of direct seeded paddy rice at different soil moisture regimes. *Korean J. Crop Sci.* 38:228-234.

Lu, Z. and P. M. Neumann. 1999. Water stress inhibits hydraulic conductance and leaf growth in rice seedlings but not the transport of water via mercury- sensitive water channels in the root. *Plant Physiol.* 120:143-152.

Maruyama, S., and K. Tajima. 1990. Leaf conductance in japonica and indica rice varieties. *Jpn. J. Crop Sci.* 59:801-808.

Oka, H. I. and Y. K. Rho. 1957. Studies on drought resistance in rice varieties. *Agri. & Hort.* 32:851-855.

Price, A. H., E. M. Young, and A. D. Tomos. 1997. Quantitative trait loci associated with stomatal conductance, leaf rolling and heading date mapped in upland rice *(Oryza sativa)*. *New Phytol.* 137:83-91.

Termaat, A., and R. Munns. 1986. Use of concentrated macronutrient solutions to separate osmotic from Nacl-specific effects on plant growth. *Aust. J. Plant Physiol.* 13:509-522.

Verslues, P. E., E. S. Ober, and R. E. Sharp. 1998. Root growth and oxygen relations at low water potentials. Impact of oxygen availability in polyethylene glycol solutions. *Plant Physiol.* 116:1403-1412.

Yoshida, S. and S. Hasegawa. 1982. The rice root system: Its development and function. *In.* "Drought Resistance in Crops with Emphasis on Rice". IRRI(ed.). pp. 97-114.

Yoshida, S., D. A. Forno, J. H. Cock, and K. A. Gomez. 1976. Laboratory manual for physiological studies of rice (3rd). IRRI. pp. 61-66.