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Differences in Flood-Stress Tolerance among Sprout Soybean Cultivars

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ABSTRACT In this study, the response of 22 soybean cultivar sprouts to flooding stress was investigated. After sprouts were subjected to flooding stress for 10 days at the V4-V5 growth stages, their dry weights were compared. All plants were kept in a greenhouse under natural light conditions, an average daytime temperature of 35.6 ± 5.3℃ and an average nighttime temperature of 18.2±1.7°C. Soybeans were grown in a concrete bed filled with silt loam soil. Subjecting plants to flooding stress resulted in a large reduction in plant dry weight, plant height, number of nodes, and number of leaves. Cultivars differed significantly in their responses to flooding stress, as indicated by these characteristics ($p<0.05$). Soybean cultivars were classified into three groups based on their degree of flood tolerance: strong, moderate, and weak. Hannamkong, Namhaekong, Sobaegnamulkong, and Sorogkong had strong tolerance for flood conditions. Tawonkong, Pureunkong, Eunhakong, Myeongjunamulkong, Doremikong, Saebyeolkong, Paldokong, Sowonkong, Pungsannamulkong, Dagikong, Dachaekong, and Anpyeongkong had weak tolerance for flood conditions.

Keywords : sprout soybean, flooding stress, relative dry weigh

Because soybeans, which has high protein and fat content, are widely used for food, industry and forage, the worldwide production and consumption of soybeans increases every year. However, because of low yield and income per unit area of cultivated soybean and insufficient mechanization of cultivation, the area devoted to the cultivation of soybeans decreased rapidly from 297,000 ha in 1970 to 77,849 ha in 2011. The self-supply of soybeans was, at most, 10.1% in 2011 (MFAFF. 2012.). Therefore, in order to increase the self-supply of soybeans, it is essential to increase the yield per unit area. It is also very important to expand the area in which soybeans are cultivated, apply new cultivation techniques, and develop quality cultivars (Cho and Yamakawa 2006; Cho *et al*., 2006; Park, *et al*. 2001).

Soybean growth and yield are affected by water conditions during the growth season and significant quantities of water are required during the growing season. Water can improve potential plant growth rates when either too much or too little is available. The effect of too much water is known as aeration stress and too little water was referred to as drought stress (Scott *et al*. 1989). Plant damage due to flooding is usually attributed to an oxygen supply that is insufficient to maintain root respiration. Flooding may be detrimental to root growth, nodule formation, and nodule function in soybean (Cho *et al*., 2006; Sallan and Scott, 1987). The duration of flood conditions also affects soybean plants, as plants subjected to prolonged flooding exhibited in yellowing and abscission of leaves at the lower nodes, stunting, and reduced dry weight and seed yield (Scott *et al*., 1989).

Plants in early reproductive stages (R1-R5) have greater sensitivity to flooding than those in vegetative stages (emergence-R1). The flooding sensitivity of plants at specific developmental stages throughout the soybean life cycle has not been identified, but the greatest sensitivity to flooding occurs at the R3 stage (Linkemer *et al*., 1998). Flooding for as little as 2 days can reduce soybean yield by 18% at the V4 stage (Fehr and Cavines, 1977) and 26% at the R2 stage (Scott *et al*., 1989). Yields are generally similar for plants at different growth stages when flood periods last 1-2 days. However, when flood periods last longer than 2 days, the average yield of plants at the R2 stage is about 50% of the yield of non-treated plants (Griffin & Saxton, 1988). In addition, the determinate soybean cultivars are more susceptible to prolonged excess water stress during early reproductive growth than during early vegetative growth (Griffin & Saxton, 1988). Soybean

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Table 1. Difference of dry weight on leaf and stem among 22 soybean cultivars with flooding for 10 days.

Cultivars	Leaf			Stem			Total		
	Con.(a)	treat.(b)	b/a×100	Con.(a)	treat.(b)	b/a×100	Con.(a)	treat.(b)	b/a×100
Kwangankong	0.89	0.65	73.0c-f♪	0.76	0.45	59.2ef	1.65	1.10	66.7de
Namhaekong	0.94	0.95	101.1a-d	0.80	0.79	98.8a	1.73	1.74	100.6a
Tawonkong	0.94	0.78	83.0b-f	0.88	0.73	83.0bcd	1.82	1.51	83.0a-d
Doremikong	0.55	0.54	99.2a-d	0.37	0.35	94.6abc	0.92	0.91	98.9ab
Dagikong	0.79	0.60	75.9c-f	0.47	0.31	66.0de	1.26	0.91	72.2cde
Dachaekong	0.79	0.73	92.4a-f	0.36	0.33	91.7ab	1.15	1.06	92.2ab
Myeongjunamulkong	0.82	0.60	76.7c-f	0.68	0.41	60.3de	1.50	1.01	67.3de
Bukwangkong	0.73	0.78	106.8a-d	0.86	0.86	99.4a	1.59	1.64	103.1a
Saebyeolkong	1.23	0.65	52.8f	0.93	0.44	47.3f	2.16	1.09	50.5e
Sunamkong	0.98	0.83	84.7b-f	0.64	0.52	83.9bcd	1.62	1.35	83.3a-d
Sobaegnamulkong	1.03	1.27	122.5a	0.84	0.78	92.9abc	1.87	2.05	109.2a
Sorogkong	1.63	1.50	92.0a-f	0.91	0.81	89.0bc	2.54	2.31	90.9abc
Somyeongkong	0.74	0.51	68.9def	0.59	0.39	66.1de	1.33	0.90	67.7de
Sowonkong	0.54	0.50	92.6a-f	0.52	0.41	78.8cde	1.06	0.91	85.8a-d
Sohokong	1.25	1.27	101.2a-d	0.79	0.78	98.5a	2.04	2.05	100.5a
Anpyeongkong	1.18	0.76	64.4def	0.63	0.47	74.6cde	1.81	1.23	68.0de
Eunhakong	0.70	0.49	70.0c-f	0.64	0.47	73.2cde	1.34	0.96	71.6cde
Iksannamulkong	0.95	1.01	119.4a	0.92	0.92	100.0a	1.87	1.93	103.2a
Paldokong	0.92	0.52	56.5f	0.74	0.38	51.1f	1.66	0.90	54.2e
Pureunkong	0.83	0.72	87.0a-f	0.65	0.48	74.4cde	1.48	1.20	81.1a-d
Pungsannamulkong	0.84	0.69	82.1b-f	0.56	0.43	76.8cde	1.40	1.12	80.0a-d
Hannamkong	0.75	0.87	116.0ab	0.78	0.75	96.2ab	1.53	1.62	105.9a
Means	0.87	0.75	87.7	0.67	0.53	80.7	1.54	1.28	84.2
CV (%)	-	-	26.1	-	-	24.9	-	-	22.3

♪ different letters in the same row indicate significant differences at the 0.05 level by DMRT.

genetic lines from southeastern China are adapted to high water table conditions (Ralph, 1983) and appear more tolerant of simulated laboratory flooding than some soybean cultivars from the Midwest (Vantoai *et al*. 1993). The flooding tolerance of 84 U.S. soybean cultivars has been fully tested under field conditions (Vantoai *et al*. 1994). In addition, Choi *et al*. (1995, 1996) reported the physiological responses of different soybeans under excessive soil water stress. Thus, objectives of this study are to determine the variability among soybean cultivars in flooding tolerance at the V4-V5 growth stage, and to provide basic data to inform parental selection for breeding.

MATERIALS AND METHOD

A concrete bed (11 m×2 m×1 m) in a greenhouse was filled with silt loam soil. Three seeds of each of 22 soybean cultivars (Anpyeongkong, Bukwangkong, Dachaekong, Dagikong, Doremikong, Eunhakong, Hannamkong, Iksannamulkong, Kwangankong, Myeongjunamulkong, Namhaekong, Paldokong, Pungsannamulkong, Pureunkong, Saebyeolkong, Sobaegnamulkong, Sohokong, Somyeongkong, Sorogkong, Sowonkong, Sunamkong, and Tawonkong) were sown at a plant density of 50×10 cm. Basal fertilization was applied to the soil at a rate of 3 kg N, 3 kg P, and 4 kg K per 10 a. Plants were grown under natural photoperiod and

Table 2. The changes in the growth of flooded soybean plants relative the growth of controls (%)for top dry weight, plant height, number of nodes on the main stem, and number of leaves on the main stem among 22 soybean cultivars, 10 and 20 days after the end of a 10-day flood period.

Cultivars	Top dry weight		Plant height		Node No.		Leaf No.	
	10 DAT♩	20 DAT	10 DAT	20 DAT	10 DAT	20 DAT	10 DAT	20 DAT
Kwangankong	66.6de♪	45.7de	67.5cde	53.2gh	74.9a-d	77.3e-i	79.0abc	72.9abc
Namhaekong	96.0ab	56.8d	86.7a	96.4a	91.3abc	84.6a-f	80.2abc	67.7bcd
Tawonkong	50.4g	66.8c	59.9def	59.4e-h	74.9a-d	66.8ij	61.7bc	68.8bcd
Doremikong	53.1fg	38.7ef	79.5abc	61.3d-h	81.3a-d	63.9j	64.6bc	78.5abc
Dagikong	54.0fg	50.5de	55.8ef	53.6gh	67.8bcd	77.4e-i	54.3bc	53.3de
Dachaekong	58.6ef	58.5cd	52.5ef	56.4fgh	75.5a-d	80.5d-h	65.6bc	60.9cde
Myeongjunamulkong	51.3fg	26.5g	61.3def	46.2h	77.3a-d	70.6hij	61.7bc	60.7cde
Bukwangkong	70.4d	30.7g	83.1a	77.3bcd	72.6bcd	80.0d-h	66.9abc	45.3e
Saebyeolkong	33.7f	27.7g	53.9ef	56.3fgh	60.9d	68.7hij	46.5c	49.0de
Sunamkong	65.8de	65.2c	64.7def	73.9cde	78.8a-d	87.8a-e	54.9bc	73.3abc
Sobaegnamulkong	96.3ab	63.6c	85.0a	72.2c-f	92.0a	80.7d-h	105.8a	65.1cde
Sorogkong	70.1d	80.6b	80.7ab	83.3bc	87.8a-d	88.6a-e	60.6bc	79.8abc
Somyeongkong	85.1c	41.2ef	63.4def	63.3d-g	88.8a-d	74.8f-j	89.6ab	72.6abc
Sowonkong	56.0fg	37.0ef	67.9cde	63.6c-g	74.3a-d	81.5b-g	69.8abc	65.3cde
Sohokong	75.7cd	41.8ef	67.1cde	64.1c-g	77.4a-d	87.8a-f	62.5bc	61.6cde
Anpyeongkong	57.8ef	63.9cd	63.9def	68.4c-g	72.6bcd	88.1a-e	68.6abc	56.4de
Eunhakong	45.9g	42.9ef	68.3cde	79.2bc	92.0a	96.2a	60.5bc	60.6cde
Iksannamulkong	62.9de	69.7c	83.9a	93.4ab	82.8a-d	93.2ab	67.2bc	81.3ab
Paldokong	34.2f	49.0de	59.7def	67.8c-g	70.1cd	94.5ab	48.2c	69.0cde
Pureunkong	48.5g	44.5e	69.6bcd	74.2cde	83.8a-d	88.7a-e	64.8bc	83.6a
Pungsannamulkong	45.8g	35.2f	51.7f	54.0gh	80.6a-d	83.3b-g	74.2abc	58.9de
Hannamkong	109.4a	99.6a	89.2a	108.8a	90.4abc	94.4ab	91.3ab	84.9a
Means	60.8	50.2	66.3	67.2	73.2	79.5	62.9	64.8

All data are shown as flooded plant/control×100(%)
♩ DAT indicates the number of days after the end of flooding.
♪ different letters in the same row indicate significant differences at the 0.05 level by DMRT.

light with an average daytime temperature of 30.6±2.3°C and nighttime temperature of 17.8±2.5°C. The concrete bed was flooded for 10 days when plants were at the V4−V5 of trifoliolate leaf stage. Tap water was added to the concrete bed until it reached 1 cm above the level of the soil surface. Control plants remained well watered (about 60% soil moisture) during the experiment. Experimental design for growth data was a completely randomized design with three replications. Measurements were obtained on the final day of flooding, and again 10 and 20 days after removal of flood conditions. Dry matter, plant height, leaf area, number of main stem nodes, and number leaves number were measured. To obtain dry matter, all plant parts were dried for 3 days at 80°C and then weighed. Leaf area was measured using a leaf area meter (Licor Model LI-3100, USA).

RESULTS

The dry weight of soybean leaves and stems after 10 days of flooding at the V4−V5 growth stage is shown in Table 1. Control leaf dry weight for the 22 soybean

Table 3. Analysis of variance for different characteristics of 22 soybean cultivars 10 and 20 days after the end of a 10-day flood period.

Source	df	10 DAT┘					20 DAT				
		Leaf D.W.	Stem D.W.	Plant height	Leaf no.	Node no.	Leaf D.W.	Stem D.W.	Plant height	Leaf no.	Node no.
Cultivars	21	**	**	**	**	*	**	**	**	**	**
CV, %		15.9	15.4	9.8	27.1	13.4	16.4	33.4	11.7	12.8	5.5

*, ** significant at the 0.05 and 0.01 level, respectively.
┘DAT indicates days after removal of flooding.

cultivars ranged from 0.54 g to 1.63 g per plant (average, 0.89 g) and stem dry weight ranged from 0.36 g to 0.93 g per plant (average, 0.66 g). The leaf dry weight of flooded soybean plants ranged from 0.49 g to 1.50 g per plant (average, 0.74 g) and the dry weight stem ranged from 0.31 g to 0.92 g per plant (average, 0.53 g). The waterlogging index (flooding/control×100) ranged from 52.8 to 122.5 (average, 87.7) for leaves and ranged from 47.3 to 100.0 (average, 80.7) for stems. There were significant differences between cultivars in the dry weight of flooded plants.

Table 2 shows changes in the relative growth rate (%) of flooded plants, as compared to controls, of top dry weight, plant height, node number and leaf number at 10 and 20 days after removal of flooding in 22 soybean cultivars. The relative growth rate of top dry weight on 10 and 20 days in 22 soybean cultivars was 60.8 and 50.2, respectively. The dry weight of flooded cultivars relative to that of controls tended to be lower 20 days after the end of the flood period than it was 10 days after the end of flooding. It was ranged from 109.4 (Hannamkong) to 33.7 (Saebyeolkong) on 10 days after removal of flooding, and ranged from 99.6 to 26.5 on 20 days after removal stress. The height of flooded plants was an average of 67.2% of the height of controls 10 days after flooding and was 73.2% of the height of controls 20 days after flooding. Similarly, the number of nodes per plant was, on average of 73.2% of the number found on control plants 10 days after flooding and averaged 79.5% of the number found on control plants 20 days after flooding. The number of leaves per flooded plant ranged from 46.5% to 105.8% (average, 62.9%) of the number of leaves per control plant 10 days after flooding, and ranged between 45.3% and 84.8% (average, 64.8%) 20 days after flooding.

The leaf dry weight, stem dry weight, plant height, number of leaves, and number of nodes of the flooded plants were all significantly different from those of control plants at 10 and 20 days after flooding ($p < 0.05$ and 0.01, respectively: Table 3). In addition, growth measurements for flooded plants relative to those for controls on the last day flooding were linearly related to relative growth measurements obtained 10 and 20 days after the end of flooding (R^2=0.23 and R^2=0.47, respectively; Fig. 1). Based on these results, the soybean cultivars were classified as having strong, moderate, or weak tolerance for flooding. Hannamkong, Namhaekong, Sobaegnamulkong, and Sorogkong had strong flood tolerance, while Tawonkong, Pureunkong, Eunhakong, Myongjunamulkong, Doremikong, Saebyeolkong, Paldokong, Sowonkong, Pungsannamulkong, Dagikong, Dachaekong, and Anpyeongkong had weak tolerance for flooding (Table 4).

DISCUSSION

This study was conducted to identify soybean cultivars that were flood-tolerant. The damage to plants caused by various stresses during the growing season differs between growth stages. In general, the disaster occurred vigorously at seedling, early vegetative growth, reproductive growth, and germination stage Flooding is a major limiting factor of soybean growth and yield during the rainy season, which occurs when soybean plants are in the early vegetative growth stage. Therefore, the reaction of these plants to flooding during the early vegetative growth stage is very important. Soybean crops are sensitive crop to flooding and flooding generally influences growth and yield when it occurs during the V3-R5 growth stages. Soybeans subjected to flood conditions while at the vegetative stage have reduced leaf area, dry weight, and plant weight relative to those that are not subjected to flooding (Choi, et. al. 1996; Choi, *et al*. 1995; Griffin & Saxton, 1988; Linkemer *et al*., 1998; Scott *et al*., 1989). Griffin & Saxton (1988) stated that flooding soybean plants at the V6 stage resulted in severe chlorosis and stunting after 4 days of standing water. These researchers also reported that crop growth rates are typically affected when flooding stress is applied for longer than 2 days. In the present study, the dry weight of the leaves and stems of 22 soybean cultivars that were subjected to flooding for 10 days relative to those of controls were 87.7% and 80.7%, respectively (Table 1). The reduction in stem growth was more severe than that of leaves. Differences in X among stressed soybean cultivars at the V4-V5 growth stage were significant ($p<0.05$) Comparison of the relative growth parameters among the 22 soybean cultivars showed that flooded Hannamkong, Iksannamulkong, Namhaekong, Bukwangkong, and Sobaegnamulkong had growth parameters that were more similar to controls than those of any of the other cultivars. In contrast, flooded Saebyeolkong and Paldokong had growth parameters that were the most different from control growth parameters (measurements for flooded plants were an average of 50.5% and 54.2%, respectively, of control measurements).

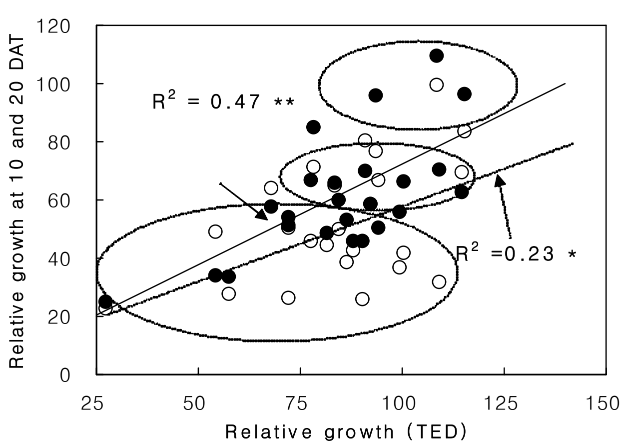

Fig. 1. Relationship between relative growth on last day of flooding (TED), at 10 days after of the end of flooding (DAT; closed marks, dotted line), or 20 DAT (open marks, solid line) flooding. *, ** indicate significance at the 0.05 and 0.01 level, respectively.

On the other hand, previous studies have indicated that soybeans are more sensitive during the early reproductive stage than during vegetative stages (Griffin & Saxtion, 1988; Scott *et al*., 1989). Grifin & Saxtion (1988) stated that the recovery and yield of soybean flooded was less affected at vegetative stages than when flooding was applied postflowering stages and soybean with flooding at V3–V5 had yield as if it had. Bacanamwo and Purcell (1999) reported that, although 7 days of flooding had no effect on biomass accumulation in soybean plants, biomass accumulation was significantly inhibited after 14 days of flooding.

The soybean cultivars in the present study can be classified into 3 groups, based on their response to flooding: (i) a severely decreased soybean cultivars group, (ii) a soybean cultivars group similar to growth of ending date, and (iii) a restarting soybean cultivars group (Table 2). The overall growth of flooded soybean plants was lower relative to the growth controls at 10 days (60.8%) and 20 days (50.2%) after removal of stress than on last day of flooding (Table 1, Table 2). Sohokong, Namhaekong, Sobaegnamulkong, Myeongjunamulkong, and Somyeong-

Table 4. Classification of 22 soybean cultivars according to flood tolerance, as determined by relative growth (in percent of control) after flooding for 10 days.

Degree of tolerance to flooding	Cultivars	Number of Cultivars
Strong (above 80%)	Hannamkong, Namhaekong, Sobaegnamulkong, Sorogkong	4
Moderate (79-60%)	Somyeongkong, Sohokong, Kwangankong, Bukwangkong, Iksannamulkong, Sunamkong	6
Weak (below 59%)	Tawonkong, Pureunkong, Eunhakong, Myeongjunamulkong, Doremikong, Saebyeolkong, Paldokong, Sowonkong, Pungsannamulkong Dagikong, Dachaekong, Anpyeongkong	12

kong should be classified to a severe decreased soybean cultivars group. The dry weight of flooded Hannamkong, relative to the dry weight of controls, was similar at 10 and 20 days after the end of flooding, and it can therefore be classified as a cultivar that did not change relative to controls. Tawonkong, Iksannamulkong, and Sorogkong, should be classified to a growth restarting soybean cultivar group. The results of analysis of variance showed a highly significant difference ($p < 0.01$ or $p < 0.05$) in all factors with flooding for 10 days (Table 3).

On the other hand, the coefficient of determination for relative dry weight on the last day of flooding and 10 days after the end of flooding (R^2=0.23) was lower than that for relative dry weight on the last day of flooding and 20 days after the end of flooding (R^2=0.47). This analysis was used to classify the tolerance of 22 soybean cultivars to flooding as strong, moderate, or weak. Hannamkong, Namhaekong, Sobaegnamulkong, and Sorogkong had strong tolerance for flooding, while Tawonkong, Pureunkong, Eunhakong, Myeong-junamulkong, Doremikong, Saebyeolkong, Paldokong, Sowonkong, Pungsannamulkong, Dagikong, Dachaekong, and Anpyeongkong had weak tolerance for flooding (Fig. 1, Table 4).

Linkemer *et al*. (1998) reported significant yield loss when soybean plants in the V2 growth stage were subjected to flooding and stated that waterlogging must be avoided during the early vegetative period (V2) in order to obtain optimal yield. Scott *et al*. (1989) reported a high significant between yield and canopy height or dry weight to flooding at V4. Although the classification of cultivars into tolerance categories was based only on growth characters, in the present study, the classifications can be used to inform the breeding and cultivation of soybean cultivars that are tolerant to flooding.

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