

Flooding Tolerance of Soybean [*Glycine max* (L.) Merr.] Germplasm from Southeast Asia under Field and Screen-House Environments

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Abstract: Soybean (*Glycine max* L. Merr.) cultivars from the U.S. are generally intolerant to flooding stress. Soybean germplasm and cultivars originating from other countries and grown in rotations with paddy rice potentially could have better flooding tolerance. Screen-house and field tests were conducted to determine variations in flooding tolerance among 21 soybean varieties from Southeast Asia. Flooding for two weeks at the R2 growth stage reduced grain yield under field conditions between 36% and 100% (all plants dead). However, plants that survived were, on the average, 13% taller than control plants. Tolerance to R2 flooding was associated with higher number of pods per plant and 100-grain weight. Growth response to flooding stress, as determined by plant height, was correlated with grain yield in all three environments. While there was no correlation in yield between field and screen-house tests, the flood tolerance ranking of the field test was correlated with the ranking of one screen-house test. Screen-house tests could distinguish tolerant from susceptible varieties based on plant survival and grain yield. Three varieties - VND2, Nam Vang and ATF15-1 - showed the best flooding tolerant responses under field and screen-house conditions. These lines provide new germplasm resources for the genetic improvement of flooding tolerance in soybean.

Keywords: Flooding tolerance, landraces, plant growth, grain yield, flooding, yield components.

INTRODUCTION

Flooding is a common environmental stress that injures plant growth and reduces soybean grain yield in the humid temperate region of the United States, where heavy rainfalls sometimes exceed surface and subsurface drainage capabilities [1-3]. In the Mississippi delta region, Asia, and other regions of the world where soybean crops are rotated with paddy rice, injuries due to flooding and flood irrigation are estimated to reduce overall soybean grain yield by as much as 25%. According to Oosterhuis, *et al.* [4], flooding can reduce soybean yield 17% to 43% at the vegetative growth stage, and 50% to 56% at the reproductive stage. However, genetic variability for flooding tolerance exists among U.S. soybean cultivars [2]. In a three-year field screening of 360 soybean cultivars for flooding tolerance, Shannon *et al.* [5] reported a 40% yield reduction in the flood-tolerant group versus an 80% reduction in the flood-susceptible group.

Research on the late-planted flooding-sensitive soybean cultivar "Centennial" conducted in the southeastern United States indicates that flooding during the early vegetative (V2) and early reproductive (R1 to R3) stages is more damaging to grain yield than during other stages [6]. Yield loss

primarily resulted from fewer pods per reproductive node. However, the variation in the effects of flooding on yield components of diverse soybean genotypes grown under different environments has not been fully investigated.

A great deal of research on flooding tolerance has been conducted in controlled greenhouse and growth chamber environments. Contrary to field flooding, which is detrimental to plant survival when lasting for two weeks or less [3, 5], flooding in greenhouse and growth chamber studies usually does not result in plant death. In the greenhouse, soybean plants can produce aerenchyma and adventitious roots closer to the soil surface. The access and transportation of O₂ to the deeper roots [7] allow soybean plants to adapt to flooding stress, survive, grow and reproduce. Bacanamwo and Purcell [8] reported that flooding treatment for up to 21 days at the V4-V6 growth stage under greenhouse conditions did not significantly reduce the shoot and root biomass of three soybean genotypes. According to Henshaw *et al.* [9-10] flooding for up to four weeks did not result in plant death in either tolerant or susceptible soybean genotypes. A quick, reproducible and seasonally-independent greenhouse or screen-house test for flooding tolerance that simulates field test conditions would facilitate flooding research, including germplasm screening and testing transgenic soybean plants for flooding tolerance. For such greenhouse or screen-house tests to be useful, the correlation between responses to flooding in the field and responses in screen-house or greenhouse conditions needs to be validated.

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Because current U.S. soybean cultivars have a narrow genetic base [11-12], soybeans with better flooding tolerance may be found in cultivars and landraces from other countries. Soybeans in Southeast Asia are often cultivated under wet conditions and exhibit high tolerance to soil flooding [13]. In this study, we determined the responses of 21 soybean cultivars, landraces and plant introductions from Vietnam to flooding at the R2 growth stage under field and screen-house conditions. Comparative responses of soybean to flooding in the two environments were documented to verify if testing under screen-house conditions could simulate field tests. Plant growth and yield components after recovery from flooding stress were quantified and their correlation with grain yield analyzed.

MATERIALS AND METHODS

Plant Materials

The study was conducted with 21 soybean genotypes, including popular cultivars developed by traditional or mutation breeding, flood-tolerant landraces from Vietnam and Cambodia, and plant introductions (PI) from Australia, China, Japan and Taiwan (Table 1). These lines are determinate in growth habit with a life cycle from emergence to maturity of 75 to 80 days.

Weather Conditions

Weather conditions during the growing season are summarized in Table 2. The average temperature in the spring of

Table 1. Origin, Flower Color and Senescence of 21 Germplasm Lines Developed in, Native to, or Introduced into Vietnam Evaluated for Flooding Tolerance at Cuu Long Delta Rice Research Institute, Cantho, Vietnam in 2005 and 2006

Variety	Origin	Flower Color	Maturity (d) ^a	
			CO	FL
DNOM 1	Landrace from Thonot district	purple	90	73
DNOM 3	Landrace from Thonot district	purple	86	76
DNOM 5	Landrace from Thonot district	purple	87	78
MTD652-5	Cantho Univ. collection	purple	87	78
MTD676	Cantho Univ. collection	purple	84	75
ATF15-1	Southern Agric. Inst. Collection. Selected from AFT15 (Australia)	purple	88	79
DT93	Agric Genetics Inst. From a cross of 821 (Vietnam) x 134 (Japan)	purple	84	74
Nam Vang	Landrace from Cambodia	purple	83	74
BR5-1	From a cross of Hood x Hill (Brazil)	purple	88	74
HL125	Hung loc Agric. Res. Inst. collection. Selected from AGS-327B (Taiwan)	purple	85	74
MSBR22	PI from Australia	purple	85	73
DT94	Agric. Genetics Inst. From a cross of DT 84 x EC2004	purple	84	74
HL203	Hung loc Agric Res Inst. collection. Selected from GC84058-18-4 (Taiwan)	purple	84	76
96113	PI from Australia	purple	90	76
MTD176	Cantho Univ. collection. From a cross of DT76 x CES79-13	purple	87	75
VND2	Inst Oilseed Crops collection. Selected from TN12 (China)	white	83	76
HL92	Hung loc Agric. Res. Inst. collection. Selected from AGS-327B (Taiwan)	purple	84	74
GC90013-21-15-10	Hung loc Agric. Res. Inst. collection. From a cross of Shih Shih x SRF 400 x PI 153240 (Taiwan)	white	87	75
MTD654-2	Cantho Univ. collection	purple	86	74
CPAC368-7-6	PI from Brazil	purple	89	77
M 103	Released by Vietnam Agric. Sci. Inst. (VASI) & Agric. Univ. No. 1 by mutation breeding of V70	purple	85	72

^aMaturity was determined as days after sowing in the FD06 experiment; CO = control treatment; FL= flooding treatment.

Table 2. Average Monthly Weather Data During the Screen-House and Field Flooding Tolerance Screening Experiments at the Cuu Long Delta Rice Research Institute, Cantho, Vietnam in 2005 and 2006

	Month								
	3	4	5	6	7	8	9	10	Avg
Screen-house Experiment SP05									
Average temperature (°C)	27.0	28.4	28.0	27.6					27.8
Mean maximum daytime temperature (°C)	31.9	33.3	33.2	32.0					32.6
Mean minimum nighttime temperature (°C)	23.5	24.8	25.0	23.7					24.3
Total precipitation (mm)	2.6	0.0	91.1	183.0					69.2
Screen-house Experiment SU05									
Average temperature (°C)					26.3	27.0	27.0	27.4	26.9
Mean maximum daytime temperature (°C)					30.4	30.9	30.7	31.1	30.8
Mean minimum nighttime temperature (°C)					23.9	24.5	24.9	25.0	24.6
Total precipitation (mm)					130.1	169.4	208.9	465.6	243.5
Field Experiment SP06									
Average temperature (°C)	27.2	27.8	27.7	27.0					27.4
Mean maximum daytime temperature (°C)	31.9	32.7	32.7	31.3					32.2
Mean minimum nighttime temperature (°C)	24.1	24.6	24.5	24.6					24.5
Total precipitation (mm)	106.3	51.3	256.5	222.4					153.9

2005 and 2006 was 27.8 °C and 27.4 °C, respectively. April and May are the hottest months in the Vietnam Cuu Long Delta. During these two months in 2005, the average maximum daytime temperature exceeded 33 °C. The spring of 2005 was much drier than normal with almost no rain in March and April. In the spring of 2006, when soybean plants were tested under field conditions, rainfall was more normal and more evenly distributed. The average rainfall was 153.9 mm per month from March to June. The summer average temperature of 26.9 °C did not differ much from the spring average temperature of 27.8 °C, but the summer average maximum temperature was about two degrees lower (30.8 °C) than the spring average maximum temperature (32.4 °C). Summer is also a wet season in the Cuu Long Delta region, with an average rainfall of 243.5 mm per month.

Screen-House Experiments

Plants of each of the 21 soybean genotypes were grown in the screen-house of the Cuu Long Delta Rice Research Institute, Cantho, Vietnam in the spring of 2005 (SP05 experiment) and summer of 2005 (SU05 experiment). The screen-house was covered with chicken wire on all four sides and the roof such that the plants were exposed to ambient environmental conditions while minimizing damage by rodents and other animals. In the SP05 study, two seeds each were planted in 15-cm pots filled with top-soil. After emergence, seedlings were thinned to one plant per pot. The experiment layout was a randomized block design with five replicates. The SU05 study was similar, with the exception that four seeds each were planted in 22-cm pots. After emer-

gence, seedlings were thinned to two plants per pot. Each treatment was replicated three times for each genotype.

Flooding treatment was imposed at the R2 growth stage [14] for two weeks by placing individual pots in 30-cm buckets and adding water to 5 cm above the soil surface. Plants in the control treatment were watered to maintain stress-free normal growth. At the end of the flooding treatment, pots were drained and plants permitted to recover and grow to maturity. Grain yield in grams per plant, plant height, number of reproductive branches, number of reproductive nodes, number of three-seed pods per plant, total number of pods per plant, and 100-grain weight were measured on individual plants.

Field Experiment

The field experiment (FD06) was conducted in the spring of 2006 on two adjacent fields at the Cuu Long Delta Rice Research Institute, Cantho, Vietnam (latitude 10°05' N and longitude 105°42' E) using the same 21 genotypes. The soil type is Eutric Gleysol, alluvial clayey silt with pH levels between 5.6 and 5.8. The control field had drainage ditches around and between replications, whereas the flooded field was surrounded by dikes. The genotypes were planted in a randomized complete block design with three replications in each field. Plots consisted of six 3.0 meter long rows separated by 0.4 meter. Seeds were hand-planted in the six rows on 3 March 2006 at a density of four seeds per hill, spaced 20 cm apart within each row. After two weeks, seedlings were thinned to two plants per hill. Fertilizer was applied at the rate of 60-60-30 kg NPK/ha. Weeds were controlled

though herbicide application and manual weeding. Pesticides for diseases and insect control were applied as needed.

The flooding treatment was imposed by pumping water to a depth of 10-15 cm above the soil surface when the majority of soybean genotypes reached the R2 growth stage. Additional water was added every two days to maintain flooding at the same level. After two weeks, flooded plots were drained. The plants were then watered in a similar manner to the control - as needed until maturity. At harvest, data were recorded for plant height, number of pods per hill, 100-grain weight and grain yield. Plant height was determined based on five randomly selected plants per plot. The pod number was counted from five randomly selected hills per plot. Grains were threshed by hand and grain yield was determined on a per plot basis.

Statistical Analysis

Analyses of variance were conducted using PROC GLM of SAS[®] PC for Windows Version 9.1.3 (SAS Institute Inc., Cary, NC) to compute the mean and examine varietal differences in plant height, grain yield and other yield parameters.

A dependent variable “percent reduction from flooding in relation to the control treatment” was calculated according to the formula: Yield reduction = (control-flooding)/ control*100. To identify flooding-tolerant genotypes, the yield reduction due to flooding was ranked in each of the three different experiments using the PROC RANK. The most tolerant (lowest reduction in yield) was assigned the score =1 and the least tolerant =21. Pearson correlation analyses were conducted using the PROC CORR.

RESULTS

Analyses of variance showed that plant height and grain yield were significantly different among the 21 varieties in both screen-house and field tests. Flooding significantly affected both the height and grain yield of soybeans in all three SP05, SU05 and FD06 experiments. The interaction of flooding and variety was also highly significant in all three experiments.

Yield Response of Soybean Germplasm from Southeast Asia to Flooding

In the SP05 experiment, control grain yield of the 21 soybean varieties ranged from 7.6 to 17.7 g/plant (Fig. 1A). Flooding reduced grain yield by an average of 52.5% with the range in yield reduction from less than 1% to 100% (all plants dead) depending on the varieties (Table 3). Control grain yield of the SU05 experiment ranged from 9.8 g/plant to 18.5 g/plant (Fig. 1B). Flooding for two weeks reduced grain yield by an average of 62.2% (Table 3). The average control grain yield in the field experiment (FD06) was 566.5 g/plot with the range from 264.5 g/plot to 897.5 g/plot (Fig. 1C). After two weeks of flooding, the average yield was 147.5 g/plot, a 73.9% reduction compared to control yield (Table 3).

When varieties were ranked based on yield reduction due to flooding, the ranking between the two screen-house experiments, SP05 and SU05, was significantly correlated ($r=0.69$; $p<0.05$). The ranking between the FD06 and SU05 was also significantly correlated ($r=0.52$; $p<0.05$). However,

the ranking between the FD06 and SP05 experiment was not significant ($r=0.32$). The three varieties which were consistently in the top five most tolerant of all three FD06, SP05 and SU05 experiments were VND2, NamVang, and ATF15-1. Two weeks of flooding in the field (FD06 experiment) reduced grain yield of these tolerant varieties by 43.4% as compared to the 74.0% average reduction of all the 21 varieties. DNOM1 was the variety which consistently showed a high flood-susceptible ranking in all three experiments. Two weeks of flooding in SP05, SU05 and FD06 experiments reduced seed yield of this variety by 80.2%, 75.1%, and 92.0%, respectively (Table 3).

Plant Survival and Growth of Soybean Germplasm from Southeast Asia in Response to Flooding

All control plants in all three experiments survived. Flooding for two weeks reduced plant survival to 51.8%, 69.1% and 58.9% in the SP05, SU05 and FD06 experiments, respectively. Flooding also accelerated the average maturity of the plants by 11 days. The early senescence ranged from eight days in BR5-1 to 17 days in the flood-susceptible DNOM1 variety (Table 1).

In the SP05 experiment, the plant height of 21 soybean varieties in the control treatment ranged from 21.6 to 69.4 cm with an average of 47.3 cm. Flooding reduced this average height to 30.3 cm. The average control plant height of the SU05 was 54.7 cm. Flooding reduced average plant height by 27.4% to 39.6 cm. In the FD06 experiment, plants grew 13.0% taller in response to flooding - from an average of 44.6 cm in the control treatment to 50.4 cm in the flooding treatment (Table 4). Nam Vang and VND2 were the only varieties that grew tall in response to flooding in all three experiments.

Correlation Between Grain Yield and Other Traits in Response to Flooding Stress

Flooded grain yield was highly correlated with plant survival in all three experiments (Table 5). The correlation coefficients ranged from 0.96 in the SP05 to 0.64 and 0.78 in the SU05, FD06 experiments, respectively. In all three experiments, grain yield was also correlated with plant height. The correlation coefficients for the control treatment were 0.53 ($p\leq 0.01$) in the SP05 experiment, 0.47 ($p\leq 0.05$) in the SU05 and 0.67 ($p<0.001$) in the FD06 experiment. The correlation coefficients in the flooding treatment were 0.90 ($p<0.0001$), 0.59 ($p<0.01$) and 0.45 ($p<0.05$) in the SP05, SU05 and FD06 experiments, respectively.

Among the yield components, grain yield was consistently correlated with the total pod numbers in both control and flooding treatments of all three experiments. The correlation coefficients in the control treatment were 0.42 ($p<0.05$), 0.45 ($p<0.05$) and 0.77 ($p<0.0001$) for the SP05, SU05 and FD06 treatments, respectively. For the flooding treatment, the correlation coefficients were 0.91 ($p<0.0001$), 0.47 ($p<0.05$), and 0.67 ($p<0.001$) in the three experiments, respectively. Grain yield was also correlated with the 100-grain weight in the flooding treatment with the correlation coefficients of 0.93 ($p<0.0001$), 0.77 ($p<0.0001$), and 0.50 ($p<0.05$) for the three experiments, respectively. No correlation between grain yield and 100-grain weight was detected

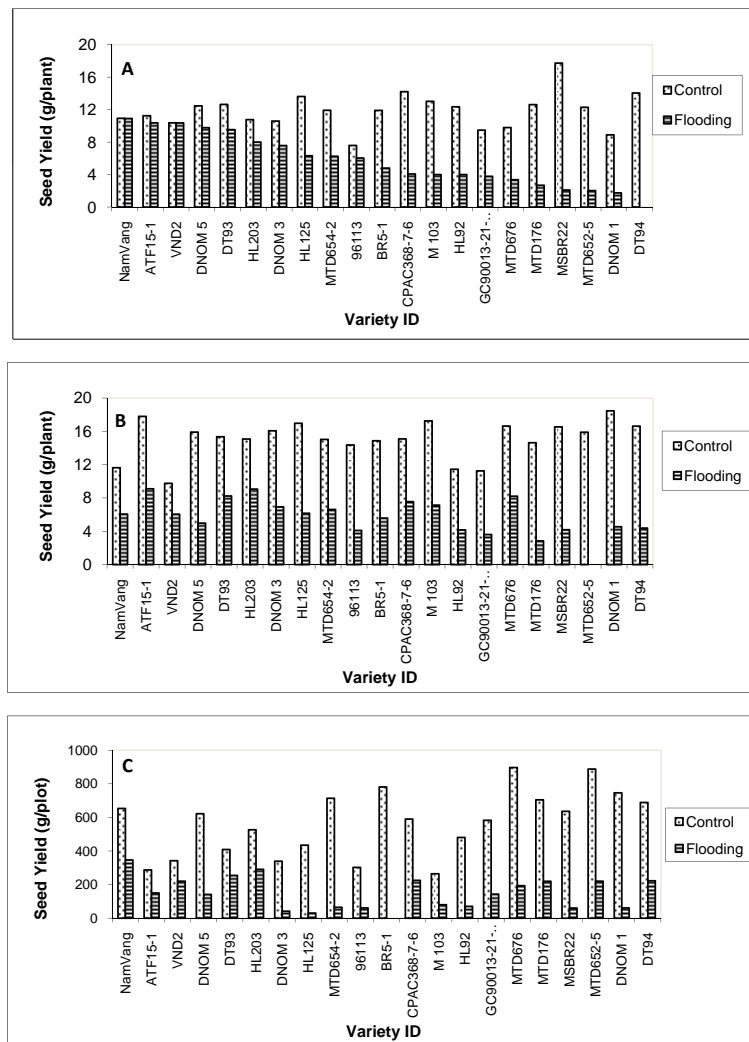


Fig. (1). Seed yield of control and flooding treatments of the spring 2005 (SP05) experiment (A), summer 2005 (SU05) experiment (B), and field 2006 (FD06) experiment (C).

Table 3. Yield Reduction and Ranking of Flooding Tolerance, Calculated as Described in the Materials and Methods Section, of the 21 Soybean Varieties in the Spring 2005 (SP05) and Summer 2005 (SU05) Screen-House and Field 2006 (FD06) Experiments at Cuu Long Rice Research Institute, Cantho, Vietnam

Variety	Experiment					
	SP05		SU05		FD06	
	Yield Reduction	Rank	Yield Reduction	Rank	Yield Reduction	Rank
	(%)		(%)		(%)	
DNOM 1	80.2	18.0	75.1	18.0	92.0	19.0
DNOM 3	37.9	9.0	57.0	8.0	88.2	17.0
DNOM 5	20.9	6.0	68.7	14.0	77.2	12.0
MTD652-5	83.0	19.0	100.0	21.0	75.2	11.0
MTD676	65.5	13.0	50.6	6.0	78.4	13.0
ATF15-1	7.8	3.0	49.0	3.0	47.6	3.0
DT93	21.5	7.0	67.9	12.0	50.9	4.0

Table 3. contd....

Variety	Experiment					
	SP05		SU05		FD06	
	Yield Reduction	Rank	Yield Reduction	Rank	Yield Reduction	Rank
	(%)		(%)		(%)	
Nam Vang	0.2	1.5	47.9	2.0	63.3	7.0
BR5-1	18.5	4.0	62.4	11.0	100.0	21.0
HL125	54.3	11.0	59.7	4.0	93.1	20.0
MSBR22	88.2	20.0	74.7	17.0	84.3	15.0
DT94	100.0	21.0	73.6	16.0	67.7	8.0
HL203	25.6	8.0	81.5	20.0	45.0	2.0
96113	20.3	5.0	71.5	15.0	80.2	14.0
MTD176	78.8	17.0	80.6	19.0	68.8	9.0
VND2	0.2	1.5	37.9	1.0	59.1	5.0
HL92	67.6	14.0	74.4	10.0	85.4	16.0
GC90013-21-15-10	59.9	12.0	68.0	13.0	37.6	1.0
MTD654-2	47.5	10.0	56.0	7.0	90.9	18.0
CPAC368-7-6	71.3	16.0	49.9	5.0	61.9	6.0
M 103	69.1	15.0	58.6	9.0	69.8	10.0

Table 4. Plant Height of 21 Soybean Varieties of Control (CO) and Flooding (FL) Treatments in the Spring 2005 (SP05) and Summer 2005 (SU05) Screen-House, and Field 2006 (FD06) Experiments at Cuu Long Rice Research Institute, Cantho, Vietnam

Variety	Plant Height (cm)					
	SP05		SU05		FD06	
	CO	FL	CO	FL	CO	FL
DNOM 1	48.4	15.4	64.2	72.9	53.4	58.5
DNOM 3	37.2	32.6	40.2	32.7	38.4	52.3
DNOM 5	57.6	51.4	66.3	38.0	37.5	47.3
MTD652-5	69.4	15.6	83.6	0.0	55.7	74.0
MTD676	51.0	26.2	68.6	43.3	45.3	57.3
ATF15-1	47.2	45.6	48.8	46.8	36.0	46.1
DT93	58.6	58.2	60.1	70.1	27.3	32.6
Nam Vang	51.8	67.2	48.2	52.8	38.9	51.3
BR5-1	46.6	31.2	46.7	31.5	40.9	51.4
HL125	52.8	35.4	52.2	53.5	46.2	45.9
MSBR22	51.8	12.4	57.3	37.1	44.5	52.0
DT94	44.6	0.0	51.7	44.7	41.4	46.7
HL203	34.6	38.6	54.3	49.7	40.6	47.5
96113	21.6	23.4	42.3	29.8	32.1	34.7

Table 4. contd....

Variety	Plant Height (cm)					
	SP05		SU05		FD06	
MTD176	55.0	14.8	79.6	19.8	62.3	65.4
VND2	25.8	37.2	23.2	26.8	30.3	35.5
HL92	48.8	23.4	55.0	41.1	40.9	42.6
GC90013-21-15-10	22.6	13.2	34.1	17.8	43.4	56.2
MTD654-2	62.8	48.4	70.5	48.3	66.6	68.9
CPAC368-7-6	55.0	25.8	47.4	30.5	37.1	49.7
M 103	49.6	21.0	53.7	44.8	37.7	42.7
Mean	47.3	30.3	54.6	39.6	44.6	50.5
Std Dev	12.6	16.9	14.4	16.7	9.8	11.1

Table 5. Correlation Coefficients of Seed Yield with Plant Height, Plant Survival, and Yield Components in Control (CO) and Flooding (FL) Treatments of the Spring 2005 (SP05) and Summer 2005 (SU05) Screen-House, and Field 2006 (FD06) Experiments at Cuu Long Delta Rice Research Institute, Cantho, Vietnam

		Plant	Plant	Reprod.	Reprod.	1-seed	2-seed	3-seed	Total	100-seed
	Treatment	Survival	Height	Branches	Nodes	Pods	Pods	Pods	Pods	Weight
SP05										
Yield	CO		0.53**	0.26	0.31	-0.47*	0.30	0.82****	0.42*	0.37
Yield	FL	0.96****	0.90****	0.79****	0.96****	0.30	0.78****	0.92****	0.91****	0.93****
SU05										
Yield	CO		0.47*	0.35	0.72	-0.03	0.18	0.22	0.45*	0.37
Yield	FL	0.64****	0.59**	0.56**	0.61**	0.35	0.33	0.07	0.47*	0.77****
FD06										
Yield	CO		0.67***						0.77****	0.21
Yield	FL	0.78****	0.40*						0.67***	0.50*

*, **, ***, **** significant at the 0.05, 0.01, 0.001, and 0.0001 levels of probability, respectively.

in the control treatment in any of the three experiments. In the SP05 and SU05 experiments, grain yield of the flooding treatment was correlated with the number of reproductive branches ($r = 0.79$, $p < 0.0001$ and 0.56 , $p < 0.01$, respectively), and number of reproductive nodes ($r = 0.96$, $p < 0.00001$ and 0.61 , $p < 0.01$, respectively).

Correlation Between Field and Screen House Tests

The correlation between the field experiment FD06 and screen-house experiments SP05 and SU05 was significant only for control plant height (Table 6). The correlation coefficients between the FD06 and SP05 experiments were 0.54 ($p < 0.01$) and between the FD06 and SU05 were 0.74 ($p < 0.0001$). Flooded plant height was not correlated between field and greenhouse experiments. Grain yield was also not correlated between field and screen-house tests of either treatment (Table 6).

DISCUSSION

Flooding stress in this study consisted of subjecting plants to water levels from 5 cm (screen-house experiments) to 10-15 cm (field experiment) above the soil surface. As such, the flooding treatment was more than just soil-waterlogging [2] but not as severe as complete submergence stress [3]. We have identified three soybean varieties which showed consistent tolerance to flooding stress under both screen-house and field tests. Of these, Nam Vang is a landrace collected from Cambodia; VND2, a germplasm in the collection of the Institute of Oilseed Crops originated from China; and ATF15-1, a germplasm in the collection of the Southern Agricultural Institute originated from Australia. The flooding tolerance of the seminal lines from which VND2 and ATF15 were selected is not known.

Flooding tolerance can be defined as minimal or no yield loss due to flooding [15]. In both screen-house and field

Table 6. Correlation Coefficients of Plant Height and Seed Yield Between Field (FD06) and Screen House (SP05 and SU05) Experiments at Cuu Long Delta Rice Research Institute, Cantho, Vietnam in 2005 and 2006. CO = Control Treatment, FL = Flooding Treatment

Correlation in plant height between field and screen-house tests				
Trait 1	CO Height FD06	CO Height FD06	FL Height FD06	FL Height FD06
Trait 2	CO Height SP05	CO Height SU05	FL Height SP05	FL Height SU05
R	0.54**	0.74***	-0.27	-0.35
Correlation in seed yield between field and screen-house tests				
Trait 1	CO Yield FD06	CO Yield-FD06	FL Yield FD06	FL Yield FD06
Trait 2	CO Yield SP05	CO Yield SU05	FL Yield SP05	FL Height SU05
R	0.1	0.11	0.26	0.13

*, **, *** significant at the 0.05, 0.01, and 0.001, levels of probability, respectively.

tests, control yields of the three tolerant varieties, which showed minimal yield loss due to flooding, were lower than the average control yield of all the varieties (Table 3). The results indicate that the reduction in yield due to flooding may be related to control yield: varieties with higher yield under control conditions were more suppressed under flooding conditions.

Flooding induces plant senescence in tobacco and tomato [16], sunflower [17], carrot [18], barley [19], peas [20], wheat [21, 22], and maize [23]. VanToai *et al.* [24] also reported that field flooding for two weeks at the R1 stage hastened soybean maturity from six to eight days. In this study, two weeks of field flooding at the R2 stage hastened the average maturity of the 21 varieties by 11 days (Table 1). Early senescence, however, was only accelerated by eight days among the three most tolerant varieties, or three days later than the overall average.

Although high grain yield is the ultimate criterion of flooding tolerance for crop producers, plant growth, including plant height, root, and shoot biomass, has also been frequently used as a determinant of flooding tolerance [9, 10, 25-26]. Two-week flooding at the R1 growth stage has been reported to reduce plant height of two soybean recombinant inbred populations and their parental lines from 16 to 28% [24]. However, growth responses of soybean to flooding were highly dependent on the plant growth stage when flooding occurred [6]. In this study, flooding for two weeks at the R2 stage reduced the average plant height in both screen house experiments; but flooded plants grew taller than control plants in the field experiment. The reason was not clear since the control plants of the field experiment were irrigated regularly and exhibited no indication of drought or any other stress. This study established the correlation between flooded plant height and flooded grain yield in both field and screen-house tests. Plant height, therefore, is a good indicator of tolerance of soybean to flooding at early reproductive stage.

In the greenhouse study by Linkemer *et al.* [6], flooding for seven days at the R3 stage reduced grain yield by 93% through reducing grain size, number of seeds per pod as well as number of pods per reproductive node. Both screen-house and field tests in our study indicated that flooded grain yield was correlated with higher number of pods per hill (or per

plant), as well as the 100-grain weight. The largest influence on grain yield in both field and screen-house tests was the number of plants which survived flooding stress.

Contrary to reports of greenhouse-grown soybean plants surviving flood conditions, screen-house tests in this study indicated that two weeks of flooding caused up to 100% plant death in susceptible varieties. The variation in results between this screen-house test and other greenhouse studies in which no plant death occurred could be due to two factors that affect plant growth: (i) the medium in which soybeans were grown in this study was non-fumigated field soil as compared to soil-less growth mixtures or sterilized soil mixture in other studies [7, 8], and injury to flood susceptible plants in this screen-house study could have been disease related. Phytophthora root and stem rot caused by *Phytophthora sojae* M.J. Kaufmann & J.W. Gerdermann is a common soybean disease in wet soil. (ii) the temperature and light intensity in our screen-house tests were much higher than the temperature and light of other greenhouse studies (Table 2). High temperature and high irradiance have been shown to increase plant injury to flooding [27, 28].

CONCLUSIONS

The present study of 21 soybean varieties grown under three conditions demonstrated that screen-house tests with non-fumigated field soil can provide a good model for flooding tolerance testing when plant growth is used as a criterion. It also indicates that screen-house tests, while not completely duplicating field tests, can distinguish tolerant varieties from susceptible varieties. Flood-tolerant varieties survived better, grew taller, produced more pods/plants and heavier seed weight than susceptible varieties in both screen-house and field tests. The three most tolerant varieties identified in this study --VND2, Nam Vang and ATF15-1-- could provide new germplasm resources for genetic improvement of tolerance of soybean to flooding up to 5-15 cm above the soil surface. Tolerance of these varieties to soil waterlogging or complete submergence will remain to be determined.

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LIST OF ABBREVIATIONS

CO	=	Control
FD06	=	Field 2006 experiment
FL	=	Flooding
SP05	=	Spring 2005 screen-house experiment
SU05	=	Summer 2005 screen-house experiment

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