Diversity in Tolerance of Soybean (*Glycine max* L. Merr.) Germplasm to Soil Waterlogging

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Introduction

Monoculture of irrigated paddy rice, common in the Mississippi delta of the United States and in Asia, diminishes soil nutrients, compacts soils, contaminates water supplies, and increases pests and diseases. While the addition of soybean (*Glycine max* L. Merr.) crops to this cropping ecosystem can attenuate many of these problems, the soybean plants must be tolerant to waterlogging.

Genetic variability for flooding tolerance exists among soybean cultivars (VanToai et al., 1994). In a three-year field screening of 360 soybean cultivars for tolerance to severe soil waterlogging, Shannon et al. (2005) reported a 40% reduction in yields of the flood-tolerant group versus the 80% reduction in yields of the flood-susceptible group.

In some cases, plants that survive flooding die after the stress is removed (Sullivan et al., 2001). The post-flooding period can be as injurious as flooding itself, in part because of senescence-associated processes initiated in response to the original stress. Plants which are tolerant to flooding not only need to survive or grow during the stress but also need to recover after the stress is removed. Yield losses are the result of plant death due to diseases and physiological stress and reduced root growth, shoot growth, nodulation, nitrogen fixation, photosynthesis, biomass accumulation, and stomatal conductance (Oosterhuis et al., 1990; VanToai et al., 1994 and 2001).

Since current U.S. soybean cultivars come from a narrow genetic base (Gizlice et al., 1994 and 1996), soybeans with better waterlogging tolerance may be found in cultivars and landraces from other countries. Soybeans in Southeast Asia are often cultivated under wet conditions and could have high tolerance to soil waterlogging. In this study, we determined the responses of 22 soybean cultivars, landraces and plant introductions from Vietnam to waterlogging at the R2 growth stages under field and screen house conditions. Comparative responses of soybean to flooding in the two environments were documented to verify if screening under screen house conditions can model field tests. Seed yield, and yield components after recovery from flooding stress were quantified and their correlation with plant growth analyzed for each of the 22 soybean genotypes.

Materials and Methods

Plant Materials

The study was conducted with 22 soybean genotypes developed in, native to, or introduced into Vietnam. They include landraces from Vietnam and Cambodia, plant introductions from Taiwan or unknown origin and cultivars developed by traditional or mutation breeding (Table 1).

Table 1

Origin and maturity of 22 germplasm lines developed in, native to, or introduced into Vietnam evaluated for flooding tolerance in screen-house and field experiments at the Cuu Long Delta Rice Research Institute, Cantho, Vietnam in 2005 and 2006.

Genotype	Origin	Screen House SP2005 CO*	Screen House SP2005 R2WL	Screen House SU2005 R2WL	Field SU2206 R2WL
		Maturity (DAS)			
DNOM 1	Landrace from Thonot district	90	77*	85	73
DNOM 3	Landrace from Thonot district	86	75	77	76
DNOM 5	Landrace from Thonot district	87	73	77	78
MTD652-5	Cantho Univ. collection	87	76	84	78
MTD676	Cantho Univ. collection	84	78	84	75
ATF15-1	Southern Agric. Inst. collection	88	71	74	74
DT93	From a cross of 821 (Vietnam) x 134 (Japan) released by Agric Univ No1,	84	69	70	74
Nam Vang	Landrace from Cambodia	83	69	71	74
BR5-1	Inst of Oilseed Crops	88	74	78	74
HL125	Hung loc Agric Res Inst	85	74	78	74
MSBR22	PI of unknown origin	85	72	79	77
DT94	From a cross of DT 84 x EC2004, Agric Genetics Inst	84	72	74	74
HL203	Hungloc Agric Res Inst- PI from Taiwan	84	72	74	76
96113	PI of unkown origin	90	72	78	76
MTD176	Cantho Univ collection	87	72	74	75
VND2	From Inst Oilseed Crops- unknown origin	83	72	70	76
HL92	Hungloc Agric Res Inst, PI from Taiwan	84	73	71	74
GC90013-21-15-10	PI of unknown origin	87	72	72	74
MTD654-2	Cantho Univ collection	86	76	78	74
CLS2111	Inst of Oilseed Crops collection		73	78	
CPAC368-7-6	PI of unknown origin	89	74	78	77
M 103	Released by Ag Univ.No. 1 by mutation breeding of V70	85	69	78	72
ATF15-2	Southern Agric Inst collection	83	69	74	74
	Average	86	75	76	75

*Control plants of summer 2005 screen house and summer 2006 field experiments showed similar maturity

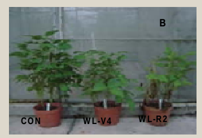
Screen House Experiments

Plants of each of the 22 soybean genotypes were grown in the screen house of the Cuu Long Delta Rice Research Institute, Cantho, Vietnam in the spring and summer 2005. Seeds were planted in 22-cm pots at 4 seeds per pot filled with fumigated top-soil. After 15 days, seedlings were thinned to 2 plants per pot.

Waterlogging stress was imposed at the R2 growth stage by placing individual pots in 30-cm buckets and adding water to the outside buckets until 5 cm above the soil surface. Plants in the control treatment were watered to maintain normal growth and no stress. After two weeks, pots in the waterlogging treatments were drained and plants allowed to recover (Figure 1). Plants were grown to maturity and seed yield in grams per plant, plant height in cm (measured from the soil surface to the top of the plant), number of branches, number of reproductive nodes, number of pods per plants, number of seeds per pod and 100-seed weight were determined. Measurements were taken on individual plants within each pot (experimental unit) and the means calculated. Each treatment was replicated three times for each variety.

Figure 1

Screen house experiment, summer 2005. A. Plants after one week of recovery from two-weeks of waterlogging. B. Close-up photo of one genotype. CON, control; WL-V4, waterlogging at the V4 stage; WL-R2, waterlogging at the R2 stage



Field Experiment

The field experiment was conducted in the spring of 2006 on two adjacent fields of Cuu Long Delta Rice Research Institute, Omon, Cantho, Vietnam (latitude 10°05' N and longitude 105° 42' E) with the same 22 genotypes. The control, non-flooded field had drainage ditches around and between replications, whereas the flooded field was surrounded by dikes. The genotypes were assigned in a randomized complete block design with three replications in each field. Plots were six rows 3.0 m long x 2.4 m wide and 0.4 m between rows. Seeds were hand-planted on 3 March 2006 at 3-4 seeds per hill at the spacing of 20 cm within each row. After two weeks seedlings were thinned to 2 plants per hill. Fertilizer was applied at the rate of 60-60-30 kg NPK/ha. Weeds were controlled by herbicides and manual weeding. Pesticides for diseases and insect control were applied as needed.

Waterlogging application was imposed when the majority of soybean genotypes reached the R2 growth stage by pumping water to a depth of 10 cm above the soil surface lasting for a total of two weeks. At maturity, plant height, number of survived plants and seed yield were recorded.

Statistical Analysis

Statistical analyses 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, seed yield and other plant growth parameters. If the variety effect from the Analysis of Variance was significant at $p < 0.05$, Least Significant Differences (LSD) were used to summarize differences among the genotypes.

A dependent variable "percent reduction from the control treatment" was calculated according to the formula: Percent reduction = [(control-waterlogged)/control] *100. To identify waterlogging-tolerant genotypes, the yield reduction due to waterlogging at the R2 stage of all genotypes 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 =22. The waterlogging tolerance index (WLTI) was devised by adding the ranking across three experiments. Pearson correlation analyses were conducted using the PROC CORR.

Results

Table 2

Plant height of 22 soybean genotypes of control and waterlogging treatments in screen-house and field experiments at the Cuu Long Delta Rice Research Institute, Cantho, Vietnam in 2005 and 2006.

Genotype	Screen-house 2005 Spring Control Plant height (cm)	Spring WL Plant height (cm)	Spring WL Height reduction (%)	Summer Control Plant height (cm)	Summer WL Plant height (cm)	Summer WL Height reduction (%)	Field 2006 Control Plant height (cm)	Field 2006 WL Plant height (cm)	Field 2006 WL Height reduction (%)
DNOM 1	48.4	56.7	-35	64.2	72.9	-21	53.4	58.6	-18
DNOM 3	37.2	52.9	-113	40.2	49.3	-56	38.4	52.5	-96
DNOM 5	55.9	61.5	-18	66.3	54.6	27	37.5	47.3	-70
MTD652-5	69.4	56.2	27	83.6	49.9	48	55.7	76.0	-65
MTD676	51.1	56.6	-21	68.6	59.9	19	45.3	57.4	-59
ATF15-1	47.2	55.7	-38	48.8	46.7	9	36.0	46.6	-82
DT93	58.6	68.3	-28	60.1	70.1	-28	38.4	56.2	-121
Nam Vang	51.8	67.2	-57	48.2	52.8	-20	38.9	51.3	-82
BR5-1	46.6	54.9	-38	46.7	48.1	-6	35.9	51.2	-119
HL125	52.8	55.7	-10	52.2	53.5	-5	41.2	46.8	-33
MSBR22	51.8	53	-4	57.3	53.7	11	39.5	54.5	-96
DT94	44.6	nd		51.7	44.7	26	36.4	47.1	-81
HL203	34.6	48.7	-118	54.3	49.7	16	35.6	47.8	-96
96113	21.6	29.3	-165	42.3	46.4	-23	27.1	35.0	-108
MTD176	55	55.4	-1	79.6	52.9	42	57.3	65.1	-24
VND2	25.8	37.2	-171	23.2	26.8	-67	25.3	31.7	-100
HL92	48.8	53.8	-21	55	45.7	31	35.9	42.6	-52
GC90013-21-15-10	22.6	33	-204	34.1	34.5	-4	27.1	32.4	-72
MTD654-2	62.8	68.7	-15	70.5	64.9	11	61.6	68.9	-19
CPAC368-7-6	55.1	56.2	-4	47.4	47.1	1	32.1	49.6	-170
M 103	49.6	51.4	-7	53.6	44.8	31	32.5	43.0	-99
ATF15-2	51.4	nd		48.3	39	40	36.5	48.9	-93
Average	47.7	53.6	-36	54.1	50.2	9	39.4	50.5	-74
SD	12.1	10.4		13.9	10.3		9.7	10.8	

Table 3

Survival and seed yield of 22 soybean genotypes of control and waterlogging treatments in screen-house and field experiments.

Genotype	Screen House SP2005 Waterlogging Survival Plants (%)	Screen House SU2005 Waterlogging Survival Plants (%)	Field SU2206 Waterlogging Survival Plants (%)	Screen House SP2005 CO Seed yield (g/plant)	SP2005 WL Seed yield (g/plant)	SU2005 CO Seed yield (g/plant)	SU2005 WL Seed yield (g/plant)	Field SU2006 CO Seed yield (g/plot)	Field SU2006 WL Seed yield (g/plot)
DNOM 1	20	67	5	44.5	8.8	92.2	32.0	746.7	60.0
DNOM 3	60	67	0	53.0	32.9	96.4	41.5	339.1	-
DNOM 5	80	50	7	61.8	48.9	95.4	29.9	622.3	141.7
MTD652-5	20	0	13	59.5	10.1	95.4	0.0	886.7	220.0
MTD676	40	67	7	49.0	16.9	99.8	49.3	897.5	193.5
ATF15-1	80	84	13	56.3	51.9	88.8	35.3	286.0	150.0
DT93	80	100	27	63.2	49.6	92.1	29.6	583.5	286.7
Nam Vang	100	100	28	54.7	54.6	69.8	36.4	653.6	240.0
BR5-1	80	67	0	59.6	48.6	89.2	33.5	780.0	-
HL125	60	84	5	69.1	31.6	101.8	61.0	435.8	30.0
MSBR22	20	50	12	88.7	10.5	99.2	25.1	635.3	100.0
DT94	0	67	13	70.3	0.0	99.7	26.3	689.6	222.5
HL203	80	67	20	53.9	40.1	97.0	17.9	527.7	290.0
96113	80	50	13	37.9	30.2	70.6	20.1	303.0	60.0
MTD176	20	33	7	63.1	13.4	87.8	17.0	705.2	220.0
VND2	100	100	20	51.9	51.8	58.5	36.3	342.4	140.0
HL92	40	67	3	61.8	20.0	68.7	36.7	480.0	70.0
GC90013-21-15-10	40	67	20	47.4	19.0	67.5	21.6	408.4	255.0
MTD654-2	60	67	5	59.6	31.3	90.2	39.7	714.1	65.0
CPAC368-7-6	40	67	5	71.1	20.4	90.6	45.4	590.5	225.0
M 103	40	100	5	65.1	20.1	103.5	42.9	264.5	80.0
ATF15-2	0	100	20	61.9	0.0	99.6	43.8	508.8	250.0
Average	50	70	11	59.2	27.8	88.8	32.8	563.7	165.0
SD	31	24	8	10.6	17.6	13.0	13.0	190.0	85.0

Table 4

Seed yield reduction and waterlogging tolerance index (WLTI) of 22 soybean genotypes calculated as described in the text.

Genotype	Screen House SP2005 Seed yield Reduction (%)	Screen House SU2005 Seed yield Reduction (%)	Field SU2206 Seed yield Reduction (%)	Screen House SP2005 Rank	Screen House SU2005 Rank	Field SU2206 Rank	**WLTI**
VND2	0.2	37.9	59.1	1.5	1.0	6.0	**9**
Nam Vang	0.2	47.9	63.3	1.5	4.0	8.0	**14**
ATF15-1	7.8	60.3	47.6	3.0	11.0	3.0	**17**
DT93	21.6	67.9	50.9	7.0	14.0	4.5	**26**
GC90013-21-15-10	60.0	68.0	37.6	12.0	15.0	1.0	**28**
CPAC368-7-6	71.3	49.9	61.9	16.0	5.0	7.0	**28**
HL203	25.6	81.5	45.0	8.0	21.0	2.0	**31**
MTD676	65.5	50.6	78.4	13.0	6.0	14.0	**33**
HL125	54.2	40.1	93.1	11.0	2.0	20.0	**33**
HL92	67.6	46.6	85.4	14.0	3.0	17.0	**34**
ATF15-2	100.0	56.0	50.9	21.5	8.0	4.5	**34**
DNOM 5	20.8	68.7	77.2	6.0	16.0	13.0	**35**
MTD654-2	47.5	55.9	90.9	10.0	7.0	18.0	**35**
M 103	69.2	58.6	69.8	15.0	10.0	11.0	**36**
96113.0	20.3	71.5	80.2	5.0	17.0	15.0	**37**
BR5-1	18.5	62.5	100.0	4.0	12.0	21.5	**38**
DNOM 3	37.9	56.9	100.0	9.0	9.0	21.5	**40**
MTD176	78.7	80.6	68.8	17.0	20.0	10.0	**47**
DT94	100.0	73.6	67.7	21.5	18.0	9.0	**49**
DNOM 1	80.3	65.3	92.0	18.0	13.0	19.0	**50**
MTD652-5	83.0	100.0	75.2	19.0	22.0	12.0	**53**
MSBR22	88.1	74.7	84.3	20.0	19.0	16.0	**55**

Table 5

Pearson correlation coefficients of seed yield with plant height and yield component traits of soybean in control and waterlogging treatments of screen-house and field experiments.

Trait	**Seed Yield Control SH-SP05**	**Control SH-SU05**	**Control FD-SU06**	**Waterlogging SH-SP05**	**Waterlogging SH-SU05**	**Waterlogging FD-SU06**
Plant height	0.53**	0.51*	0.67***	0.18	0.04	0.1
Branches	0.20	0.35		-0.13	0.23	
Repro nodes	0.32	0.58**		0.18	0.34	
1-seed pods	-0.47*	-0.10		-0.26	-0.15	
2-seed pods	-0.30	0.14		0.09	0.35	
3-seed pods	0.8***	0.36*		0.40*	0.65***	
Pods/plant	0.41*	0.41*	0.64**	0.34	0.65***	0.74***
100-seed weight	0.33	0.27	0.14	0.29	0.28	0.30

* = significant at $p \leq 0.05$
** = significant at $p \leq 0.01$
** * = significant at $p \leq 0.001$

Table 6

Pearson correlation coefficients of plant height and seed yield between field and screen-house experiments.

Plant height	Height FD-CO	Height FD-CO	Height FD-R2	Height FD-R2
Plant height	Height SU-CO	Height FA-CO	Height SU-R2	Height FA-R2
R	0.702***	0.851****	0.697**	0.656**

Seed yield	Yield-FD-CO	Yield-FD-CO	Yield-FD-R2	Yield-FD-R2
Seed yield	Yield-SU-CO	Yield-FA-CO	Yield-SU-R2	Yield-FA-R2
R	0.149	0.294	0.03	0.353

* = significant at $p \leq 0.05$
** = significant at $p \leq 0.01$
** * = significant at $p \leq 0.001$
** **= significant at $p \leq 0.0001$

Summary

Waterlogging for 2 weeks at the R2 stage reduced seed yield under field conditions between 37 and 100% (all plants dead). However, plants that survived flooding averaged 29% taller than control plants. Three genotypes, VND2, Nam Vang and ATF15-1 had the best waterlogging tolerance indexes (WLTI). These lines provide new germplasm resource for the genetic improvement of waterlogging tolerance in soybean. Tolerance to R2 waterlogging was associated with higher number of pods per plant and more seeds per pod. Growth response to waterlogging stress, as determined by plant height, was correlated between the field and screen house.

The present study of 22 soybean genotypes under three growing conditions documented that screen house studies can provide a good model for waterlogging tolerance testing when plant growth is used as criterion. It also indicated that screen house tests, while not completely duplicating field tests, could distinguish tolerant cultivars from susceptible cultivars.

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