Water-logging tolerance in pigeonpea [*Cajanus cajan* (L.) Millsp.]: Genotypic variability and identification of tolerant genotypes

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ABSTRACT

Pigeonpea is an important legume crop of the semi-arid tropics. In India, pigeonpea is mostly grown in water-logging prone areas resulting in major production losses. It is imperative to identify genotypes which show tolerance at the critical crop growth stages to prevent these losses. A panel of 272 diverse pigeonpea accessions was evaluated for seed level water submergence tolerance for different durations (0 h, 120 h, 144 h, 168 h, and 192 h) under *in-vitro* conditions in the laboratory. All genotypes exhibited high (79 to 98.6 %) survival rates for up to 120 h of submergence. After 192 h of submergence, the hybrids as a group, exhibited significantly higher survival rates (79%) than the germplasm (71%), elite breeding lines (68%), and released cultivars (58%). Ninety-six genotypes representing the phenotypic variation observed during the laboratory screening were further evaluated for water-logging tolerance at the early seedling stage using pots, and survival rates were recorded eight days after completion of the stress treatment. Genotypes were further narrowed down from 96 to 49 in order to evaluate their performance under natural field conditions. Among the cultivated varieties and hybrids the following were identified as tolerant after three-levels (*In-vitro,* pot

and field) of testing: ICPH 2431, ICPH 2740, ICPH 2671, ICPH 4187, MAL 9, ABHAYA, LRG 30, MARUTI, ICPL 20128, ICPL 20237, ICPL 20238, ASHA, and MAL 15. These materials can be used as sources of water-logging tolerance in breeding programs.

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important legume crop, mainly grown in the semi-arid tropical (SAT) regions of Asia, Africa, Latin America, and the Caribbean (Saxena, 2008). The total global area planted with pigeonpea is 4.5 m ha (FAOSTAT, 2009). India is the number one producer (3.38 m ha) of pigeonpea and imports an additional 400,000 tonnes from Myanmar and Africa to meet domestic needs. Although dozens of pigeonpea varieties have been released, productivity has remained stagnant at around 672 kg ha^{-1} (FAOSTAT, 2009) due to various genetics, management, and biotic and abiotic constraints. Since the area of cultivation is not likely to increase, breeding efforts focusing on breaking the yield barrier through hybrid breeding (Saxena *et al.* 2010) and increasing sustainability of production through incorporating tolerance to major biotic and abiotic stresses are needed to increase production and productivity.

Water-logging during the monsoon season (June to September) in India, is caused by erratic and prolonged rains and represents an important production constraint. Since pigeonpea is primarily grown in deep *vertisols* and in the areas with mean annual rainfall of 600-1,500 mm, water-logging becomes a serious problem (Chaudhary *et al.* 2011). Water-logging occurs when the water table attains a level at which the soil pores in the root zone of the plants are fully saturated and restrict normal air circulation. Consequently, oxygen level in the soil declines and carbon dioxide concentration increases, which adversely affects the growth and development of plant roots. Drastic reduction in oxygen level and increase in carbon dioxide concentrations are the primary stresses to which the plants are exposed under water-logging conditions (Vartapetian & Jackson, 1997). Inability of aerobic crop species, such as pigeonpea to endure low oxygen conditions at the rhizosphere level, results in substantial yield losses. Roots of most plants are highly susceptible to anaerobic conditions, which support a unique microbial community; and this severely affects the nutrient balance of the soil (Levitt 1980; Laanbroek 1990; Ponnamperuma 1972) and plant health. Soon after the onset of short periods of excessive moisture conditions, obligate aerobic bacteria become inactive, and facultative/obligate anaerobic bacteria become active and dominate the micro-flora in the inundated soils (Sachs *et al.* 1980; Jackson 1990). Another adverse effect of water-logging is leaching of important minerals or essential intermediate metabolites from roots into water (Laanbroek 1990; Rathore *et al.* 1997). Water-logging also induces certain changes in physical and chemical properties in the rhizosphere. The gaseous diffusion rates in flooded soils are about 100 times lower than normal (Kennedy *et al.* 1992), and respiration of plant roots, soil micro-flora and fauna leads to rapid exhaustion of soil oxygen, thereby causing anaerobiosis.

In India, about 8.5 m ha of arable land is prone to this problem. A recent comparative analysis of pigeonpea growing regions revealed that almost all the states that grow pigeonpea in India are affected by water-logging. It is estimated that around 1.1 mha of the total area under pigeonpea is affected by excess soil moisture, causing an annual loss of 25-30% in production (Chaudhary *et al.* 2011).

Considering the important yield losses caused by water-logging in pigeonpea, it is imperative to identify solutions. Although certain soil management options such as the use of raised sloping seed beds, ridge sowing, and transplanting of seedlings, help in reducing losses caused by water-logging (Abebe *et al.* 1992). These options are not economically viable for the resource poor farming community of the SAT. Hence, the use of tolerant genotypes is the most economical and simple way to minimize losses caused by water-logging in pigeonpea.

According to Khare *et al.* (2002) the initial establishment of seedlings is the most critical consideration for pigeonpea in water-logging prone areas. Therefore, the objective of this study was to assess the genotypic variability for water-logging tolerance in pigeonpea and to identify genotypes capable of withstanding water-logging stress conditions at sowing and early seedling stages under field prone conditions.

MATERIALS AND METHODS

Critical evaluation of rainfall pattern during the monsoon season (June-September) at Patancheru, Andhra Pradesh, India (latitude 17°32′N; longitude 78°16′E; elevation 545 m) and its overlap with pigeonpea growing stages allowed the most water-logging vulnerable stages as well as the time of occurrence to be identified. Pigeonpea seedlings receive maximum rain during the months of July and August (Fig. 1). Since, the seed (just after sowing), and early seedling stage (15-35 d old seedling) in pigeonpea are very sensitive to water-logging (Fig. 1), the screening methodology was optimized taking into account the crop growth stages that were most severely affected by water-logging.

Laboratory screening (seed stage evaluation): Genotypic variability of 272 pigeonpea genotypes differing in maturity, seed color, seed size and origin were evaluated for water submergence tolerance under laboratory conditions using a simple screening method that allowed evaluation of many genotypes in a short period. The genotypes used in this study consisted of 114 elite breeding lines (ICPLs), 91 germplasm accessions (ICPs), 34 pure line varieties, and 33 Cytoplasmic Male-Sterility (CMS)-based hybrids (ICPHs). All genotypes were obtained from ICRISAT’s (International Crops Research Institute for the Semi-Arid Tropics) global gene bank and from the ICRISAT’s pigeonpea breeding program (Table 4). Seeds from all the genotypes were collected from the 2009 crop season and stored at 2–4^{0}C until used in the experiment. To avoid the incidence of fungal infection, the seeds were treated with *Thiram* dust (3 g kg^{-1} seeds) before imposing submergence treatments. The genotypes were classified into different groups based on maturity duration (short, medium or late) and seed coat color (light or dark colored),. The materials included 196 medium to late (160 to 270 d) and 76 early (120 to 155 days to 75% maturity) maturing genotypes. A total of 208 genotypes had dark colored (black, purple, dark brown, brown) seeds, while 64 lines had light colored (white, off-white, and cream) seeds. The experiment was conducted under laboratory at ICRISAT, Patancheru, Andhra Pradesh, India during 2009.

The genotypes were subjected to water submergence treatments in 200 mL beakers with 10-cm diameter containing 100 mL of water at 23 ± 1^{0}C. The submergence treatments were established as a function of the submersion time (S120, S144, S168 and S192 for groups of seeds submerged for 120, 144, 168 and 192 hours, respectively). A baseline (S0 = no submergence treatment) germination test was performed by placing 20 seeds of each genotype between two paper towels in plastic petri-dishes and maintaining humidity as necessary. The durations of S120, S144, and S168 may be comparable to field observations of soil water-logging timing at the study site, especially during rainy years. The S192 duration was specifically selected for this experiment in order to check the seed viability under extended (8 days) submergence. Each test sample consisted of 20 seeds and evaluated in three replications. After completing each stress period, the seeds were dried on filter paper for 4 - 5 h to drain excess water and then placed on paper towel in a petri-plate and kept for germination at a constant temperature (25 ± 2^{0}C) in a dark room. The seeds were considered germinated when their radicle reached the length of at least 2 mm. The germinated seeds were counted and percent survival was calculated 5-6 days after completing stress treatment.

Analysis of variance was performed using SAS software (SAS, 2008) to assess the variation among genotypes, submergence durations and their interactions. The germination data (percent) were arc-sine-transformed (Gomez and Gomez, 1984) to induce linearity in the data set. In addition, further analysis was also performed to compare relative survival rate performance of the four genotypic groups within submergence durations using linear contrasts. The associations of survival rates under the different water-submergence treatments with seed color and maturity duration were assessed using a t-test.

Pot screening (early seedling stage evaluation): 96 out of 272 pigeonpea genotypes representing the four genotypic groups (hybrids, lines, germplasm and varieties) that showed tolerance or moderate tolerance and susceptibility to water submergence at the seed stage during laboratory screening were further evaluated for water-logging tolerance at the seedling stage (15 d old). The evaluation was conducted using 4'' diameter plastic pots perforated at the base at three points with orifices of 5.0 mm diameter. Pots were filled with a mixture of *vertisols*, and farmyard manure (FYM); soil to FYM ratio was 50:1 (V/V). Amount fertilizers (NPK) was calculated on soil weight basis and thoroughly mixed in the soil. Each pot was weighed after filling in order to maintain the same quantity of soil and maintain constant moisture in each pot. For each genotype, five pots were prepared (four pots for imposing stress treatment and one kept as control - no treatment). Filled pots were sown on 24 February, 2010, with 5 seeds per pot at 2.0-cm depth using a completely randomized design. All pots were kept in a glass house at an average temperature of 32 ± 2^0C. Before application of water stress treatment, the number of plants in each pot was counted. The stress treatment was imposed by submerging four pots in a tray filled with water in such a way that the pots surface remained at least 2 cm under water for 11 days while the fifth pot was kept at normal moisture as a control. The water level in the trays was kept constant throughout the experiment and maintained for 11 days. Survival rates were recorded eight days after completion of the stress treatment with reference to control. Analysis of variance was performed using SAS software (SAS, 2008) to assess the variation among genotypes for survival rates after imposing stress treatment.

Field level evaluation (Screening under natural conditions): Forty-nine genotypes were further evaluated under natural field conditions to confirm the levels of tolerance observed under laboratory and pot screening. The field trial was conducted at ICRISAT, Patancheru, Andra Pradesh, India on 14 July, 2010 with four replications using a 7 x 7 lattice design in deep *vertisols* on a flatbed rice field with no drainage. Seeds were planted with 50 cm spacing between rows and 25 cm within rows in 4-row plots with 2.5 m long rows. Before planting 46 kg nitrogen ha^{-1} in the form of DAP, was applied as a basal dose. Pre-emergence application of pendimethaline and atrazine mixture (both 0.75 kg ha^{-1}a.i.) was sprayed to keep the crop free from weeds. Soon after sowing, the rains commenced and continued for up to 60 d including 45 rainy days (950 mm rain, and $29 \pm 1^{o}C$ average temperature). Thus, the crop was exposed to continuous natural water stress beginning seven days after sowing with an average water depth of 2.0 ± 1.0 cm and continued for up to 53 d (Fig. 1). The plant survival counts were based on final plant stand at maturity (180 d from sowing). Analysis of variance was performed using SAS software (SAS, 2008) to assess the variation among genotypes for survival rates before harvest.

RESULTS

Seed stage evaluation

Effect of submergence durations on seed survival

All genotypes exhibited ≥ 90 % survival rate irrespective of their origin when germinated under normal moisture conditions (S0, control = no submergence) (Fig. 2). The analysis of variance showed highly significant differences ($p < 0.01$) among genotypes for seed survival rates for all submergence durations (Table 1). There were also significant survival rate differences among the various submergence durations (S120, S144, S168, and S192). The interaction between genotypes and submergence durations was also significant; therefore further analysis was carried out to understand genotypic performance at each submergence duration. This analysis revealed that the variation among genotypes for survival rate was highly significant at all the submergence durations (Table 2). To explore further, the four distinct genotypic groups (hybrids, germplasm, breeding lines, and varieties) were compared using linear contrasts. Significant differences between groups for survival rates were recorded for the submergence durations. However, as individual group; germplasm and hybrid, as well as varieties and lines were found statistically similar at S144, whereas at S192 the lines and germplasm performed in a similar way (Table 3). The analysis further revealed that after 120 h treatment the genotypes, irrespective of their origin, had high (> 80%) mean survival rates. Even after 168 h of submergence the mean survival rate was 73%, which suggested that most of the genotypes had potential to tolerate severe submergence stress. A sharp decline in seed viability was observed at the 192 h submergence period (Fig. 2). After 192 h of submergence the hybrids exhibited highest survival rate (>79%) followed by germplasm accessions (71%), advanced breeding lines (68%), and released varieties (> 58%) (Fig. 3).

Relationship of maturity, seed color, and seed weight with survival rate

Medium to late maturing genotypes, irrespective of their origin, had significantly ($p < 0.01$) higher mean survival rate (69.9%) than that of short maturity types (41.7%) (Fig. 4). Further group-wise analysis revealed that in general the medium to late maturing inbred lines had higher survival rates (78.3%) than short (45.3%) maturing types. Similar results were recorded among germplasm and varieties. However, hybrids exhibited consistently high survival rate irrespective of their maturity groups. It was also observed that the mean survival rate was significantly higher in the genotypes with dark colored seed coats (64.5%) in comparison with light colored seed coats (54.4%). In addition to maturity and seed coat color, the seed size was found to be positively associated ($p < 0.05$) with survival rate of the genotypes at all the levels of submergence treatment, S120 ($r = 0.234^*$), S144 ($r = 0.196^*$), S168 ($r = 0.163^*$) and S192 ($r = 0.152^*$).

Based on the results of laboratory survival rates, the genotypes were classified into four groups (Table 4); tolerant (>75), moderately tolerant (50-74%), moderately susceptible (25-49%) and susceptible (<25%). Survival rate at the S192 duration, varied from 20 to 100, 2 to 100, 2 to 100 and 0 to 93.3 in hybrids, germplasm, elite inbred lines, and varieties, respectively.

Evaluation at early seedling stage

Ninety-six pigeonpea genotypes including tolerant (46), moderately tolerant (10) and susceptible (40) were further evaluated at the seedling stage for water-logging tolerance. Analysis of variance revealed highly significant differences ($p < 0.01$) among the genotypes for seedling survival which ranged from 0 to 95 % (Table 4 and Fig. 5). Most of the genotypes (54) tested for survival rate at early seedling stage in pots were found to be sensitive to water-logging and only a few genotypes exhibited high (up to 100%) germination. The most tolerant genotypes had dark seed color, medium to late maturing type and had 100 seed weight > 10 g.

Field evaluation

The forty-nine genotypes screened under natural field conditions showed significant variability for survival rate. A subset of genotypes which showed a high level of water-logging tolerance in all the three levels of screenings (Laboratory, Pot, and field screening) during 2009 and 2010 years were: early - ICPH 2431, medium -ICPH 2740, ICPH 2671, ICPH 4187, Asha, Abhaya, LRG 30, Maruti, ICPL 20117, ICPL 20125, ICPL 20128, ICPL 20237, ICPL 20238, ICPL 99050, and late maturity- ICPL 20092, MAL 9, and MAL 15 (Table 4). All the tolerant genotypes had dark seed color with 100 seed weight > 10 g.

DISCUSSION

The diverse rainfall patterns in India render the country highly vulnerable to floods as more than 90% of pigeonpea is grown under rainfed condition (Saxena 2008). Among the abiotic stresses that affect pigeonpea, water-logging during seed germination, seedling establishment, and early vegetative growth stage result in poor plant stands (Duke & Kakefuda, 1981) which leads to significant yield losses and instability in production (Reddy & Virmani, 1981). Water-logging during germination and emergence generally results in poor plant stands. According to Powell & Mathews (1978) injury to the seeds is caused by excessive water accumulation due to rapid water absorption.

In the present *in-vitro,* pot, and in field screening of pigeonpea, genotypes for water-logging tolerance observed the significant differences for survival rates, indicating the presence of large genotypic variability (Table 4). The genotypic differences for water-logging tolerance at seedling level in pigeonpea were also studied by Dubey & Asthana 1987; Tekele & McDavid 1995; Chauhan *et al.* 1997; Perera *et al.* 2001; Sarode *et al.* 2007; and Krishnamurthy *et al.* 2011. In the present study 68% and 44% of the pigeonpea genotypes evaluated at seed and early seedling stages respectively were found tolerant, the survival rates reduced drastically, with increased duration of soaking in laboratory tests. Some of the susceptible materials started deteriorating after 120 h of soaking (Fig. 2). The reductions in survival rate under prolonged submergence were attributed to anoxia/hypoxia (Orchard & Jessop 1984). Oxygen deprivation, either complete (anoxia) or partial (hypoxia) is detrimental to most species of higher plants, inevitably raising the question of whether there are some fundamental physiological differences among plants in their cellular responses to the imposed anaerobiosis. It is often assumed that most cultivated species avoid, rather than tolerate the oxygen shortages (Armstrong *et al.* 1994). Respiration and electron transport under anoxic conditions are inhibited and adenosine tri-phosphate (ATP) formation is decreased (Johnson *et al.* 1989; Tsai *et al.* 1997) which results in decreased seed viability and poor germination. In the present study, the survival rate was found to be related with the origin of genotypes (Fig. 3). Among the four contrasting genotypic groups, the hybrids exhibited greater survival rates compared to germplasm accessions, elite inbred lines, or varieties. In most of the genotypic groups the reduction in survival rates was more or less similar after each submergence period, but the maximum reduction in survival was recorded in the pure line varieties (Fig. 3). This may be due to differences in the imbibition rates and the amounts of reserved materials present in the seeds. Significant varietal differences in response to flooding tolerance have been reported in maize (*Zea mays* L.) and it was found that hybrids performed better than inbred lines under excess soil moisture conditions (Sultana *et al.* 2009). This was attributed to the fact that hybrid seeds may have experienced less oxygen deprivation during submergence as compared to pure lines. It may also be related to relatively high initial vigor or more food reserves in the hybrids (data not published). In pigeonpea hybrids, such variability might also be related to the ability of hybrids to utilize the stored assimilates through anaerobic metabolism during germination and early seedling growth.

After evaluation for water-logging tolerance in the laboratory, pot and field levels, medium to late maturing genotypes had higher survival rate compared to short duration types that may be related to their seed size (Fig. 4). Short duration pigeonpea were more sensitive to short term water-logging because they have less time to recover from this stress in comparison to long duration types Matsunaga *et al.* (1994). In general the mean survival rate was significantly higher among the genotypes which had dark seed coat color than that of cream to white seed color after 192 h of water-stress treatment (Fig. 4). Thus, it is concluded that the dark-seeded genotypes tolerate waterlogged situation better than light seeded materials. Similar results were reported by Khare *et al.* (2002) in pigeonpea and they attributed it to slow rate of water uptake due to high levels of phenolic and tannin compounds in their seed coat.

Besides origin, maturity, or seed coat color, the seed size of genotypes played a significant role in survival after different water-submergence treatments. However, in general a decrease in survival rate was recorded after S192 treatment in small seeded elite inbred lines. The marked differences in rates of survival may be related to different rates of imbibition in different seed sizes. The small seeds have large contact surface area which may facilitate fast water movement through micropyle compared to large-seeded genotypes (de Jabrun *et al.* 1980).

The water-logging tolerant genotypes identified through natural field screening included hybrids (ICPH 2431, ICPH 2671, ICPH 2740, and ICPH 4187), varieties (Asha, LRG 30, Maruti, MAL 9, MAL 15 and Abhaya) and advanced breeding lines (ICPL 20092, ICPL 20117, ICPL 20125, ICPL 20128, ICPL 20237, ICPL 20238, and ICPL 99050). These genotypes are high yielding as well as resistant to major diseases. Therefore, we propose to promote these genotypes (after on-farm validation) in the area prone to water-logging and envisage that farmers will be able to harvest good yields under temporary water-logged conditions. This will eventually lead to reduction in overall losses caused by water-logging in pigeonpea. Highly tolerant and susceptible genotypes can also be used as parental lines to generate mapping populations in order to study the genetics of traits linked to water-logging tolerance in pigeonpea, subsequently facilitating the introgression of water-logging tolerance into different pigeonpea backgrounds by using a combination of conventional and molecular breeding approaches.

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Figures legend:

Fig. 1: The average rainfall distribution at Patancheru (17^0N, 78.47E, 545 m), India, from the last 10 years and during the 2010 pigeonpea growing season. The rectangles indicate the duration of the crop growing stages potentially affected by water-logging.

Fig. 2: During seed stage evaluation, survival rate of 272 pigeonpea genotypes after, 120, 144, 168 and 192 hours of water submergence, where bin 1 = 0-10%, 2 = 10-20%, 3 = 20-30 ….. 10 = 100 %, survival rate.

Fig. 3: Survival rates (with 95% confidence interval) of the different groups of genotype submerged for 120 (S120), 144 (S144), 168 (S168), and 192 (S192) hours under water, during seed stage screening, (G= germplasm; H=hybrids; L=lines, and V= varieties)

Fig. 4: Survival rate of pigeonpea genotypes (grouped based on maturity duration and seed coat color) after 192 h of water submergence treatment under laboratory screening; where least significant differences (LSD, 0.05) for maturity duration and seed coat color was 5.8 and 6.7 respectively.

Fig. 5: After seedling stage evaluation (pot screening), survival rates of 96 pigeonpea genotypes after completion of submergence treatment, where bin 1 = 0-10%, 2 = 10-20%, 3 = 20-30 ….. 10 = 100 %, survival rate.

Table 1: Analysis of variance of 272 pigeonpea genotypes for survival rate under four water submergence durations at seed stage.

Source	Degree of Freedom	Mean Sum of Square
Genotypes (G)	271	1.17**
Submergence duration (S)	3	19.54**
G x S	813	0.09**
Error	1088	0.04
Corrected total	2181	

** significant at p <0.01 probability

Table 2: Comparison of pigeonpea genotypes for survival rate within each water submergence treatments (S) at seed stage screening.

Submergence durations	Source	Mean Sum of Square
120 h (S120)	Genotypes(G)	0.310**
144 h (S144)	Genotypes (G)	0.342**
168 h (S168)	Genotypes (G)	0.385**
192 h (S192)	Genotypes(G)	0.419**

** Significant at p <0.01 probability

Table 3: Comparison of pigeonpea genotypes (hybrids, lines, varieties and germplasm) for survival rate using linear contrasts at seed stage screening.

Contrast	Degree of Freedom	Mean Sum of Square			
		120 h	144 h	168 h	192 h
Hybrids *vs* varieties	1	0.84**	0.75**	2.78**	3.01**
Hybrids *vs* lines	1	2.22**	0.81**	2.14**	1.34**
Hybrids *vs* germplasm	1	0.26**	0.01^{NS}	0.55**	0.78**
Varieties *vs* lines	1	0.15*	0.03^{NS}	0.34**	0.96**
Varieties *vs* germplasm	1	0.36**	0.89**	1.65**	1.47**
Lines *vs* germplasm	1	1.86**	1.20**	0.99**	0.13^{NS}

*, ** significant at p <0.05 and p <0.01 probability, respectively; NS= non-significant

Table 4: Pigeonpea genotypes representing tolerant (75-100%), moderately tolerant (50-74%), moderately susceptible (25-49%) and susceptible (<25%) on the basis of survival rate after the 192 h water submergence treatment at seed stage screening.

Survival rate (%)	Genotypic groups	Pigeonpea genotypes screened for water-logging tolerance				
Tolerant (100-75)	Elite inbred lines	ICPA 2039	ICPL 99051	ICPL 20100	ICPL 20118	ICPL 20129
		ICPL 150	ICPL 99054	ICPL 20103	ICPL 20119	ICPL 20130
		ICPL 332	ICPL 99055	ICPL 20107	ICPL 20120	ICPL 20131
		ICPL 83057	ICPL 99061	ICPL 20108	ICPL 20121	ICPL 20132
		ICPL 86005	ICPL 20058	ICPL 20109	ICPL 20122	ICPL 20133
		ICPL 87051	***ICPL 20092***	ICPL 20110	ICPL 20123	ICPL 20236
		ICPL 9048	ICPL 20093	ICPL 20112	ICPL 20124	***ICPL 20237***
		ICPL 92043	ICPL 20094	ICPL 20113	***ICPL 20125***	***ICPL 20238***
		ICPL 93101	ICPL 20095	ICPL 20114	ICPL 20126	ICPL 20241
		ICPL 99046	ICPL 20096	ICPL 20116	ICPL 20127	ICPL 20242
		ICPL 99050	ICPL 20099	***ICPL 20117***	***ICPL 20128***	ICPL 20243
	Hybrids and Varieties	***Asha***	***ICPH 2740***	ICPH 3629	***ICPH 4104***	MAL 11
		BDN 1	ICPH 3341	ICPH 3740	***ICPH 4187***	***MAL 15***
		BRG1-(w)1	***ICPH 3362***	ICPH 3766	ICPH 4301	***MAL 9***
		ICPH 2431	ICPH 3371	ICPH 3964	ICPH 4322	SIPS 15
		ICPH 2671	ICPH 3461	ICPH 3992	***JBP 110-B***	SIPS 18
		ICPH 2673	ICPH 3481	ICPH 4031	***LRG 30***	SIPS 9
	Germplasm	ICP 10948	ICP 12176	ICP 13384	ICP 14318	ICP 7597
		ICP 11059	ICP 12739	ICP 13389	ICP 1571	ICP 7815
		ICP 11130	ICP 12740	ICP 13391	ICP 2376	ICP 7977
		ICP 11378	ICP 1275	ICP 13392	ICP 4924	ICP 8465
		ICP 11811	ICP 12750	ICP 13395	ICP 5028	ICP 8466
		ICP 11813	ICP 12751	***ICP 14085***	ICP 5429	ICP 8927
		ICP 12023	ICP 12839	ICP 14092	ICP 7086	ICP 8929
		ICP 12024	ICP 13361	ICP 14146	ICP 7193	
		ICP 12043	ICP 13379	ICP 14282	ICP 7201	
Moderately tolerant (50-74)	Elite inbred lines	***ICPB 2039***	ICPL 20101	ICPL 20106	ICPL 20244	ICPL 96061
		ICPL 161	ICPL 20102	ICPL 20135	ICPL 87154	
		ICPL 20097	ICPL 20104	ICPL 20219	ICPL 90030	
		ICPL 20098	ICPL 20105	ICPL 20229	ICPL 92059	
	Hybrids and	BRG 2	ICPH 2741	ICPH 4329	SGBS 6	UPAS 120
		ICPH 2363	ICPH 3313	JBP 36B	SIPS 10	

	Varieties	ICPH 2364	ICPH 4183	***Maruti***	SIPS 17	
		ICPH 2438	ICPH 4275	SGBS 4	SIPS 5	
	Germplasm	ICP 10960	ICP 11296	ICP 14304	ICP 1575	ICP 8094
		ICP 10987	ICP 1141	ICP 14410	ICP 1941	ICP 8920
		ICP 11128	ICP 11440	ICP 14712	ICP 4928	
		ICP 11133	ICP 12057	ICP 14882	ICP 5529	
		ICP 11150	ICP 13342	ICP 15200	ICP 7741	
Moderately susceptible (25-49)	Elite inbred lines	ICPL 20200	ICPL 20222	ICPL 84060	ICPL 90034	ICPL 990091
		ICPL 20218	ICPL 84031	ICPL 87091	ICPL 95040	
	Hybrids and Varieties	ICPH 2433	ICPH 3762	MAL 12	SIPS 1	
		ICPH 3467	ICPH 4304	SGBS-3	VL-arhar 1	
	Germplasm	ICP 11106	ICP 11443	ICP 12026	ICP 12792	ICP 7349
		ICP 11120	ICP 11447	ICP 12728	ICP 13402	
		ICP 11153	ICP 1202	ICP 12751	ICP 3782	
Susceptible (<25)	Elite inbred lines	ICPA 2043	ICPL 20212	ICPL 20227	ICPL 89	ICPL 93107
		ICPB 2043	ICPL 20213	ICPL 20230	ICPL 90048	ICPL 96053
		ICPL 12747	ICPL 20215	ICPL 20231	ICPL 91032	ICPL 98011
		ICPL 12761	ICPL 20216	ICPL 81-9	ICPL 92010	ICPL 98013
		ICPL 149	ICPL 20221	ICPL 86022	ICPL 92041	ICPL 99044
		ICPL 20	ICPL 20223	ICPL 87	ICPL 92067	
		ICPL 20210	ICPL 20225	ICPL 88034	ICPL 93017	
	Hybrids and Varieties	BDN 2	ICPH 3310	Kanchen	SIPS 6	GAUT 90-1
		BRG 3	ICPH 4305	**SIPS 2**	SIPS 7	
		HPL 24	**Kamica**	SIPS 4	SIPS 8	
	Germplasm	ICP 11100	ICP 11681	ICP 12749	ICP 13581	ICP 9320
		ICP 11145	ICP 12714	ICP 12780	ICP 2131	ICP 9801
		ICP 11149				ICP 7035

[#] Genotypes in italic and bold showed consistent higher survival rate after the *in vitro*, pot and field evaluations, while genotypes underlined and bold showed susceptible reaction for water-logging tolerance across screenings.

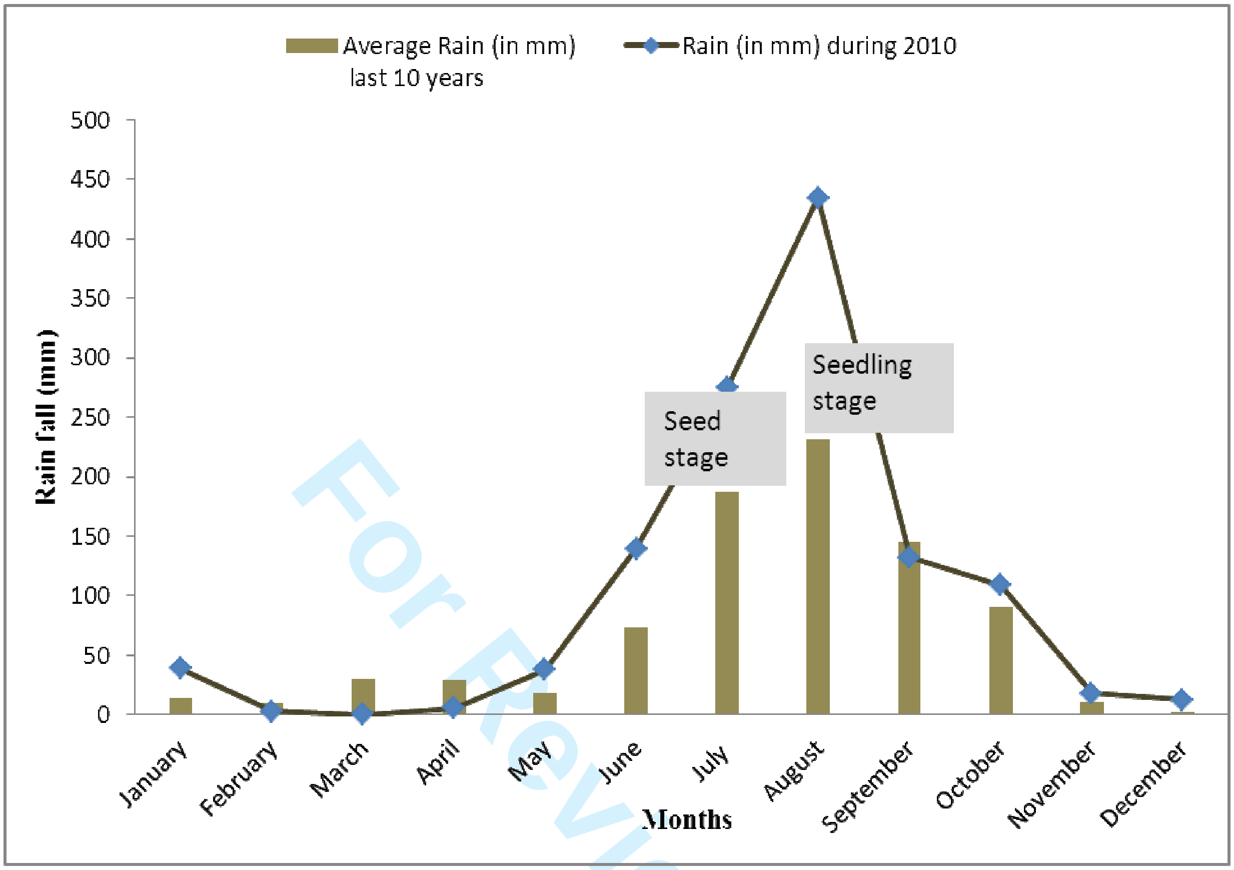
Average Rain (in mm) last 10 years
Rain (in mm) during 2010
Rain fall (mm)
500
450
400
350
300
250
200
150
100
50
0
Seed stage
Seedling stage
January
February
March
April
May
June
July
August
September
October
November
December
Months

Fig. 1:

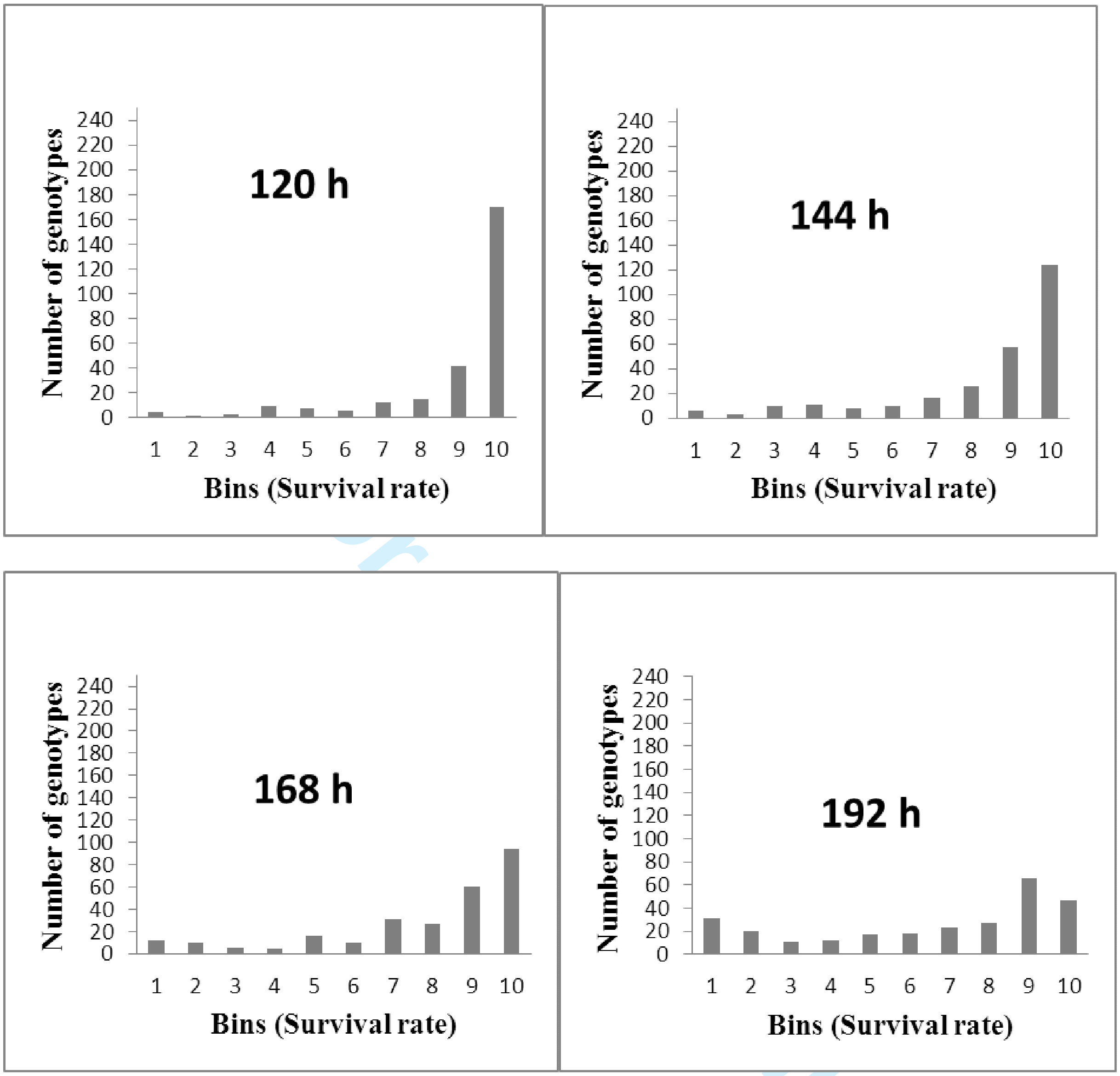
120 h
144 h
168 h
192 h
Number of genotypes
0
20
40
60
80
100
120
140
160
180
200
220
240
Bins (Survival rate)
1
2
3
4
5
6
7
8
9
10

Fig. 2:

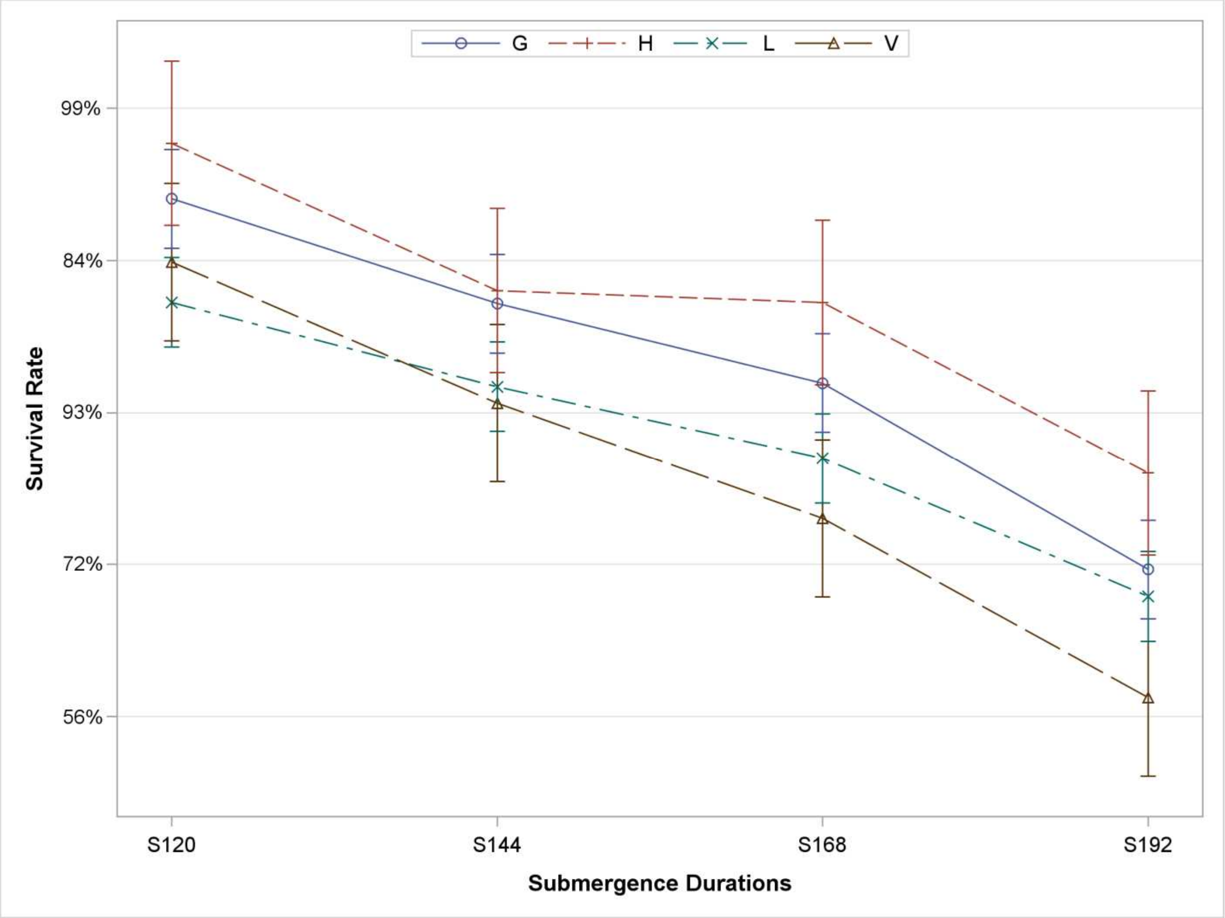
G
H
L
V
99%
84%
93%
72%
56%
Survival Rate
S120
S144
S168
S192
Submergence Durations

Fig.3:

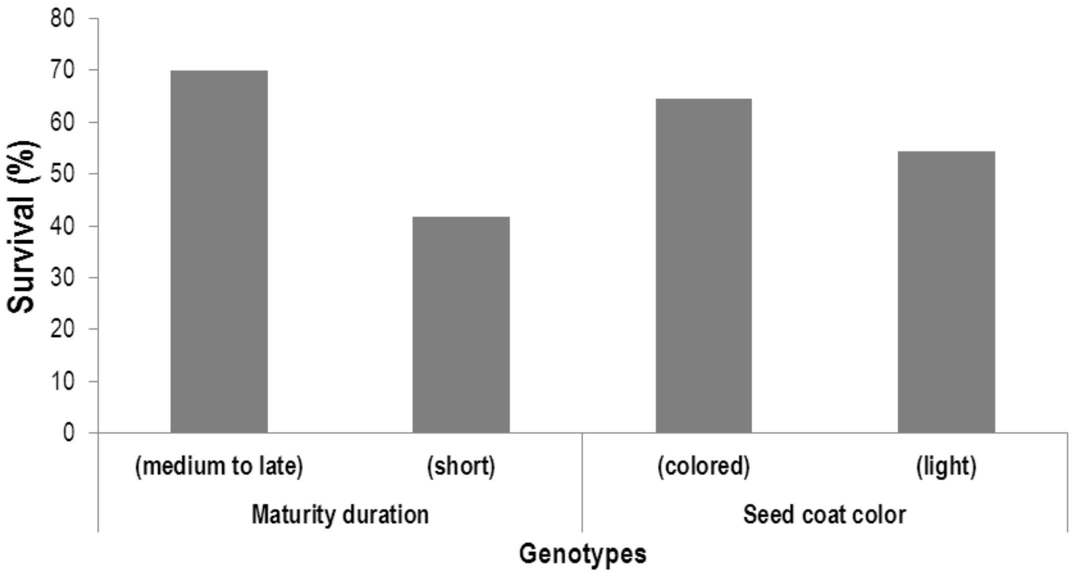
Survival (%)
80
70
60
50
40
30
20
10
0
(medium to late)
(short)
(colored)
(light)
Maturity duration
Seed coat color
Genotypes

Fig. 4:

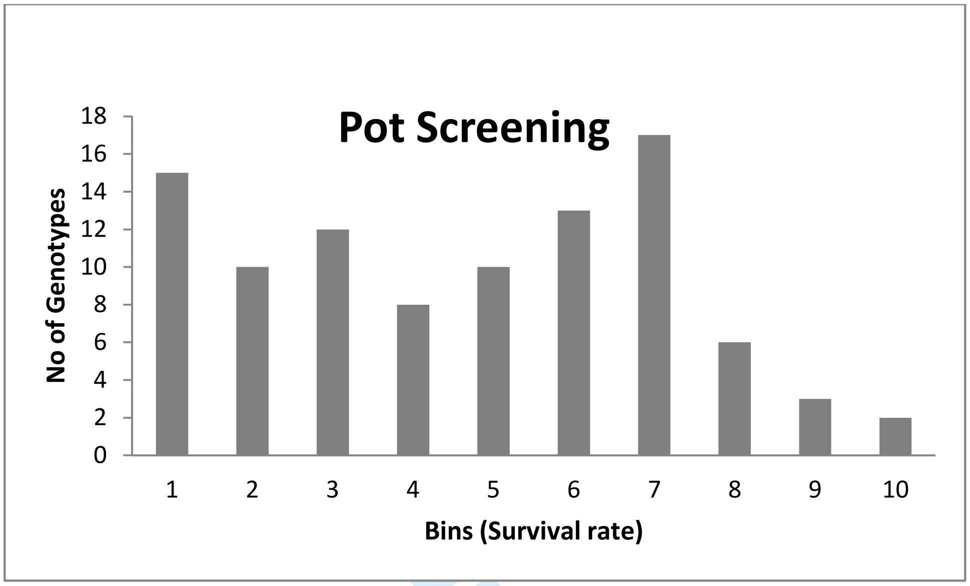
Pot Screening
No of Genotypes
0
2
4
6
8
10
12
14
16
18
1
2
3
4
5
6
7
8
9
10
Bins (Survival rate)

Fig.5: