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Screening Groundnut (*Arachis hypogaea* L.) Germplasm for Salinity Tolerance

Namita Srivastava[1, 2, *], Vincent Vadez[1], Shyam Narayan Nigam[1], Hari D. Upadhyaya[1] and Lakhsmi Narasu[2]

[1]International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Telangana, India
[2]Jawaharlal Nehru Technological University, Hyderabad, 500085, Telangana, India

*Corresponding Author: namitasrivas@gmail.com

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Abstract

Salinity is an increasing concern for the productivity of staple food crop. Crops with improved salt tolerance are highly needed to cultivate saline lands. Groundnut demand is increasing in countries like India, where saline land could be put under groundnut cultivation. The objective of this study was to identify groundnut genotypes with salinity tolerance for breeding programs. A set of 275 groundnut germplasm accessions were screened across three different seasons for salinity tolerance. Shoot biomass and seed yield under saline and non-saline conditions were recorded. Shoot biomass under saline conditions showed limited genotypic variation and was not determined as a selection criterion in the subsequent trials. While a six-fold range of variation for pod yield under salinity (10-12.5 dSm^{-1} NaCl) was observed. Pod weight under saline and control conditions had week correlation. Although there was a considerable genotypic variation of pod yield under saline conditions, the G×E interaction was observable as well. We report a set of 14 tolerant and 17 sensitive groundnut genotypes based on pod-seed yield and pod-seed numbers under saline conditions in the seasons studied. Among all the genotypes, ICGV 87187 and ICGS 76 were the most tolerant lines and ICG 6993 and ICG 4746 were the most susceptible lines in 2006 and 2006-2007, respectively. The suggested lines could be used in further breeding programs such as populations mapping. Our assumption to identify salt tolerant groundnut lines from selected landraces of putative saline areas did not help successfully to get more promising lines nevertheless the mini-core set of germplasm provided most of the salinity tolerant entries.

Keywords: Groundnut; Mini-core collection; Salinity tolerance; Pod weight; G×E interaction

Introduction

Globally, soil salinity with coverage of 100 million hectare of agricultural lands is a major non-biotic stress affecting productivity of several crops (Rangaswamy, 2006). Soil salinity can be more severe in irrigated lands of semi-arid, arid and coastal regions. The measuring unit of soil salinity is soil solution in term of g/l or electric conductivity (ECe) in ds/m. Soils are classified as follows: non-saline when ECe is < 2 ds/m, as weakly saline when ECe is between 2-4 ds/m, as moderately saline when ECe is between 4-8 ds/m, as strongly saline when ECe is between 8-16 ds/m and as very strongly saline when ECe is > 16 ds/m (Bernstein, 1964).

The primary method of controlling soil salinity is to leach salts from the affected soils. This can be done by permission of 10-20% of irrigation water to leach the soil and collection of drained out water in appropriate drainage system. Some plants are able to tolerate high levels of salinity while others are highly sensitive to it. Many factors influence a plant's tolerance to salinity including climate (particularly the amount and seasonality of rainfall to leach salts from soil), soil type and drainage characteristics.

Groundnut (*Arachis hypogaea* L.) belongs to leguminosae family is an important legume crop which is sensitive to salinity stress. Groundnut is grown both in rainy and post-rainy seasons. Post-rainy crop is being more frequently encountered with higher level of salt stress due to irrigation practices, particularly in coastal areas. Although, groundnut plant may tolerate higher level of salt stress however pod growth may be affected at lower concentrations of stress (www.dpi.nsw.gov.au, 2017). To address this issue, utilization of breeding methods are the most appropriate tool in order to compensate yield losses. The development of such cultivars requires identification and incorporation of salinity tolerant genes in the breeding populations. So far, no thorough assessment with respect to the range of variation for salinity tolerance has been performed in groundnut germplasm. Understanding the true genetic diversity of groundnut germplasm is difficult task due to existence of over 20,000 germplasm accessions. Therefore, the aim of the present investigation was to report genetic variation related to salinity tolerance among groundnut germplasm accessions.

Materials and Methods

A set of 275 groundnut genotypes were studied in this research including 188 accessions from the mini-core collection reported by Upadhyaya *et al.* (2002), 37 accessions from salinity affected Chaco area that spans across Argentina, Paraguay and Bolivia countries, and 50 released cultivars and high yielding advanced breeding lines from India. The screening trials were initiated on 19April 2005, 22 April 2006, and 25 November 2006-2007 in 10.5- inch diameter pots each containing 9 kg of Alfisols. The soil was fertilized with di-ammonium phosphate (DAP) as 300 mg kg^{-1} soil at the time of pot filling. In each pot, four seeds were planted and later were thinned to two plants. The assessment for salinity tolerance in 2005 was carried out on the basis of vegetative shoot biomass produced in 65 days after sowing (DAS); while in the other two experiments it was done on the basis of pod yield. All the three assessments were carried out in outdoor conditions equipped with a rain-out shelter to protect the trials from rains and to provide all possible field conditions except that the pots soil was artificially salinized to ensure homogeneity of salinity treatment to all entries.

Experimental design and treatments

For all the three experiments, an alpha lattice (25x11) design was followed with three replications and two treatments (saline and non-saline). In 2005 and 2006, the concentration of the saline treatment was 11.09 g NaCl pot^{-1}, applied in three split doses during the first two weeks after sowing. Overall, it is equivalent to an application of 1.17 g NaCl kg^{-1} soil leading to an electric conductivity of 10dSm^{-1}. In 2006-2007, we applied 13.14 g NaCl pot^{-1}, equivalent to 1.46 g NaCl kg^{-1} soil and an electric conductivity of 12.4 dS m^{-1}. These treatments were based on our previous results of standardization experiments to elicit the genotypic differences for tolerance to salinity in groundnut (Srivastava *et al.*, 2007). A slightly higher 1.68 g NaCl kg^{-1} soil in 2006-2007 was given to compensate for a lower evaporative demand (and then lesser stress) during vegetative and reproductive stages of crop due to low temperature of winter season.

The pots were irrigated with tap water each pot was maintained at field capacity (determined gravimetrically) to avoid an increase salt concentration in soil solution. The bottom of the pots in the saline treatment was sealed to avoid any salt leaching, and utmost care was taken in the saline treatment to avoid water-logging. Non saline (control) pots were kept open at the bottom for drainage and watered regularly to avoid water stress. The first experiment was harvested on 23th June 2005 (65 DAS) and the second on 30th August 2006 (till the days to maturity). In the third experiment the harvesting was done between March 30th and 10th May, 2006-2007 when the individual genotype was matured. Then, the pod sampling was done after sun drying following by shoot drying at 80°C for three days and weighing.

Average of maximum temperatures and relative humidity in first two months of the experiment conducted in year 2006 (20th April-20th June 2006) was 36.3 ^{0}C and 35.0%. However, it was 28.9 ^{0}C and 41.5 % in first two months in the

2006-2007 experiment (25th Nov 06-25th Jan 2007). This period of both the experiments covering most of vegetative and reproductive stages (Fig. 1) (https://www.icrisat.org).

Statistical analyses

Each parameter was analyzed using the residual maximum likelihood (ReML) method by treating the replication and replication × block effect as fixed, whereas genotype effect was treated as random effect. For the analysis across the seasons, year was treated as fixed, while genotype x environment interaction (GxE) as random effect. The best linear predictions (BLUPs) were obtained using GenStat version 9th edition (Payne *et al.*, 2006). Unbiased estimates of variance components σ^2_g and σ^2_e, were also calculated to estimate broad-sense heritability.

Assessment for salinity tolerance

Several previous reports have suggested that the salinity tolerance should be based on yield data under saline stress conditions (Francois and Mass, 1994; Tester and Davenport, 2003; Vadez *et al.,* 2007; Singh *et al.*, 2008). Hence, for screening salinity tolerance, we measured shoot biomass in 2005 and pod yield in 2006 and 2006-07 under saline and control conditions. In 2005, data were also recorded based on other parameters such as number and weight of total pods and mature pods, leaf area (LA), leaf weight (LW), specific leaf area (SLA), shoot dry weight (SHW) and number of gynophores under saline and non-saline conditions at 65 DAS. In 2006 and 2006-07, salinity tolerance was assessed by pod yield. To identify the actual part of reproductive stage in samples studied affected by salt stress, pod yield was also dissected into different parameters such as total number of pods (PN, number plant^{-1}), total pod weight (PW, g plant^{-1}), number of mature pods (MPN, number plant^{-1}), and matured pod weight (MPW, g plant^{-1}).

Results

Shoot biomass under salinity

The leaf and shoot biomass were reduced by 65% and 67 % respectively, due to salinity treatment in 2005. The variation (12.7 - 16.7 g plant^{-1}) observed for shoot dry weight under saline conditions was narrow. In contrast, the variation for shoot dry weight under control conditions was greater and it ranged from 36.9 to 51.9 g plant^{-1} (Table 1). Since the flowering time was around 35 DAS for all the entries, they developed gynophores by the time of harvest following by counting their number. Although the gynophore number was decreased by salinity in proportion similar to the shoot weight (62%) across the tested entries, the range of variation for the gynophore number was large under saline conditions (about 2 to 30 gynophores plant^{-1}), as compared to 20 to 50 under the control. However, the gynophore number was not related to the flowering time in all treatments (data not shown) in 2005. The above mentioned results and the lack of large variation for shoot biomass under salinity led to the use of yield rather than shoot biomass for assessment of salinity tolerance in subsequent screenings.

Table 1. Mean of different parameters under saline and control conditions of 275 groundnuts in 2005

Saline (1.17 g NaCl kg^{-1} soil)			Control (0 g NaCl)		
Parameter	**Mean ± SE**	**Range**	**Mean ± SE**	**Range**	**Reduction (%)**
Leaf weight (g)	7.03 ± 0.03	5.76-9.22	20.04 ± 0.11	15.00-25.85	65
Shoot dry weight (g)	14.53 ± 0.04	12.66-16.66	44.75 ± 0.16	36.94-51.25	67
Number of gynophores	11.12 ± 0.15	2.33-30.00	29.33 ± 0.16	20.39-52.19	62

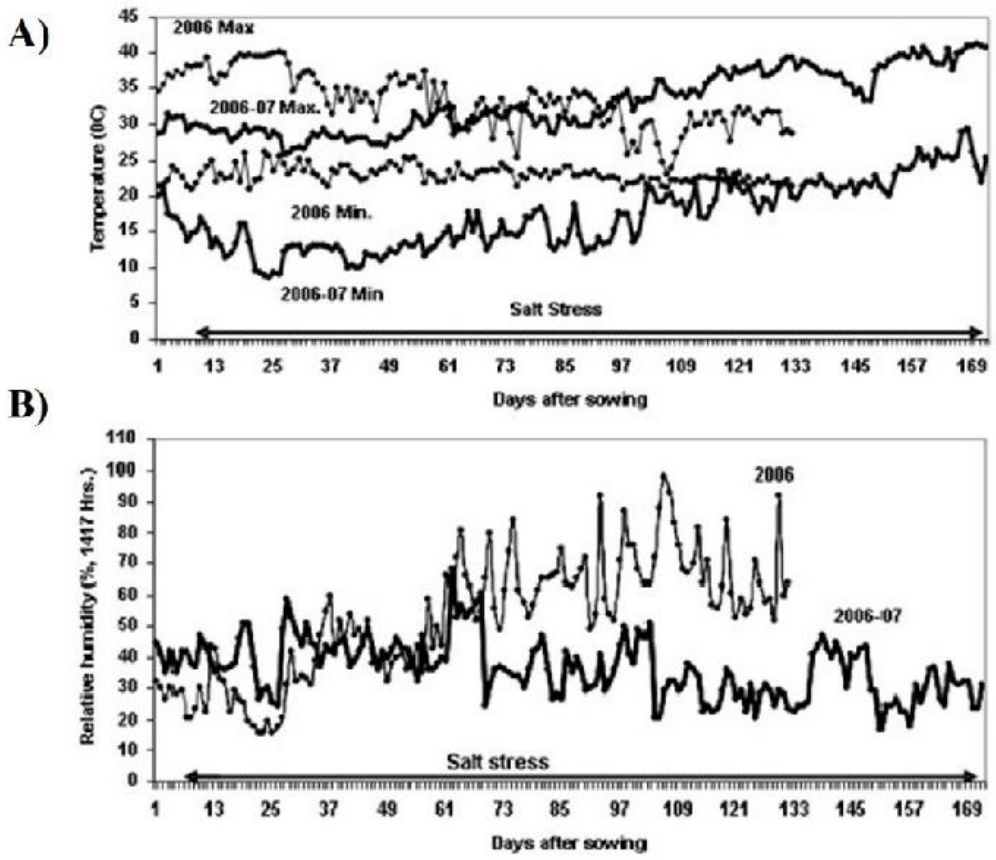

Fig. 1. The temperature and humidity diagram. (A) Minimum and maximum temperature and (B) relative humidity during 2006 (thin line) and 2006-2007 (thick line) at ICRISAT, Patancheru.

Yield and components

Total pod dry weight decreased under salinity relatively more in 2006 (69%, Table 2) as compared to 2006-07 (47%, Table 3). In both years, though, the range of variation for total pod dry weight under saline conditions was large i.e. 6-7 folds in both years. The heritability for total pod dry weight was higher for control compare to saline conditions in 2006.The heritability parameter was improved under saline conditions in 2006-07 (Table 3), where it was similar under both control and saline conditions (circa 40%). The total number of pods per plant under salinity remained fairly large as compared to control and decreased only by 40% and 19%, respectively, in 2006 and 2006-07 in comparison to control. The heritability for total pod number was high in both control and saline conditions (> 46%) in 2006. It was even higher under saline conditions in 2006-07 (circa 55% vs 40% in control). In fact, the decrease of total pod weight was related to a similar decrease in the number of mature pods, which decreased by 68% and 35% in 2006 and 2006-07. As a consequence, the mature pod weight showed a slightly higher decrease (76 and 51% in 2006 and 2006-07) than the total pod weight. Both mature pod weight and mature pod number had fairly high heritability under both control and saline conditions in 2006-07. The shoot dry weight at harvest was also considerably decreased by salinity (67% and 47% in 2006 and 2006-07), i.e., in a similar proportion to the decrease of pod weight (Table 2 and Table 3).

Table 2. Overall trial mean, range of best linear unbiased predicted means of genotypes (BLUPs), genetic variance (σ^2_g), heritability (h^2), and percentage reduction of mean parameter value under saline conditions compare to control (%) of pod weight, pod number, mature pod weight, mature pod number, and shoot dry weight (DW) measured at maturity under saline and control conditions in 275 groundnut genotypes at ICRISAT, Patancheru, 2006.

	Saline (1.17 g NaCl kg^{-1} soil)				Control (0 g NaCl)				
Parameter	**Mean**	**Range**	**σ^2_g**	**h^2**	**Mean**	**Range**	**σ^2_g**	**h^2**	**%**
Total pod weight (g)	6.96± 0.16	0.87-14.56	3.8	20.8	22.80 ± 0.44	5.06-47.58	44.2	61.0	69
Total pod number	24.81± 0.55	5.42-61.46	65.6	46.7	41.56 ± 0.79	11.54-91.88	129.6	50.4	40
Mature pod weight (g)	4.71 ± 0.15	0.08-11.73	2.9	21.9	19.75 ± 0.42	3.98-42.37	13.3	11.0	76
Mature pod number	6.84 ± 0.22	0.08-18.74	7.4	26.5	21.55 ± 0.47	2.94-50.81	27.4	20.9	68
Shoot dry weight (g)	14.04± 0.22	4.29-27.86	16.4	89.3	42.69 ± 1.04	8.53-145.23	119.0	91.7	67

Table 3. Overall trial mean (± SE of mean), range of best linear unbiased predicted means of genotypes (BLUPs), genetic variance (σ^2_g), heritability (h^2), and percentage reduction of mean parameter value under saline conditions compare to control (%) of pod weight, pod number, mature pod weight, mature pod number, and shoot dry weight (DW) measured at maturity under saline and control conditions in 275 groundnut genotypes at ICRISAT, Patancheru in 2006-2007

	Saline (1.17 g NaCl kg^{-1} soil)				Control (0 g NaCl)				
Parameter	**Mean**	**Range**	**σ^2_g**	**h^2**	**Mean**	**Range**	**σ^2_g**	**h^2**	**%**
Total pod weight (g)	19.32±0.30	0.51-34.43	12.6	38.5	36.66±0.61	5.01-73.03	70.9	40.0	47
Total pod number	59.02±1.05	22.64-110.39	265.5	54.9	73.18±1.28	17.16-147.52	305.1	39.5	19
Mature pod weight (g)	15.47±0.28	2.55-28.13	13.3	37.0	31.87±0.60	2.31-55.68	48.9	29.1	51
Mature pod number	25.06±0.52	0.82-52.08	50.8	42.9	38.38±0.83	6.32-72.03	143.0	44.3	35
Shoot dry weight (g)	18.81±0.36	4.75-39.88	27.2	51.1	35.70±0.56	10.97-68.91	69.4	52.9	47

Weather conditions during yield

The weather conditions in 2006 and 2006-07 were very different. For a period of approximately 70 DAS, the maximum and minimum temperatures in 2006 were higher than 2006-07, while the relative humidity was about the same (Fig.1). This was resulted in a higher evaporative demand in 2006 than in 2006-07 at these 70 DAS, where the crop had reached the stage of pod-filling. After 70 DAS, the relative humidity increased in 2006 and was higher than in 2006-07 until maturity, while temperatures were similar in 2006 and 2006-07 during the period of 70-100 DAS, and then higher in 2006-07 than in 2006 for the rest of the season. So, the evaporative demand was higher in 2006-07 than in 2006 from 70 DAS onwards. The minimum temperature during early stages in 2006-07 appeared to have no impact on control yield, which was higher in 2006-07 than in 2006 (Table 2 and 3). The solar radiation was highest in 2006-07 (18.13 Mj/m^2) than in 2006 (17.4 Mj/m^2) and which was explained to some extent the lower control (non-saline) yield in 2006 than in 2006-07.

GxE interaction for pod yield

Overall, there was a predominant effect of growing season on yield and yield components, which was explained mostly by the large differences in the growing season. The season effect was visible both under control and saline conditions (Table 4). However, there were some significant genotypic differences for yield and yield components, both under saline and control conditions (Table 4). The interaction between seasons and genotypes was also significant for both the treatments in all the yield-related parameters measured. In case of total pod weight and mature pod weight, the magnitude of genotypic effect was similar to the magnitude of

genotype-by-season effect under saline and control conditions. By contrast, for total pod number and number of mature pods, the magnitude of genotypic effect was relatively larger than the genotype-by-season effect under saline and non-saline conditions (Table 4).

Table 4. Analysis of variance for yield parameters (pod weight, pod number, mature pod weight, mature pod number) across the two season when yield was assessed (2006 and 2006-2007)

	Control (0 g NaCl)			Saline (1.17 g NaCl kg^{-1} soil)		
	Wald Statistic	**F-statistics**	**F-probability**	**Wald Statistic**	**F-statistics**	**F-probability**
Parameter			**Total pod weight**			
Season	503.7	503.7	<0.001	2612.95	2612.95	<0.001
Genotypes	441.46	1.60	<0.001	523.33	1.9	<0.001
G×E	423.65	1.53	<0.001	551.56	2	<0.001
Parameter			**Total pod number**			
Season	1062	1062.51	<0.001	1965.84	1965.84	<0.001
Genotypes	893.5	3.24	<0.001	798.41	2.89	<0.001
G×E	471.72	1.71	<0.001	488.92	1.77	<0.001
Parameter			**Mature pod weight**			
Season	429.6	429.6	<0.001	2184.98	2184.98	<0.001
Genotypes	479.52	1.74	<0.001	515.96	1.87	<0.001
G×E	424.48	1.54	<0.001	487.35	1.77	<0.001
Parameter			**Mature pod number**			
Season	418.11	418.11	<0.001	2188.19	2188.19	<0.001
Genotypes	704.87	2.55	<0.001	696.29	2.52	<0.001
G×E	377.93	1.37	<0.001	459.79	1.67	<0.001

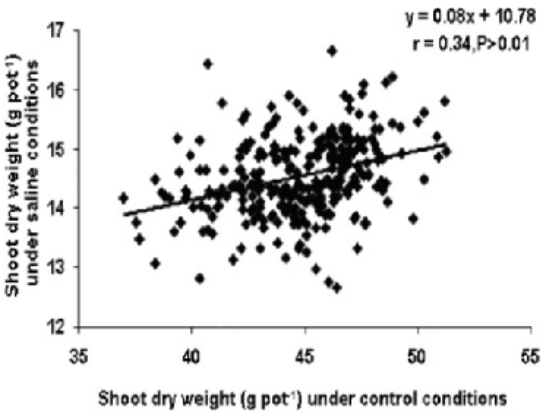

Fig. 2. The short biomass diagram. Relationship of shoot biomass under saline and control conditions in 2005. Data are the mean (n=3) of 275 genotypes.

Relationship between biomass and yield under control and saline conditions

There was a significant relationship between shoot dry weight under saline and control conditions in 2005 (r=0.34, P<0.01) (Fig. 2). We also found such relationship in 2006 (r=0.33; P> 0.01) and in 2006-2007 (r=0.60; P> 0.01) (data not shown). The relationship between total pod weight under saline and control conditions was non-significant in 2006 (r = 0.14; non-significant), although it was significant in 2006-2007 (r =0.33; P>0.01) (Fig. 3). From all these relationships, it might be suggested that screening of shoot or pod yield under saline conditions could not be precisely inferred from assessment of these traits under control conditions, even if the significant was fairly weak.

Range of genotypic variation among 275 genotypes

The weak relationships between pod yields under saline and control conditions indicated that the previous use of ratio (pod yield under saline /pod yield under control conditions) as a screening tool could lead to identification of genotypes with high ratio and poor yield under control conditions (Vadez *et al.*, 2007). Therefore, we focused our choice on genotypes showing large contrast in pod yield under saline conditions for better breeding efforts. Singh *et al*. (2008) also concluded that seed yield per unit area under saline conditions was the best criterion for selection of the salinity tolerant genotypes. Fig. 3 shows a large range of pod yield under salinity at any given level of yield

potential. The extent of genotypic variation for pod weight under saline conditions was six- to seven-folds, with total pod weight ranging from 2 g pot^{-1} to 12 g pot^{-1} in 2006 and 5 g pot^{-1} to 35 g pot^{-1} in 2006-2007 (Fig. 4).

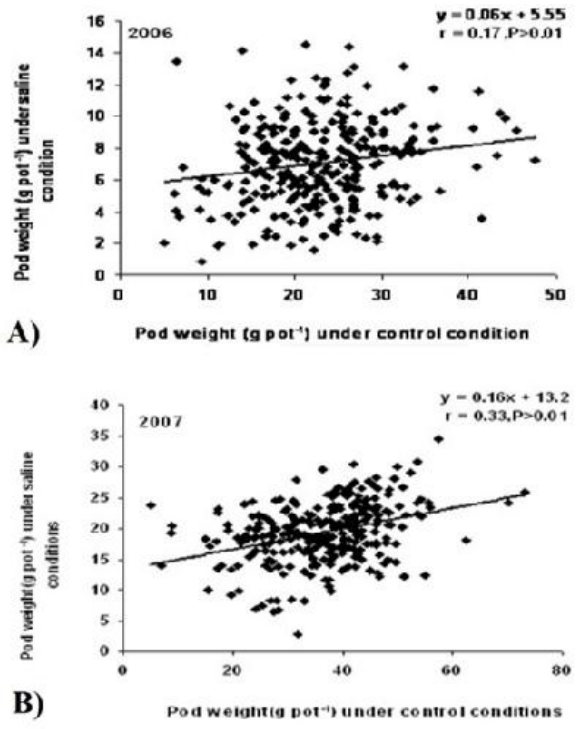

Fig. 3. The pod dry diagram. The relationship of pod dry weight under control and saline conditions in 2006 (A) and 2006-2007 (B). Data are means (n = 3) of 275 genotypes.

Selection for contrasting genotypes

The choice of contrasting genotypes for salinity tolerance was made from genotypes that showed high and low values of four yield components including total pod weight, mature pod weight, total pod number, and mature pod number in 2006 and 2006-2007 consistently. In Table 5, we reported 14 tolerant and 17 sensitive genotypes related to salinity stress. The tolerant and susceptible genotypes were considered based on their mean (±SE) performance under salinity in both seasons. Among all the genotypes studied, ICGV 87187 and ICGS 76 were the most tolerant and ICG 6993 and ICG 4746 were the most susceptible lines in 2006 and 2006-07, respectively. Based on the total pod weight under saline condition, the order of salinity tolerance was ICGV 87187> ICGV 86156> ICGV 00309> ICG 5195 > ICGS 76> ICGV 86155> ICG (FDRS) 10> ICG 1519 > ICG 2106 > ICG 1711 > ICG 7283 > ICGS 44 > ICGV 99181> ICG 442 in 2006. This ranking was slightly modified in 2006-2007 and was recorded as ICGS 76> ICG 7283 > ICGV 87187> ICGV 86155> ICG 1519 > ICGV 00309> (FDRS) 10> ICG 2106 > ICGS 44 > ICGV 86156> ICGV 99181> ICG 442>1711 > ICG 5195.

Comparison of genotypic variation among selected landraces, breeding lines, and the mini-core

The overall mean values of total pod weight were 8.31 (2006) and 20.15 (2006-2007) for breeding lines, 6.66 (2006) and 19.13 (2006-2007) for mini-core collection and 6.41 (2006) and 19.20 (2006-2007) for selected land-races from the saline areas under salinity, suggesting that breeding lines had slightly higher pod yield under saline conditions. There was no particular advantage of the selected lines from putatively salinity-affected areas over the mini-core genotypes. Indeed, the mini-core set appeared to have the largest range of pod yield under saline conditions (0.87-14.56 g) in 2006 and (2.81-34.43g) in 2006-2007 (data not shown) in comparison with the breeding lines and selected landraces.

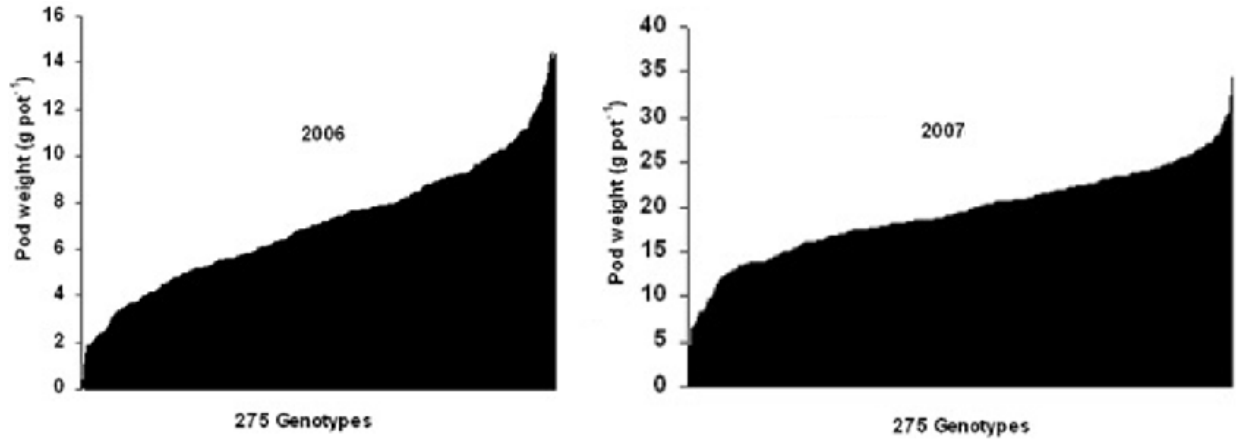

Fig. 4. The pod dry weight of 275 genotypes: Range of genotypic variation (6-7 folds) for pod dry weight under saline condition in 2006 and 2006-2007; Data are means (n = 3) of 275 genotypes.

Discussion

Our data showed a large range of variation for pod yield of groundnut under saline conditions, whereas an early assessment of plant biomass revealed little genotypic contrast. Pod yield was conditioned by an equally significant genotypic and genotype-by-season interaction. We used a set of germplasm that included the mini-core collection of ICRISAT (Upadhyaya *et al.*, 2002), which represents the diversity available in the entire groundnut collection. To the best of our knowledge, this was the first attempt to carry out such a large scale screening with diverse genotypes (mini-core, breeding lines, landraces from saline affected areas, and released cultivars), except for large scale field trials that have been done by Singh *et al*. (2008; 2010) by using 83 groundnut cultivars at 4-7 ds m^{-1} level of salt stress. An *in vitro* large screening was also conducted by Mungala *et al*., 2008 using 123 Indian groundnut cultivars. Indeed, finding an approach in order to select landraces from a region exposed to salinity was reported to be a problem due to lack of showing higher level of salinity tolerance. The outcome of this work indicated a set of highly contrasting genotypes across seasons that can be used to breed salinity tolerant genotypes.

The assessment of biomass at 65 DAS revealed a limited range of variation. These results contradict with previous reports where salinity tolerance was based on the vegetative growth at 25-35 days after sowing under saline conditions (Joshi *et al.*, 1994). However, this study used only a few genotypes and did not measure pod yield under saline conditions. In 2005, there were large differences in the gynophore numbers, while the shoot biomass varied much less resulted in focusing on pod weight in subsequent screening in order to reveal a broader range of genotypic variation. Moreover, it was hypothesized that the differences in how reproductive processes tolerate salinity may explain part of the differences in pod yield, in agreement with the results on chickpea reported by Vadez *et al*., 2007. The obtained result was also compatible with the data from Francois and Mass (1994) and Singh *et al.* (2008; 2010) in groundnut which suggested that salinity tolerance would be evaluated in optimum level by assessing yield per unit area than with biomass production. Subsequent trials were then carried out until maturity to enable yield estimation.

By obtaining the range of variation of groundnut germplasm studied for pod yield in both seasons (6-7 folds), we could introduce new and thorough sources of groundnut in order to undertake a breeding program for salinity tolerance. Other reports have also shown genotypic variation for salinity tolerance (Mensah *et al.,* 2006; Singh *et al.,* 2008; 2010). However, the fact that genotypic effect for pod yield was of same magnitude as the G×E effect showed that the season played an important role in determination of salt tolerance in groundnut genotypes.

Table 5. List of 14 most tolerant and 17 most susceptible genotypes, including germplasm type (MC, mini-core, BL, breeding line) and origin, and data o days to flowering, shoot dry weight at maturity (SDW) and pod weight at maturity (PW) from two seasons evaluation under saline (S, 1.17 g NaCl kg^{-1} soil) and control (C, 0 g NaCl) conditions. Data are the mean (± SE) of 3 replicated pots (containing 2 plants pot^{-1}); DAS= Days to flower

Genotype	Type	Origin	Season	DAS		SDW (g pot^{-1})		PW (g pot^{-1})	
Tolerant				**S**	**C**	**S**	**C**	**S**	**C**
ICG 5195	MC	Sudan	2006	34	25	19.0 ± 1.60	28.1 ± 1.12	12.6 ± 0.16	22.4 ± 3.55
			2006-07	45	42	18.3 ± 0.11	35.6 ± 5.44	17.1 ± 0.81	34.9 ± 6.43
ICGV 86156	BL	ICRISAT	2006	30	28	15.4 ± 2.03	23.7 ± 5.50	13.7 ± 1.5	14.1 ± 2.02
			2006-07	51	40	11.0 ± 2.51	26.1 ± 0.11	23.1 ± 3.15	44.2 ± 3.82
ICG (FDRS)10	BL	ICRISAT	2006	28	25	25.8 ± 8.10	35.3 ± 3.12	11.5 ± 4.60	19.8 ± 3.44
			2006-07	52	39	25.1 ± 0.01	41.3 ± 5.00	24.5 ± 3.33	45.1 ± 3.09
ICGV 99181	BL	ICRISAT	2006	32	29	14.9 ± 1.03	32.3 ± 9.69	9.4 ± 1.33	14.6 ± 0.38
			2006-07	39	37	17.1 ± 1.62	29.7 ± 3.52	22.2 ± 2.41	49.4 ± 2.42
ICGV 00309	BL	ICRISAT	2006	38	27	14.1 ± 1.75	32.6 ± 10.3	12.2 ± 1.67	26.5 ± 4.38
			2006-07	59	37	16.7 ± 2.29	29.4 ± 6.58	24.5 ± 4.04	34.3 ± 8.59
ICGS 44	BL	ICRISAT	2006	33	28	13.3 ± 1.24	29.8 ± 5.53	9.5 ± 0.37	33.6±13.52
			2006-07	47	43	21.5 ± 3.58	23.9 ± 0.81	23.2 ± 2.48	52.7 ± 6.45
ICG 442	MC	USA	2006	34	24	13.1 ± 1.86	55.3 ± 5.55	7.6 ± 1.30	20.5 ± 5.17
			2006-07	45	41	17.6 ± 1.08	26.6 ± 3.28	20.6 ± 0.57	40.7 ± 4.44
ICG 7283	MC	Paraguay	2006	32	26	16.2 ± 2.14	29.4 ± 2.93	9.5± 2.53	28.9 ± 0.85
			2006-07	45	26	17.5 ± 6.12	27.2 ±12.27	26.1 ± 6.13	32.4±14.08
ICG 1711	MC	Boliva	2006	30	27	12.9 ± 2.45	30.6 ±1.69	10.5 ± 2.57	24.1 ± 4.60
			2006-07	44	39	20.5 ± 1.91	40.9 ± 6.25	18.0 ± 2.65	36.4 ± 7.66
ICGV 86155	BL	ICRISAT	2006	33	30	15.8 ± 2.73	36.7 ± 5.40	11.6 ± 1.47	28.5 ± 8.03
			2006-07	75	41	9.42 ±1.85	28.9 ± 5.45	25.2 ± 1.46	35.9 ± 9.61
ICG 2106	MC	India	2006	36	28	18.0 ± 3.81	30.9 ± 3.46	10.7 ± 3.39	17.9 ± 0.91
			2006-07	75	41	16.7 ± 1.17	36.1 ± 4.33	23.4 ± 0.77	45.4 ± 0.92
ICGS 76	BL	ICRISAT	2006	37	35	17.2 ± 2.12	47.8 ±11.11	11.7 ± 2.89	34.7±14.01
			2006-07	54	54	19.1 ± 0.83	37.4 ± 4.04	27.2 ± 1.64	42.3 ± 6.55
ICG 1519	MC	India	2006	37	27	14.6 ± 0.52	45.5 ±15.37	11.3 ± 2.54	21.7 ± 5.32
			2006-07	77	43	13.8 ± 1.70	29.4 ± 2.58	25.2 ± 4.51	39.7 ± 2.54
ICGV 87187	BL	ICRISAT	2006	36	17	11.0 ± 2.21	17.3 ± 0.52	14.4± 1.75	29.6 ± 0.88
			2006-07	56	51	17.9 ± 0.83	33.3 ± 0.60	25.2 ± 1.11	48.4 ± 0.11
Susceptible									
ICG 6402	MC	Unknown	2006	33	29	11.4 ± 2.88	31.6 ± 2.72	1.6 ± 1.11	14.8 ± 2.19
			2006-07	73	43	17.6 ± 2.1	34.2 ± 0.5	12.1 ± 5.64	51.6 ±1.49
ICG 5149	MC	Paraguay	2006	30	26	13.6 ± 1.58	59.0 ± 8.60	3.1 ± 1.94	16.08±6.59
			2006-07	42	37	26.4 ± 1.21	40.5 ± 1.41	11.6 ± 0.32	33.9 ± 8.33
ICGV 92196	BL	ICRISAT	2006	37	29	8.8 ± 2.75	34.1 ± 4.05	3.8 ± 1.74	26.3 ± 3.36
			2006-07	44	45	8.8 ± 2.32	48.4 ± 9.86	20.9 ± 0.81	37.9 ± 4.53
ICG 6993	MC	Brazil	2006	38	33	4.1 ± 2.97	22.6 ± 0.16	1.5 ± 0.59	4.9 ± 2.01
			2006-07	54	50	28.1 ± 3.18	68.6 ± 4.57	15.9 ± 4.28	26.1 ± 6.50
ICG 13856	MC	Uganda	2006	36	26	11.5 ± 2.04	37.5 ± 0.05	6.7 ± 0.86	31.1 ±2.20
			2006-07	81	42	11.6 ± 1.18	24.7 ± 3.19	14.1 ± 6.16	34.9 ± 5.56
ICG 8083	MC	Russia/ CISs	2006	26	23	6.3 ± 1.38	20.7 ± 1.66	5.5 ± 0.93	17.9 ± 1.75
			2006-07	78	40	8.3 ± 0.33	11.1 ± 1.12	8.6 ± 4.29	28.5 ± 3.48
ICG 8760	MC	Zambia	2006	37	33	17.3 ± 1.22	31.6 ± 1.64	4.3 ± 1.80	13.9 ± 0.53
			2006-07	57	45	26.3 ± 2.18	66.2 ± 3.42	21.4 ± 2.48	30.4 ± 5.08
ICG 9905	MC	Zambia	2006	49	34	19.4 ± 1.48	28.1 ± 6.2	1.8 ± 0.67	26.7 ±1.38
			2006-07	57	54	30.3 ± 0.86	64.6 ± 0.55	19.9± 2.19	42.9 ± 2.69
ICG 6022	MC	Sudan	2006	29	27	18.8 ± 5.93	53.0 ± 8.84	3.2 ± 2.16	23.7 ± 5.63
			2006-07	52	40	23.8 ± 1.62	24.6 ± 2.50	16.6 ± 0.83	43.3 ± 4.06
ICG 5016	MC	USA	2006	34	31	13.2 ± 1.96	21.5 ± 2.78	5.8 ± 0.41	22.4 ± 2.90
			2006-07	57	45	13.6 ± 1.27	37.0 ± 4.85	13.0 ± 6.64	39.9 ± 3.39
ICG 4746	MC	Israel	2006	41	29	8.14 ± 2.13	21.1 ± 5.35	4.7 ± 2.06	20.9 ±6.77
			2006-07	61	45	16.9 ± 3.84	37.2 ± 4.67	7.5 ± 2.26	26.6 ±2.85
ICGV 86699	BL	ICRISAT	2006	38	26	8.5 ± 0.49	40.6 ± 2.45	3.00 ± 0.85	41.2 ± 7.76
			2006-07	73	52	18.8 ± 0.27	41.0 ± 2.65	10.2 ± 3.64	29.3 ± 3.35
ICG 11426	MC	India	2006	31	32	6.7 ± 1.25	27.6 ± 2.40	4.2 ± 2.36	27.7 ± 5.74
			2006-07	61	45	7.5 ± 1.84	23.8 ± 4.20	8.3 ± 0.28	32.5 ± 4.91
ICG 15419	MC	Mexico	2006	28	25	14.1 ± 3.86	45.3 ± 5.64	2.1 ± 0.85	20.1 ± 2.95
			2006-07	43	37	23.5 ± 0.66	38.0 ± 2.54	17.6 ± 2.91	44.1 ± 3.30
ICG 5051	MC	USA	2006	34	29	16.5 ± 0.80	45.6 ± 2.92	3.8 ± 0.94	12.2 ± 0.70
			2006-07	48	43	24.5 ± 3.38	41.6 ± 0.46	9.9 ± 1.55	21.2 ± 3.41
JL 24	BL	India	2006	34	27	10.3 ± 1.76	40.3 ± 1.76	6.7 ± 0.88	28.7± 0.91
			2006-07	87	42	26.6 ± 3.05	35.6± 0.87	17.6 ± 4.01	49.6 ± 0.88
CSMG 84-1	MP	ICRISAT	2006	-	-	-	-	-	-
			2006-07	66	52	11.6 ± 1.02	32.6 ± 1.02	16.6 ± 0.98	51.0 ± 2.69
Trial mean			2006	34	28	13.9 ± 0.22	42.6± 1.04	6.9 ± 0.16	22.8 ± 0.44
			2006-07	59	42	18.8 ± 0.36	35.7±0.56	19.2 ± 0.30	36.6 ± 0.61

Therefore, the choice of genotypes for further crossing and development of mapping population was based on lines that were consistently contrasting across the both seasons. Explaining of reasons for the observable large genotype and environmental interactions was not part of the current work. However, it might reflect that the evaporative demand at the time of stress exposure is an important parameter which sets genotypic response to salt stress in groundnut, as previously reported by Lauter and Munns 1987 in case of chickpea.

In most of cereal crops like wheat and rice, a very close correlation usually exists between the yield under control conditions and saline conditions (Quarrie and Mahmood, 1993; Richards, 1992). However, we could not find a strong correlation between the pod weights (pod yield) under control and saline conditions in the present study. This indicated that pod yield in saline conditions was independent from its performance under control conditions. Therefore, the selection of high yielding lines under saline conditions was employed to find tolerant genotypes suggested by Tester and Davenport (2003). Information on salinity tolerance based on pod yield is limited. Only a few studies (Singh *et al*., 2008; Singh *et al*., 2010) have considered pod yield along with other traits (plant stand, plant mortality etc.) under salinity conditions a criterion to screen tolerant lines in groundnut. Our study, although conducted during 2005-2007, highlights some of the key facts and data that are probably not included elsewhere, hence it becomes more relevant in the current scenario. A number of contrasting genotypes were identified based on their consistently higher pod weight across the seasons under salinity (Table 5). ICGV 87187 and ICGS 76 had the highest pod weight under saline conditions and considered as good sources of salinity tolerance, whereas ICG 4746 and ICG 6993 were the most sensitive ones.

The use of selected landraces from putatively affected saline areas offered no advantage over the breeding lines or the mini-core genotypes. Consequently, there was no superior source of tolerance among the selected landraces. This could be related to an uneven quality of passport data in the groundnut collection, related to the fact that many genotypes might have been collected from town/city markets located far from production zones.

Conclusion

The present study revealed a very large range of genotypic variation for pod weight under salinity which could serve as a selection criterion for salinity tolerance. Narrow range of variation in shoot dry weight, and pod yield under non-saline conditions did not allow their use for screening purposes. This variation for pod weight under saline conditions provided a set of contrasting genotypes, which are currently used as diverse sources for salinity tolerance in breeding efforts. Since, there was only a weak relationship between pod weight under saline and control conditions, we considered the pod weight under salinity as the best fitted trait to screen for salinity tolerance. The selection of genotypes from putative saline areas did not improve the probability of obtaining superior variant for salt tolerance than mini-core and breeding lines.

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