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Screening of tropically adapted genotypes of soybean (*Glycine max* (L.) Merrill) for aluminium stress tolerance in short-term hydroponics

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1 SUMMMARY

The screening of genotypes is a prerequisite for the identification of aluminium tolerant varieties. Four (4) levels of aluminium activity (0, 5, 50 and 300μMAl^{3+}) were used to screen forty nine (49) genotypes of soybean in hydroponics at the Crop Science Laboratory of the University of Agriculture, Makurdi, Nigeria, with the objective of identifying aluminium tolerant genotypes. The four levels of aluminium activity constituted the main plots while the 49 soybean genotypes constituted the subplots in a split-plot design, with three replications. The soybean seedlings were germinated for 4 days and transferred to nutrient solutions containing the various levels of aluminium activity. The seedlings grew for 3 days (3D) in hydroponics, and data were taken on the primary root length, root dry weight, and shoot dry weight. Highly significant Al, genotype and Al x genotype effects were observed for all the traits studied. Four genotypes, namely TGX 1896–3F, TGX 1844–18E, TGX 1873–16E and TGX 1878–7E were identified as aluminium stress tolerant in hydroponics and recommended for field trial on acid soils of Nigeria.

2 INTRODUCTION

Aluminium is the third most abundant element in the earth crust and a major phytotoxic element in acid soils (Kochian, 1995). Toxic aluminium levels retard root growth causing various root deformations, and discolouration, that ultimately result in low grain yield in acid soils (Blum, 1986; Villagarcia, 2001). Liming has been used to ameliorate the problem of aluminium toxicity/low pH in soils. Liming the top soil however, remains a temporary solution due to subsoil acidity. Restriction in root growth due to subsoil acidity reduces plant nutrient acquisition and access to subsoil water, which culminates in the reduction of crop yield (Ferrufino *et al*., 2000). Moreover, the cost of liming particularly in developing countries like Nigeria is high and does not justify such a huge investment given the return is low from grain yield of soybeans. The development of aluminium tolerant cultivars of soybeans therefore remains a viable alternative. Various screening methodologies ranging from hydroponics, sand culture, to pot/field experiments at different stages of plant growth have been adopted in searching for aluminium tolerant genotypes of soybean (Campbell and Carter, 1990; Carter and Rufty, 1993; Spehar, 1994; Bianchi-Hall *et al*., 1998; Bianchi-Hall *et al*., 2000; Silva *et al*., 2001; Villagarcia *et al*., 2001). However, hydroponics screening has advantages of close observation of the roots as the experiment progresses and it can be regulated and reproduced. Hence, hydroponics has been used in the rapid screening of large numbers of germplasm and identification of parental stock for soybean breeding (Villagarcia *et al*., 2001).

The appropriate characterization of soybean genotypes for aluminium stress tolerance has often been compounded by limited published and often contradictory data (Villagarcia *et al.* 2001), and therefore remains a problem in breeding for aluminium stress tolerance. Previous effort at rating of soybean for aluminium stress tolerance in Nigeria have been concentrated on adaptive studies on the acid soils of South-East and South-South Nigeria (Okpara and Ibiam, 2000; Yusuf and Idowu, 2001; Okpara *et al.,* 2002; Osedeke and Ojeniyi, 2003 and 2005) with inconsistent findings. There is therefore the need to generate reliable and reproducible information on the aluminium stress tolerance rating of tropically adapted varieties of soybean prior to any field trial.

The objective of the research therefore, was to identify aluminium tolerant tropically adapted genotypes of soybean in hydroponics that could be selected for field trials on acid soils of Nigeria.

3 MATERIALS AND METHODS

Four levels of aluminium activity (0, 5, 50 and 300μMAl^{3+}) were used to screen forty-nine (49) IITA released TGX varieties of soybean for aluminium stress tolerance in hydroponics in 2004. The four levels of aluminium activity were arrived at after a preliminary screening through ten levels of aluminium activity in 2002 (Ojo, 2010; Ojo and Bello, 2010). The four levels of aluminium activity constituted the main plots in a split-plot design, while the forty-nine genotypes constituted the sub-plots. The 49 varieties included the six (TGX 923-2E, TGX 1740-2E, TGX 1805-31F, TGX 1802-1F, TGX 1485-1D, and TGX 1440- 1E) that were reported in previous adaptability studies in Nigeria (Okpara and Ibiam, 2000; Yusuf and Idowu, 2001) and the most popular genotype (TGX 1448-2E) currently in production in the major soybean producing areas of Nigeria. The Experiment was replicated three times. The experiment commenced on the 8th January 2004 and lasted until 18th March 2004. The experiment was conducted on the laboratory tables in the Crop Science Laboratory of the University of Agriculture, Makurdi, Nigeria. Seeds of the 49 genotypes were surface sterilized with ethanol for 1 minute and then with sodium hypochlorite for 3 minutes and rinsed 6 times with deionised water (Ramirez *et al.* 1997), prior to germination. Petri dishes were similarly sterilized. Thereafter, cotton wool was soaked with deionised water in Petri dishes and the seeds were placed on them for germination. After four days, seedlings with poor vigour and twisted radicles were discarded, while ten vigorous healthy seedlings of each genotype were transferred to each of the continuously bubbling hydroponics tanks, fitted with aerators. Each tank was a 5-litre capacity plastic tank of 20cm diameter covered with a removable plastic lid. Each lid had holes of 0.6cm diameter in which single seedlings were fitted and held in place with cotton wool. The nutrient solution culture was composed following the procedures of Howell and Bernard (1961) with some modification (Table 1).

Each tank was filled with 3 litres of deionised water, and nutrients required for 5 litres were weighed and dissolved in it. The pH of the nutrient solution was then adjusted to 4.05±0.05 by adding a few drops of concentrated sulphuric acid. The desired aluminium activity for each tank was prepared separately in one litre of deionised water adjusted to pH of 4.05±0.05. Thereafter, the one litre aluminium solution was poured into the nutrient solution, and the solution made up to 5-litre mark with deionised water (pH 4.05±0.05). Aluminium treatments were in the form of $Al_2(SO_4)_3$. Aerators were then connected to the tank and the solution allowed to bubble continuously for two hours before transferring seedlings to it.

Table 1: Composition of nutrients in hydroponics

Chemical	Concentration
KH_2PO_4	$0.5mML^{-1}$
KCl	$0.5mM\ L^{-1}$
$NaH_2PO_4.2H_2O$	$1.0mM\ L^{-1}$
NH_4NO_3	$0.8mM\ L^{-1}$
$Ca(NO_3)_2.4H_2O$	$1.5mM\ L^{-1}$
$MgSO_4$	$1.00mM\ L^{-1}$
$Fe(NO_3)_2$	$80\mu M\ L^{-1}$
H_3BO_3	$20\mu M\ L^{-1}$
$ZnSO_4.7H_2O$	$3\mu M\ L^{-1}$
$MnCl_2.4H_2O$	$3\mu M\ L^{-1}$
$CuSO_4.5H_2O$	$3\mu M\ L^{-1}$
$(NH_4)_6M_{O7}O_{24}.4H_2O$	$0.8\mu M\ L^{-1}$

$mM\ L^{-1}$ = Millimole per litre $\mu M\ L^{-1}$ = Micromole per litre The various levels of Al^{3+} were supplied in the form of $Al_2\ (SO4)_3$. Adapted from Howell and Bernard (1961)

Each tank was filled with 3 litres of deionised water, and nutrients required for 5 litres were weighed and dissolved in it. The pH of the nutrient solution was then adjusted to 4.05±0.05 by adding a few drops of concentrated sulphuric acid. The desired aluminium activity for each tank was prepared separately in one litre of deionised water adjusted to pH of 4.05±0.05. Thereafter, the one litre aluminium solution was poured into the nutrient solution, and the solution made up to 5-litre mark with deionised water (pH 4.05±0.05). Aluminium treatments were in the form of $Al_2(SO_4)_3$. Aerators were then connected to the tank and the solution allowed to bubble continuously for two hours before transferring seedlings to it. Seedlings grew for three days (3D) in the nutrient solution and were harvested at the age of seven days. On harvesting, five seedlings were randomly picked from each tank, and data taken on primary root length, root dry weight and shoot dry weight. Primary root length was defined as the distance from the root tip to the junction region between the root and the hypocotyls (Bianchi-Hall *et al.*, 1998). Roots and shoots were separated, air dried for three hours, and then oven dried at 70°C for 48 hours before taking their respective weights. The data were subjected to analysis of variance by the General Linear Model (GLM) and the Analysis of variance (ANOVA) procedures of SAS (1990).

4 RESULTS

Mean squares for primary root length, root dry weight and shoot dry weight are summarized in Table 2. Aluminium levels showed highly significant effects on the primary root length, root dry weight and shoot dry weight. Highly significant differences were observed between the control ($0\mu MAl^{3+}$) and the three levels of aluminium treatment (5, 50, & $300\mu MAl^{3+}$) for the primary root length, root dry weight and shoot dry weight. Aluminium activity at $5\mu MAl^{3+}$ was highly significantly different from the $50\mu MAl^{3+}/300\mu MAl^{3+}$ levels for all the three traits. Highly significant differences were also observed between the $50\mu MAl^{3+}$ and the $300\mu MAl^{3+}$ levels of aluminium activity for the three traits.

Table 2: Mean squares for root and shoot traits of 49 soybean genotypes grown at 4 levels of aluminium activity (0, 5, 50, & 300 μ MAl^{3+}) in hydroponics for 3 days (3D)

Source of Variation	Df	Primary root Length (cm)	Root dry weight (g)	Shoot dry weight (g)
Reps	2	0.3354	0.000001	0.0002
Aluminium (Al)	3	928.6982**	0.00203**	0.010267**
0Al Vs Others	1	1393.0473**	0.00554**	0.0154**
5Al Vs 50/300Al	1	835.8284**	0.00033**	0.009255**
50Al Vs 300Al	1	557.2189**	0.00022**	0.00615**
Genotype (Gen.)	48	41.05115**	0.000045**	0.00165**
Gen. X Al	144	7.36715**	0.00005**	0.0007**
Gen. X 0Al Vs Others	48	11.0507**	0.000025**	0.00105**
Gen. X 5Al Vs 50/300Al	48	6.63045**	0.000015**	0.00065**
Gen. X 50Al Vs 300Al	48	4.4203**	0.00001**	0.0004**
Error	390	0.30645	0.000001	0.0002

Significant at $P< 0.05$ and $P < 0.01$ level respectively, 0Al = 0μMAl^{3+} 5Al = 5μMAl^{3+} 50Al = 50μMAl^{3+} 300Al = 300 μMAl^{3+}

Genotypic effects and the genotype × aluminium interaction were highly significant for all the traits. The genotype × 0μMAl^{3+} versus others, genotype x 5μMAl^{3+} Vs 50/300μMAl^{3+} and genotype x 50μMAl^{3+} Vs 300μMAl^{3+} interaction effects were highly significant for all the three traits studied.

Primary root length growth inhibition increased as aluminium activity increases for most of the genotypes (Table 3).

Table 3: Character means and coefficients of variation for root and shoot traits of 49 soybean genotypes grown at 4 levels of aluminium activity (0, 5, 50, & 300 µMAl^{3+}) in hydroponics for 3 days (3D)

	Primary Root Length (cm)				**Root Dry Weight (g)**				**Shoot Dry Weight (g)**			
GENOTYPE	**0**	**5**	**50**	**300**	**0**	**5**	**50**	**300**	**0**	**5**	**50**	**300**
TGX 1740-2E	6.583	3.167	2.667	2.017	0.019	0.011	0.010	0.009	0.153	0.058	0.048	0.046
TGX 1897-17F	9.250	4.117	2.500	2.308	0.018	0.013	0.009	0.007	0.132	0.061	0.051	0.048
TGX 1485-1D	10.700	4.350	2.617	2.517	0.018	0.012	0.011	0.009	0.130	0.061	0.051	0.048
TGX 1805-8F	7.083	5.000	2.133	2. 083	0.019	0.014	0.008	0.008	0.115	0.059	0.049	0.048
TGX 1830-20E	2.733	2.833	2.300	2.208	0.013	0.012	0.009	0.008	0.123	0.058	0.048	0.048
TGX 1835-10E	10.083	9.017	2.608	2.583	0.017	0.013	0.009	0.008	0.123	0.057	0.046	0.045
TGX 1876-4E	8.417	5.500	2.200	2.117	0.018	0.016	0.009	0.008	0.131	0.061	0.051	0.049
TGX 1895-33F	6.167	3.300	2.483	2.408	0.019	0.011	0.009	0.008	0.114	0.060	0.050	0.050
TGX 1831-32E	9.667	8.050	2. 517	2.400	0.024	0.012	0.008	0.008	0.141	0.056	0.049	0.048
TGX 1871-12E	10.667	6.833	2.517	2.508	0.027	0.014	0.008	0.008	0.114	0.062	0.056	0.055
TGX 1895-23F	7.667	4.683	2.717	2.617	0.018	0.013	0.008	0.008	0.127	0.056	0.048	0.048
TGX 1892 -10F	6.500	6.133	2.717	2.692	0.020	0.015	0.008	0.008	0.124	0.065	0.057	0.056
TGX 1895-19F	8.083	6.833	2.800	2.717	0.025	0.014	0.009	0.009	0.110	0.054	0.046	0.045
TGX 1895-49F	9.667	3.967	2.517	2.500	0.021	0.012	0.009	0.008	0.151	0.056	0.046	0.045
TGX 1895-22F	6.167	2.683	2.517	2.408	0.018	0.011	0.009	0.008	0.141	0.059	0.050	0.049
TGX 1805-31F	9.333	5.100	4.767	3.133	0.018	0.013	0.012	0.012	0.111	0.063	0.059	0.057
TGX 1895-50F	10.083	7.150	3.781	3.000	0.019	0.016	0.009	0.008	0.158	0.075	0.068	0.065
TGX 1888-15F	10.083	7.083	3.233	3.117	0.020	0.017	0.009	0.009	0.096	0.083	0.074	0.071
TGX 1873-16E	6.583	6.956	4.642	4.041	0.018	0.017	0.016	0.013	0.102	0.106	0.098	0.089
TGX 1802-3F	12.000	6.533	3.517	3.442	0.020	0.015	0.012	0.010	0.137	0.078	0.068	0.064
TGX 1878-7E	9.450	12.183	8.517	8.083	0.022	0.026	0.018	0.016	0.112	0.084	0.080	0.078
TGX 1893-7F	7.167	4.000	2.517	2.508	0.020	0.016	0.010	0.009	0.158	0.068	0.059	0.056
TGX 1894-3F	7.250	4.500	2.717	2.508	0.020	0.015	0.011	0.009	0.121	0.079	0.068	0.064
TGX 1882-2F	5.000	2.700	2.317	2.317	0.018	0.016	0.009	0.009	0.151	0.069	0.069	0.065
TGX 1019-2EN	7.667	6.167	3.517	3.117	0.020	0.013	0.009	0.008	0.140	0.083	0.075	0.073
TGX 1890-7F	9.833	4.450	3.617	3.608	0.021	0.015	0.010	0.009	0.130	0.066	0.058	0.055
TGX 1802-1F	13.250	5.417	3.000	2.908	0.023	0.012	0.009	0.008	0.101	0.051	0.044	0.040
TGX 1886-33F	6.833	5.333	2.817	2.808	0.020	0.015	0.011	0.009	0.161	0.059	0.049	0.045
TGX 1869-31E	7.500	5.133	3.108	3.000	0.017	0.016	0.009	0.009	0.151	0.080	0.072	0.070
TGX 1880-3E	7.667	6.200	3.583	3.508	0.020	0.017	0.009	0.009	0.137	0.077	0.070	0.065
TGX 1891-3F	10.583	5.000	3.633	3.492	0.026	0.015	0.009	0.006	0.162	0.094	0.088	0.086

TGX 1893-10F	7.833	4.967	3.517	3.400	0.021	0.017	0.012	0.011	0.111	0.077	0.075	0.073
TGX 1842-1E	8.850	6.167	3.717	2.417	0.012	0.013	0.012	0.011	0.084	0.087	0.076	0.073
TGX 1838-5E	11.167	9.500	7.133	7.083	0.025	0.012	0.012	0.008	0.135	0.063	0.053	0.049
TGX 1893-6F	10.167	9.167	3.617	3.608	0.020	0.018	0.011	0.009	0.120	0.081	0.073	0.073
TGX 1896-3F	9.583	14.330	9.617	9.181	0.020	0.026	0.020	0.014	0.105	0.094	0.093	0.092
TGX 1869-13E	7.417	4.500	3.817	3.608	0.020	0.017	0.013	0.011	0.124	0.077	0.067	0.064

	Primary Root Length (cm)				**Root Dry Weight (g)**				**Shoot Dry Weight (g)**			
GENOTYPE	**0**	**5**	**50**	**300**	**0**	**5**	**50**	**300**	**0**	**5**	**50**	**300**
TGX 1844-18E	10.917	15.208	9.500	7.067	0.020	0.025	0.020	0.014	0.125	0.096	0.090	0.089
TGX 1886-38F	8.167	7.033	3.000	2.408	0.021	0.017	0.013	0.011	0.098	0.088	0.057	0.057
TGX 1440-1E	7.750	4.283	3.517	3.508	0.018	0.013	0.012	0.010	0.092	0.074	0.065	0.063
TGX 1844-4E	9.167	4.450	3.417	3.417	0.017	0.014	0.011	0.010	0.096	0.078	0.065	0.063
TGX 1448-2E	9.667	3.267	3.217	3.000	0.025	0.014	0.011	0.010	0.155	0.086	0.075	0.072
TGX 1864-17F	10.883	8.167	3.333	3.183	0.020	0.016	0.012	0.011	0.080	0.072	0.062	0.061
TGX 1889-12F	9.167	6.150	3.017	3.000	0.030	0.020	0.012	0.011	0.135	0.062	0.050	0.044
TGX 1866-7F	10.967	4.475	3.633	3.417	0.020	0.011	0.010	0.010	0.136	0.071	0.062	0.060
TGX 1846-10E	8.917	4.083	3.517	3.500	0.022	0.019	0.012	0.011	0.101	0.059	0.048	0.044
TGX 1866-12F	9.483	3.150	2.433	2.117	0.030	0.015	0.010	0.009	0.120	0.071	0.062	0.060
TGX 1895-35F	4.750	4.017	3.808	3.680	0.023	0.018	0.014	0.010	0.110	0.074	0.067	0.057
TGX 923-2E	14.500	5.017	4.517	4.080	0.020	0.018	0.012	0.011	0.120	0.046	0.040	0.035
GRAND MEAN	8.702	5.937	3.600	3.294	0.017	0.015	0.011	0.010	0.125	0.070	0.062	0.061
LSD (0.05)	0.850	0.460	0.320	0.280	0.002	0.001	0.001	0.001	0.004	0.004	0.004	0.010
C.V. (%)	6.000	4.800	5.500	5.200	6.800	3.600	5.600	4.900	2.000	3.500	3.800	10.1

Primary root length in the control (0μMAl^{3+}) ranged from 2.733cm for TGX 1830-20E to 14.500cm for TGX 923-2E with 55.1% of the genotypes recording means higher than the population mean (8.702cm). Imposition of aluminium treatment at 5μMAl^{3+} aluminium activity inhibited growth in most of the genotypes with >60% of them recording lower primary root length than the population mean. The least growth in the primary root length (2.683cm) at the 5μMAl^{3+} aluminium activity was observed for TGX 1895-22F while the best growth (15.208cm) was observed for TGX 1844-18E. Primary root length growth at the 5μMAl^{3+} aluminium activity however, compares favourably with that of the control (0μMAl^{3+}) in many of the genotypes. Primary root length in fourteen genotypes was significantly different from population mean at the 5μMAl^{3+} level of activity with TGX 1873–16E, TGX 1878–7E, TGX 1896–3F, TGX 1830–20E, TGX 1844–18E, and TGX 1842–1E producing longer primary root lengths at 5μMAl^{3+} than in the control (0μMAl^{3+}). Primary root length of TGX 1896–3F at the 5μMAl^{3+} aluminium activity was 149.5% of its length in the control (0μMAl^{3+}). The 50μMAl^{3+} and the 300μMAl^{3+} levels of aluminium activity produced the greatest inhibition in the growth of the primary roots. Primary root length at these two levels of aluminium activity ranged between 2.000cm and <4.000cm in most of the genotypes with only 7 and 10 genotypes recording significantly longer lengths than population mean at the 50μMAl^{3+} and 300μMAl^{3+} levels of aluminium activity respectively. A few genotypes were however exceptional, experiencing little or no inhibition due to aluminium treatment at these levels (50 & 300μMAl^{3+}). Primary root lengths of TGX 1896–3F, TGX 1844–18E, TGX 1873–16E, TGX 1878–7E and TGX 1895–35F at the 50μMAl^{3+} and 300μMAl^{3+} levels of aluminium activity were in the range of 70 – 100% of their respective control (0μMAl^{3+}) conditions. Coefficient of variations of 6.0%, 4.8%, 5.5% and 5.2% were observed for primary root length at 0, 5, 50 and 300μMAl^{3+} levels of aluminium activity respectively.

A progressive decline in root dry weight was generally observed with increasing aluminium activity as the percentage of genotypic means higher than the population mean declined from 89.8% in the control to as low as 26.5% at the highest (300μMAl^{3+}) level of aluminium activity. Root dry weight ranged from 0.012g plant^{-1} for TGX 1842-1E to 0.030g plant^{-1} for TGX 1866-12F and TGX 1889-12F in the control. Four genotypes, namely, TGX 1740-2E, TGX 1895-33F, TGX 1895-22F and TGX 1866-7F maintained the least root dry weight of 0.011g plant^{-1} while TGX 1896-3F and TGX 1878-7E maintained the highest weight of 0.026g plant^{-1} at the 5μMAl^{3+} level of aluminium activity. Root dry matter accumulation at the 5μMAl^{3+} level of aluminium activity was the same or higher than that of the control (0μMAl^{3+}) for some genotypes, namely TGX 1805–31F, TGX 1873–16E, TGX 1878–7E, TGX 1842–1E and TGX 1896–3F. Root dry matter accumulation in TGX 1873–16E, TGX 1878–7E, TGX 1838 – 5E, TGX 1844–18E and TGX 1896–3F at the 50μMAl^{3+} and 300μMAl^{3+} levels of aluminium activity was also significantly higher than their respective population means. The C.V. for root dry weight at 0, 5, 50 and 300μMAl^{3+} levels of activity were 6.8%, 3.6%, 5.6% and 4.9% respectively.

Shoot dry weight ranged from 0.084g plant^{-1} for TGX 1842-1E to 0.162g plant^{-1} for TGX 1891-3F in the control (0μMAl^{3+}). Aluminium stress on the shoot was generally severe. Shoot dry matter accumulation was least in TGX 923-2E (0.046g plant^{-1}) and highest in TGX 1844-18E (0.106g plant^{-1}) at the 5μMAl^{3+} level of aluminium activity with about 50% of the genotypes accumulating higher dry matter than the population mean. Shoot dry matter accumulation was also least in TGX 923-2E at both the 50μMAl^{3+} and 300μMAl^{3+} levels of aluminium activity, while TGX 1896-3F maintained the highest shoot dry weight at both levels. Seven genotypes (TGX 1896–3F, TGX

1842–1E, TGX 1844–18E, TGX 1864–17E, TGX 1873–16E TGX 1878-7E and TGX 1888–15F) were however outstanding in their performance, with shoot dry matter accumulation at the 50 and 300μMAl^{3+} levels of aluminium activity >70% of that accumulated in their respective controls (0μMAl^{3+}) conditions. Shoot dry weights of ten genotypes were significantly higher than their respective population means at the 50 and 300μMAl^{3+} levels of aluminium activity. The highest C.V. of 10.1% was observed at 300μMAl^{3+} level of aluminium activity for shoot dry weight.

5 DISCUSSION

The highly significant genotypic effects observed for all the traits (primary root length, root dry weight and shoot dry weight) studied are indications that the soybean genotypes are genetically diverse in response to aluminium stress. The highly significant genotype × aluminium and its various components of interaction (genotype x 0μMAl^{3+} versus others, genotype x 5μMAl^{3+} Vs 50/300μMAl^{3+} and genotype x 50μMAl^{3+} Vs 300μMAl^{3+}) observed for all the traits was due to changes in genotypic ranking in response to changes in the levels of aluminium activity. The increasing growth inhibition in the primary root length and the decreasing dry matter accumulation observed with increasing level of aluminium activity, is an indication that tender seedlings are highly sensitive to aluminium treatment at all levels. Tender seedlings are highly sensitive to changes in the levels of aluminium activity and experience heavy root damage in hydroponics (Ermolayev *et al.*, 2003) than older plants. Similar observations in previous studies have led to the conclusion that differential aluminium tolerance is better expressed in young seedlings than in older plants (Mugwira *et al.*, 1976; Blum, 1986; Villagarcia *et al.*, 2001; Ermolayev *et al.*, 2003). The ability of some genotypes to root vigorously and accumulate higher dry matter than other genotypes both in the presence and in the absence of aluminium had been previously observed and attributed to constitutive morphological characteristic (Urrea-Gonzalez *et al.*, 1996; Villagarcia *et al.*, 2001) which could be advantageous in the breeding of aluminium tolerant cultivars. In the current study, an aluminium stress tolerant genotype was considered as any genotype whose growth and dry matter accumulation is significantly higher than their respective population mean at the 5, 50 and 300μMAl^{3+} levels of aluminium activity. Root growth and dry matter accumulation at these three levels of aluminium activity (5, 50 and 300μMAl^{3+}) should also be ≥70% of the aluminium control conditions in such genotypes. Only TGX 1896–3F, TGX 1844–18E, TGX 1873–16E and TGX 1878–7E met these criteria and were appropriately identified as aluminium stress tolerant.

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