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# Screening of tropically adapted soybeans for aluminium stress tolerance in sand culture

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## ABSTRACT

*Objective:* To identify tropically adapted soybean genotypes tolerant to aluminium toxicity in sand culture.

*Methodology and results:* The experiment was conducted at the Teaching and Research Farm of the University of Agriculture, Makurdi, Nigeria, in 2003 and 2004. The treatment was a factorial combination of 49 soybean genotypes and two levels of aluminium activity (zero and 450µM$Al^{3+}$) laid out in a randomized complete block design and replicated three times. The soybean seeds were planted in the sand and watered with deionized water for seven days. Thereafter, two levels of nutrient solutions containing 0µM$Al^{3+}$ or 450µM$Al^{3+}$aluminium activity were used to water the seedlings for the next 18 days. Plants were harvested at 25DAP and data were recorded on the root dry weight, shoot dry weight and relative root surface area. Highly significant differences were observed for Al, genotype, Al x genotype and Al x genotype x year interaction effects for all the measured traits.

*Conclusion and application of findings:* the study identified six genotypes, TGX 1897 – 17F, TGX 1878–7E, TGX 1893–7F, TGX 1894–3F, TGX 1896–3F, and TGX 1844–18E as aluminium tolerant in sand culture. These genotypes could further be explored in the development of acid/aluminium tolerant variety through genetic manipulations and testing in multi-locational field trials on the acid soils of Nigeria.

**Keywords:** aluminium activity, genotype, aluminium stress tolerance, sand culture, screening

## INTRODUCTION

Soybean is a very important oil seed crop in both human and livestock nutrition and in the industry (Ojo, 2010). It has higher protein content than any other pulse (Giller and Dashiel, 2007). Soybean has also become an increasingly important agricultural commodity, with a steady increase in worldwide annual production (Liu, 1997). According to FAO (2005), the average World production of soybean for 1999 to 2003 was 177 million tons/year, of which Nigeria accounted for 439,000 tons/year representing only 0.25% of the World output. This level of soybean production in Nigeria is very low and cannot meet up with domestic demand for the country. Commercial production of soybeans in Nigeria is being concentrated in the Guinea Savanna agro ecological zone of the country. The deficit in soybean production can be addressed by extending its commercial production to other parts of the country, particularly the South-East and South-South rain forest ecology. However, this part is largely predominated by acid soils (Osedeke and Ojeniyi, 2005). Pockets of acid soils also exist in various parts of Nigeria. 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 discolorations, that ultimately result in low grain yield (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. Moreover, heavy application of lime could lead to undesirable runoff effects (de la Fuente *et al*., 1997), deficiencies of other nutrients and culminate in adverse effects on other crops in rotation (Whitten, 1997). Furthermore, the cost of liming material in Nigeria is very expensive and does not justify such huge input cost given the return on investment from grain yield of soybeans. Therefore, the development and identification of aluminium tolerant soybeans cultivars remains a viable and cost-effective alternative.

The screening of genotypes is a prerequisite for the selection and development of tolerant varieties (Ojo *et al*., 2010). Previous studies (Foy *et al.*, 1969; Hanson and Kamprath, 1979; Campbell and Carter Jr., 1990; Hanson, 1991; Spehar, 1994; Bianchi-Hall *et al.,* 1998; Bianchi-Hall *et al.,* 2000; Villagarcia *et al.*, 2001; Ermolayev *et al.*, 2003;Ojo, 2010; Ojo and Bello, 2010; Ojo *et al.,* 2010) have used various screening media that ranged from solution culture to soil cultures in identifying aluminium tolerant soybean genotypes. However, soil and hydroponics media have shortcomings that make them less suitable in screening of soybean genotypes for aluminium stress tolerance compared to the sand culture. The hydroponics screening is restricted to the seedling stage (Villagarcia *et al.*, 2001), while field-based screening techniques are expensive, laborious and time consuming (Wang *et al*., 2006b). Moreover, the problem of spatial variability could greatly bias the interpretation of field screening results (Ball *et al.,* 1993). As a solid substrate that is almost inert and physically similar to the soil, experiments in the sand culture can be regulated with consistency (Villagarcia *et al*., 2001). Seeds could also be directly planted and roots completely excavated at harvest.

Despite these advantages of sand culture over other media and its readiness as a viable alternative to the soil and hydroponics in screening of crop plants for aluminium stress tolerance, plant breeders in the tropics, particularly Nigeria, are yet to adopt the technology. The dearth of information on the appropriate characterization of tropically adapted soybean genotypes for aluminium stress tolerance necessitated this research. The objective of this study was to identify tropically adapted soybean genotypes tolerant to aluminium toxicity in a sand culture for testing in multi-location field trials on acid soils.

## MATERIALS AND METHODS

Forty-nine released soybean varieties developed at IITA were used as genetic materials for this experiment. The 49 genotypes have been described by previous workers (Ojo, 2010; Ojo and Bello, 2010; Ojo *et al*., 2010). Two levels of aluminium activity (0μM$Al^{3+}$ and 450μM$Al^{3+}$) were chosen for this sand culture experiment based on the outcome of a preliminary screening conducted in 2001 and 2002 (Ojo, 2010). The experiment was arranged in a randomized complete block design with three replications. The treatments were factorial combinations of 49 genotypes and two levels of aluminium activity (0μM$Al^{3+}$ and 450μM$Al^{3+}$). The experiment was conducted following the procedure of Villagarcia *et al. (2001)*, with some modifications on the time of imposition of aluminium treatment and duration of the experiment. Nutrient stock solution concentration was developed following the procedure of Howell and Bernard (1961) and Villagarcia *et al*. (2001) (Table 1).

**Table 1:** Composition of nutrients in the sand culture

| Chemical | Concentration |
|---|---|
| $KH_2PO_4$ | 1.5 mM |
| $K_2SO_4$ | 1.5 mM |
| $NaH_2PO_4.2H_2O$ | 1.0 mM |
| $NH_4NO_3$ | 2.0 mM |
| $CaSO_4.½H_2O$ | 3.0 mM |
| $MgSO_4$ | 100 μM |
| $Fe(NO_3)_2$ | 20 μM |
| $H_3BO_3$ | 10 μM |
| $ZnSO_4.7H_2O$ | 1.5 μM |
| $MnCl_2.4H_2O$ | 1.5 μM |
| $CuSO_4.5H_2O$ | 0.5 μM |
| $(NH_4)_6M_{O7}O_{24}.4H_2O$ | 0.8 μM |

mM = Millimole μM = Micromole, The various levels of $Al^{3+}$ were supplied in the form of $Al_2(SO4)_3$

Adapted from Howell and Bernard (1961) and Villagarcia (2001)

The 0μMAl$^{3+}$aluminium activity was regarded as the control. Polyethylene bags measuring 20cm in diameter were each filled with 10kg of builders' grade sharp sand and flushed with deionized water adjusted to pH 4.05±.05. The sand was flushed again with deionized water adjusted to pH 7.0 to remove the acidity and allowed to drain for 24 hours. Thereafter, the sand was heavily watered with deionized water and six seeds were planted in each bag and lightly covered with the sharp sand. The pots were then watered daily with deionized water (pH 7.0) until five days after planting (5DAP) when emerged seedlings were thinned down to three/pot The watering with deionised water (pH 7.0) continued till 7DAP. Thereafter, nutrient solution with either of the two levels of aluminium activity (0μMAl$^{3+}$ or 450μMAl$^{3+}$) were used to water each of the pots for the next eighteen days, with each pot receiving one litre of solution per day. To avoid a build-up of nutrients, each pot was flushed daily with deionised water (pH 4.05±0.05) and a time lag of two hours was allowed for the pots to drain prior to watering with the nutrient solution. The Experiment was conducted during the dry season of January to March 2003 and repeated within the same period in 2004. Plants were harvested at 25 DAP and data were taken on root dry weight (RDW), shoot dry weight (SDW) and relative root surface area (RRSA). RRSA was taken according to Carley and Watson (1966) prior to oven drying. Plants were separated into root and shoot. Thereafter, root and shoot were separately dried to a constant weight at 70$^0$C and their weights taken as RDW and SDW respectively. The data was subjected to Analysis of variance (ANOVA) procedures using general Linear Model (GLM) in SAS (1990).

**RESULTS**

Mean squares for root and shoot characteristics of the 49 soybean genotypes grown at two levels of aluminium activity (0μMAl$^{3+}$ and 450μMAl$^{3+}$) in sand culture are presented in Table 2. There was no significant difference in years and reps/years were observed for all the traits except in the shoot dry weight (Table 2).

**Table 2:** Mean squares for root and shoot characteristics of 49 tropically adapted soybean genotypes screened at two levels of aluminium activity (0μMAl$^{3+}$ and 450μMAl$^{3+}$) in acid sand culture for 2 years

| Source of Variation | Df | Root Dry Weight (g) | Shoot Dry Weight | Relative Root Surface Area |
|---|---|---|---|---|
| Years | 1 | 0.0019 | 0.0176* | 0.0806 |
| Reps /Years | 4 | 0.0004 | 0.0008 | 0.0032 |
| Aluminium | 1 | 0.5266** | 6.0640** | 369.3070** |
| Genotype | 48 | 0.1798** | 0.7309** | 15.9641** |
| Years × Al. | 1 | 0.0006 | 7.0154** | 0.0144 |
| Gen. × Years | 48 | 0.0025 | 0.0035 | 0.0944 |
| Gen. × Al. | 48 | 0.0340** | 0.1461** | 4.4417** |
| Genotype × Al.× Years | 48 | 0.0378** | 0.1536** | 5.2317** |
| Error | 388 | 0.0028 | 0.0028 | 0.0767 |

*, **: Significant at P<0.05 and P<0.01 respectively

Highly significant differences were observed in aluminium, genotypes, genotypes × aluminium and genotypes × aluminium × years interaction effects for root dry weight, shoot dry weight and relative root surface area. Highly significant aluminium x years interaction effects was detected for shoot dry weight. Mean separation of absolute means and percentage of control (PC) for root dry weight, shoot dry weight, and relative root surface area are presented in Tables 3, 4 and 5.

**Table 3:** Root Dry Weight (g plant$^{-1}$) of 49 Soybean Genotypes Grown at 0µM$Al^{3+}$ and 450µM$Al^{3+}$ (0 & 450) and Percentage of Control (PC) in Sand Culture in 2003 and 2004

| Genotype | 2003 | | | 2004 | | | Genotype | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 450 | PC | 0 | 450 | PC | | 0 | 450 | PC | 0 | 450 | PC |
| TGX 1740-2E | 0.31 | 0.21 | 66 | 0.31 | 0.20 | 65 | TGX 1890-7F | 0.36 | 0.19 | 53 | 0.31 | 0.20 | 65 |
| TGX 1897-17F | 0.39 | 0.38 | 98 | 0.39 | 0.37 | 95 | TGX 1802-1F | 0.33 | 0.25 | 76 | 0.39 | 0.37 | 95 |
| TGX 1485-1D | 0.50 | 0.27 | 54 | 0.50 | 0.27 | 54 | TGX 1886-33F | 0.36 | 0.22 | 61 | 0.50 | 0.27 | 54 |
| TGX 1805-8F | 0.32 | 0.21 | 66 | 0.32 | 0.22 | 69 | TGX 1869-31E | 0.33 | 0.24 | 73 | 0.32 | 0.22 | 69 |
| TGX 1830-20E | 0.31 | 0.21 | 68 | 0.31 | 0.22 | 71 | TGX 1880-3E | 0.35 | 0.22 | 63 | 0.31 | 0.22 | 71 |
| TGX 1835-10E | 0.35 | 0.22 | 63 | 0.35 | 0.22 | 63 | TGX 1891-3F | 0.40 | 0.21 | 53 | 0.35 | 0.22 | 63 |
| TGX 1876-4E | 0.31 | 0.22 | 71 | 0.31 | 0.22 | 71 | TGX 1893-10F | 0.33 | 0.26 | 79 | 0.31 | 0.22 | 71 |
| TGX 1895-33F | 0.35 | 0.28 | 80 | 0.35 | 0.29 | 83 | TGX 1842-1E | 0.33 | 0.26 | 79 | 0.35 | 0.29 | 83 |
| TGX 1831-32E | 0.30 | 0.20 | 67 | 0.30 | 0.20 | 67 | TGX 1838-5E | 0.51 | 0.30 | 59 | 0.30 | 0.20 | 67 |
| TGX 1871-12E | 0.30 | 0.19 | 63 | 0.31 | 0.19 | 61 | TGX 1893-6F | 0.39 | 0.20 | 51 | 0.31 | 0.19 | 61 |
| TGX 1895-23F | 0.27 | 0.21 | 77 | 0.28 | 0.21 | 75 | TGX 1896-3F | 0.70 | 0.66 | 94 | 0.28 | 0.21 | 75 |
| TGX 1892 -10F | 0.30 | 0.21 | 70 | 0.31 | 0.21 | 68 | TGX 1869-13E | 0.40 | 0.27 | 68 | 0.31 | 0.21 | 68 |
| TGX 1895-19F | 0.28 | 0.19 | 68 | 0.28 | 0.21 | 75 | TGX 1844-18E | 0.60 | 0.55 | 92 | 0.28 | 0.21 | 75 |
| TGX 1895-49F | 0.28 | 0.18 | 64 | 0.28 | 0.19 | 68 | TGX 1886-38F | 0.31 | 0.23 | 74 | 0.28 | 0.19 | 68 |
| TGX 1895-22F | 0.25 | 0.20 | 80 | 0.25 | 0.20 | 80 | TGX 1440-1E | 0.28 | 0.25 | 89 | 0.25 | 0.20 | 80 |
| TGX 1805-31F | 0.35 | 0.27 | 77 | 0.35 | 0.27 | 77 | TGX 1844-4E | 0.33 | 0.23 | 70 | 0.35 | 0.27 | 77 |
| TGX 1895-50F | 0.24 | 0.18 | 75 | 0.24 | 0.18 | 75 | TGX 1448-2E | 0.30 | 0.26 | 87 | 0.24 | 0.18 | 75 |
| TGX 1888-15F | 0.25 | 0.18 | 72 | 0.25 | 0.19 | 76 | TGX 1864-17F | 0.33 | 0.27 | 82 | 0.25 | 0.19 | 76 |
| TGX 1873-16E | 0.30 | 0.27 | 90 | 0.30 | 0.26 | 87 | TGX 1889-12F | 0.36 | 0.22 | 61 | 0.30 | 0.26 | 87 |
| TGX 1802-3F | 0.33 | 0.24 | 73 | 0.34 | 0.24 | 71 | TGX 1866-7F | 0.43 | 0.34 | 79 | 0.34 | 0.24 | 71 |
| TGX 1878-7E | 0.36 | 0.34 | 94 | 0.37 | 0.34 | 92 | TGX 1846-10E | 0.32 | 0.21 | 66 | 0.37 | 0.34 | 92 |
| TGX 1893-7F | 0.34 | 0.33 | 97 | 0.35 | 0.33 | 94 | TGX 1866-12F | 0.32 | 0.19 | 59 | 0.35 | 0.33 | 94 |
| TGX 1894-3F | 0.39 | 0.38 | 97 | 0.40 | 0.38 | 95 | TGX 1895-35F | 0.35 | 0.23 | 66 | 0.40 | 0.38 | 95 |
| TGX 1882-2F | 0.35 | 0.27 | 77 | 0.34 | 0.27 | 79 | TGX 923-2E | 0.33 | 0.18 | 55 | 0.34 | 0.27 | 79 |
| TGX 1019-2EN | 0.34 | 0.23 | 68 | 0.34 | 0.22 | 65 | | | | | | | |
| | | | **Grand Mean** | | | | | **0.35** | **0.26** | **73** | **0.35** | **0.25** | **72** |
| | | | **$LSD_{.05}$** | | | | | **0.09** | **0.08** | | **0.09** | **0.08** | |
| | | | **CV (%)** | | | | | **16.3** | **19.0** | | **16.3** | **19.4** | |

Genotype × Al. × Years LSD.05=0.06

**Table 4:** Shoot Dry Weight (g plant$^{-1}$) of 49 Soybean Genotypes Grown at 0µM$Al^{3+}$ and 450µM$Al^{3+}$ (0 & 450) and Percentage of Control (PC) in Sand Culture in 2003 and 2004

| Genotype | 2003 | | | 2004 | | | Genotype | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 450 | PC | 0 | 450 | PC | | 0 | 450 | PC | 0 | 450 | PC |
| TGX 1740-2E | 0.64 | 0.35 | 55 | 0.64 | 0.34 | 53 | TGX 1890-7F | 0.80 | 0.48 | 60 | 0.79 | 0.46 | 58 |
| TGX 1897-17F | 0.77 | 0.60 | 78 | 0.76 | 0.60 | 79 | TGX 1802-1F | 0.68 | 0.35 | 51 | 0.66 | 0.34 | 52 |
| TGX 1485-1D | 0.56 | 0.36 | 64 | 0.54 | 0.34 | 63 | TGX 1886-33F | 0.82 | 0.48 | 59 | 0.80 | 0.46 | 58 |
| TGX 1805-8F | 0.64 | 0.36 | 56 | 0.63 | 0.35 | 56 | TGX 1869-31E | 0.72 | 0.42 | 58 | 0.70 | 0.40 | 57 |
| TGX 1830-20E | 0.62 | 0.33 | 53 | 0.60 | 0.30 | 50 | TGX 1880-3E | 0.71 | 0.40 | 56 | 0.69 | 0.39 | 57 |
| TGX 1835-10E | 0.71 | 0.39 | 55 | 0.69 | 0.37 | 54 | TGX 1891-3F | 1.04 | 0.43 | 41 | 1.01 | 0.42 | 42 |
| TGX 1876-4E | 0.67 | 0.37 | 55 | 0.66 | 0.36 | 55 | TGX 1893-10F | 0.83 | 0.46 | 55 | 0.81 | 0.44 | 54 |
| TGX 1895-33F | 0.75 | 0.49 | 65 | 0.73 | 0.47 | 64 | TGX 1842-1E | 0.98 | 0.40 | 41 | 0.96 | 0.40 | 42 |
| TGX 1831-32E | 0.63 | 0.33 | 52 | 0.61 | 0.31 | 51 | TGX 1838-5E | 0.99 | 0.56 | 57 | 0.97 | 0.54 | 57 |
| TGX 1871-12E | 0.63 | 0.35 | 56 | 0.62 | 0.34 | 55 | TGX 1893-6F | 0.99 | 0.40 | 40 | 0.97 | 0.40 | 41 |
| TGX 1895-23F | 0.60 | 0.34 | 57 | 0.60 | 0.33 | 55 | TGX 1896-3F | 1.12 | 1.08 | 96 | 1.11 | 1.06 | 95 |
| TGX 1892 -10F | 0.60 | 0.33 | 55 | 0.58 | 0.31 | 53 | TGX 1869-13E | 0.97 | 0.65 | 67 | 0.95 | 0.65 | 68 |
| TGX 1895-19F | 0.60 | 0.30 | 50 | 0.60 | 0.28 | 47 | TGX 1844-18E | 0.95 | 0.87 | 92 | 0.95 | 0.85 | 89 |
| TGX 1895-49F | 0.61 | 0.32 | 52 | 0.61 | 0.30 | 49 | TGX 1886-38F | 0.88 | 0.48 | 55 | 0.88 | 0.47 | 53 |
| TGX 1895-22F | 0.52 | 0.32 | 62 | 0.52 | 0.30 | 58 | TGX 1440-1E | 0.52 | 0.31 | 60 | 0.50 | 0.29 | 58 |
| TGX 1805-31F | 1.02 | 0.53 | 52 | 1.01 | 0.51 | 50 | TGX 1844-4E | 0.83 | 0.51 | 61 | 0.81 | 0.50 | 62 |
| TGX 1895-50F | 0.51 | 0.32 | 63 | 0.50 | 0.31 | 62 | TGX 1448-2E | 0.73 | 0.33 | 45 | 0.70 | 0.30 | 43 |
| TGX 1888-15F | 0.56 | 0.32 | 57 | 0.55 | 0.30 | 55 | TGX 1864-17F | 0.87 | 0.55 | 63 | 0.85 | 0.53 | 62 |
| TGX 1873-16E | 0.60 | 0.57 | 95 | 0.59 | 0.57 | 97 | TGX 1889-12F | 0.90 | 0.63 | 70 | 0.88 | 0.60 | 68 |
| TGX 1802-3F | 0.66 | 0.31 | 47 | 0.65 | 0.31 | 48 | TGX 1866-7F | 1.13 | 1.05 | 93 | 1.11 | 1.00 | 90 |
| TGX 1878-7E | 0.61 | 0.56 | 92 | 0.59 | 0.54 | 92 | TGX 1846-10E | 0.95 | 0.44 | 46 | 0.93 | 0.42 | 45 |
| TGX 1893-7F | 0.69 | 0.61 | 88 | 0.69 | 0.59 | 86 | TGX 1866-12F | 0.91 | 0.48 | 53 | 0.91 | 0.45 | 49 |
| TGX 1894-3F | 0.67 | 0.62 | 93 | 0.65 | 0.62 | 95 | TGX 1895-35F | 0.90 | 0.67 | 74 | 0.88 | 0.65 | 74 |
| TGX 1882-2F | 0.72 | 0.43 | 60 | 0.70 | 0.41 | 59 | TGX 923-2E | 0.90 | 0.40 | 44 | 0.89 | 0.38 | 43 |
| TGX 1019-2EN | 0.69 | 0.41 | 59 | 0.66 | 0.39 | 59 | | | | | | | |
| | | | | | Grand Mean | | | 0.76 | 0.47 | 0.75 | 0.45 | 60.0 | |
| | | | | | LSD.05 | | | 1.00 | 0.08 | 0.09 | 0.07 | | |
| | | | | | CV (%) | | | 8.1 | 10.3 | 7.6 | 9.8 | | |

**Table 5:** Relative Root Surface Area (g plant$^{-1}$) of 49 Soybean Genotypes Grown at 0µMAl$^{3+}$ and 450µMAl$^{3+}$ (0 & 450) and Percentage of Control (PC) in Sand Culture in 2003 and 2004

| Genotype | 2003 | | | 2004 | | | Genotype | 2003 | | | 2004 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 450 | PC | 0 | 450 | PC | | 0 | 450 | PC | 0 | 450 | PC |
| TGX 1740-2E | 5.60 | 3.06 | 55 | 5.54 | 3.06 | 55 | TGX 1890-7F | 6.30 | 3.25 | 52 | 6.27 | 3.20 | 51 |
| TGX 1897-17F | 6.80 | 6.50 | 96 | 6.87 | 6.50 | 95 | TGX 1802-1F | 5.50 | 3.17 | 58 | 5.48 | 3.04 | 55 |
| TGX 1485-1D | 4.55 | 3.00 | 66 | 4.55 | 3.10 | 68 | TGX 1886-33F | 6.58 | 4.32 | 66 | 6.50 | 4.20 | 65 |
| TGX 1805-8F | 5.42 | 3.23 | 60 | 5.41 | 3.23 | 60 | TGX 1869-31E | 6.35 | 3.86 | 61 | 6.34 | 3.72 | 59 |
| TGX 1830-20E | 5.37 | 3.00 | 56 | 5.37 | 3.02 | 56 | TGX 1880-3E | 5.87 | 3.59 | 61 | 5.80 | 3.50 | 60 |
| TGX 1835-10E | 6.58 | 3.49 | 53 | 6.60 | 3.49 | 53 | TGX 1891-3F | 5.09 | 3.97 | 78 | 5.05 | 3.70 | 73 |
| TGX 1876-4E | 5.99 | 3.27 | 55 | 5.90 | 3.27 | 55 | TGX 1893-10F | 7.43 | 3.21 | 43 | 7.43 | 3.11 | 42 |
| TGX 1895-33F | 6.26 | 3.34 | 53 | 6.26 | 3.30 | 53 | TGX 1842-1E | 7.59 | 3.07 | 40 | 7.57 | 3.00 | 40 |
| TGX 1831-32E | 5.49 | 3.09 | 56 | 5.49 | 3.00 | 55 | TGX 1838-5E | 7.70 | 3.48 | 45 | 7.76 | 3.30 | 43 |
| TGX 1871-12E | 5.27 | 3.24 | 61 | 5.27 | 3.20 | 61 | TGX 1893-6F | 5.95 | 3.60 | 61 | 5.97 | 3.40 | 57 |
| TGX 1895-23F | 5.35 | 3.17 | 59 | 5.35 | 3.10 | 58 | TGX 1896-3F | 7.16 | 6.94 | 97 | 7.15 | 6.94 | 97 |
| TGX 1892 -10F | 5.48 | 3.00 | 55 | 5.48 | 3.03 | 55 | TGX 1869-13E | 7.70 | 5.56 | 72 | 7.75 | 5.43 | 70 |
| TGX 1895-19F | 5.25 | 2.90 | 55 | 5.25 | 2.93 | 56 | TGX 1844-18E | 7.21 | 6.68 | 93 | 7.20 | 6.45 | 90 |
| TGX 1895-49F | 5.22 | 2.95 | 57 | 5.22 | 2.99 | 57 | TGX 1886-38F | 7.55 | 3.61 | 48 | 7.55 | 3.50 | 46 |
| TGX 1895-22F | 4.70 | 2.90 | 62 | 4.70 | 2.96 | 63 | TGX 1440-1E | 7.63 | 3.43 | 45 | 7.63 | 3.32 | 44 |
| TGX 1805-31F | 7.50 | 3.57 | 48 | 7.54 | 3.57 | 47 | TGX 1844-4E | 6.50 | 4.57 | 70 | 6.50 | 4.47 | 69 |
| TGX 1895-50F | 4.60 | 2.94 | 64 | 4.73 | 2.94 | 62 | TGX 1448-2E | 6.63 | 3.64 | 55 | 6.65 | 3.64 | 55 |
| TGX 1888-15F | 5.10 | 2.93 | 57 | 5.12 | 2.93 | 57 | TGX 1864-17F | 6.96 | 5.01 | 72 | 6.94 | 4.75 | 68 |
| TGX 1873-16E | 5.36 | 4.87 | 91 | 5.35 | 4.87 | 91 | TGX 1889-12F | 7.10 | 5.03 | 71 | 7.13 | 5.00 | 70 |
| TGX 1802-3F | 5.60 | 3.15 | 56 | 5.60 | 3.10 | 55 | TGX 1866-7F | 6.98 | 6.63 | 95 | 6.99 | 6.63 | 95 |
| TGX 1878-7E | 7.58 | 5.57 | 73 | 7.58 | 5.60 | 74 | TGX 1846-10E | 7.72 | 3.37 | 44 | 7.71 | 3.37 | 44 |
| TGX 1893-7F | 5.49 | 5.35 | 97 | 5.49 | 5.30 | 97 | TGX 1866-12F | 7.10 | 3.23 | 45 | 7.10 | 3.10 | 44 |
| TGX 1894-3F | 6.46 | 5.50 | 85 | 6.48 | 5.56 | 86 | TGX 1895-35F | 8.08 | 5.94 | 74 | 8.08 | 5.80 | 72 |
| TGX 1882-2F | 6.44 | 3.47 | 54 | 6.45 | 3.47 | 54 | TGX 923-2E | 7.20 | 3.11 | 43 | 7.20 | 3.14 | 44 |
| TGX 1019-2EN | 5.66 | 3.58 | 63 | 5.75 | 3.58 | 62 | | | | | | | |
| | | | | | Grand Mean | | | 6.31 | 3.95 | 62.6 | 6.31 | 3.89 | 61.6 |
| | | | | | LSD.05 | | | 1.35 | 1.06 | | 1.35 | 1.05 | |
| | | | | | CV (%) | | | 13.2 | 16.5 | | 13.1 | 16.7 | |

Genotype × Al. × Years LSD.05=0.06

Root dry weight in the control (0µM$Al^{3+}$) ranged from 0.24g plant$^{-1}$ for TGX 1895-50F in both years to 0.71g plant$^{-1}$ for TGX1896-3F in 2004 with a mean of 0.35g plant$^{-1}$. Similarly, root dry weight ranged from 0.18g plant$^{-1}$ for TGX 1895-50Fto 0.66g plant$^{-1}$ for TGX 1896-3Fat 450µM$Al^{3+}$. Root dry matter accumulation in seven genotypes (TGX 1897 – 17F, TGX 1878–7E, TGX 1893–7F, TGX 1894–3F, TGX 1896–3F, TGX 1844–18E and TGX 1866–7F) at 450µM$Al^{3+}$indicated that these genotypes are tolerant to aluminium stress. Percentage of control (PC) in these was >70%. Root dry matter accumulation at 450µM$Al^{3+}$ for TGX 1897–17F was almost the same as that accumulated in the aluminium control condition (PC of 98%). Some genotypes, namely experienced severe inhibition due to aluminium stress (450µM$Al^{3+}$) and only recorded a PC of <56%; and the mean PC for their root dry weight was 73% and 72% for 2003 and 2004, respectively. The coefficient of variation (C.V) for root dry weight at 0µM$Al^{3+}$ was 16.3% in both years while the C.V. for root dry weight at 450µM$Al^{3+}$ was slightly higher, with 19.0% and 19.4% in 2003 and 2004, respectively. The least shoot dry weight of 0.50g plant$^{-1}$ was observed for TGX 1895 – 50F while the highest shoot dry weight of 1.13g plant$^{-1}$ was observed for TGX1866–7F (2003) in the aluminium control (0µM$Al^{3+}$) condition (Table 4). The shoot dry weight at 450µM$Al^{3+}$ ranged from 0.28g plant$^{-1}$ for TGX 1895-19F(2003)to 1.08g plant$^{-1}$ for TGX 1896 – 3FThe PC for this trait ranged from 40% for TGX 1893-6F (2003) to 97% for TGX 1873-16E (2004) with PC means of 61.8% and 60% for 2003 and 2004,respectively.Shoot dry matter accumulation was clearly demonstrated in ten genotypes (TGX 1897–17F, TGX 1873 – 16E, TGX 1878–7E, TGX 1893–7F, TGX 1894–3F, TGX 1896–3F, TGX 1844–18E, TGX 1889-12F, TGX 1866–7F and TGX 1895-35F) at 450µM$Al^{3}$PC of >70% in each case, hence identifying them as aluminium tolerant for shoot dry weight. . Aluminium treatment was however very severe on shoot dry matter accumulation in some genotypes. Five genotypes, TGX 1890–7F, TGX 1891-3F, TGX 1893–6F, TGX 1866–12F and TGX 923–2E recorded lower shoot dry weights than the population mean with PC of <60%. Lower CVs of 8.1 %( 2003) and 7.6 % (2004) were observed for the shoot dry weights at the 0µM$Al^{3+}$ level compared to the 10.3 %( 2003) and 9.8 %( 2004) observed at the 450µM$Al^{3+}$ level of aluminium activity.

Relative root surface area in the aluminium control (0µM$Al^{3+}$) condition ranged from 4.55g plant$^{-1}$ for TGX 1485-1D to 8.08g plant$^{-1}$ for TGX 1895-35F with a mean of 6.31g plant$^{-1}$. At the 450µM$Al^{3+}$ level, relative root surface area ranged from 2.90g plant$^{-1}$ for TGX 1895-19F and TGX 1895-22F in 2003 to 6.94g plant$^{-1}$ for TGX 1896-3F in 2003 and 2004.The least PC of 40% was observed for TGX 1842-1E while the highest PC of 97% was observed for TGX 1896-3F and TGX 1893-7F in both years. Relative root surface area in nine genotypes(TGX 1897–17F, TGX 1893–7F, TGX 1896–3F, TGX 1878–7E, TGX 1894–3F, TGX 1844–18E and TGX 1869–13E, TGX 1889-12F and TGX 1895-35F) was significantly higher than the population mean at the 450µM$Al^{3+}$ level with PCs of >70%. The CV for relative root surface area at 0µM$Al^{3+}$ was 13.2% and 13.1% for 2003 and 2004 respectively, while CV at 450µM$Al^{3+}$ was 16.5% and 16.7% for 2003 and 2004, respectively.

## DISCUSSION

The highly significant aluminium effect observed for all the traits measured in the current work was due to aluminium toxicity, which restricted the growth of the plants. This observation is consistent with findings of previous studies (Villagarcia *et al.,* 2001; Ojo and Bello, 2010). Villagarcia *et al.* (2001), grew ten varieties of soybean at two levels of aluminium activity (0 and 450µM$Al^{3+}$) in sand culture and observed a reduction in dry matter accumulation and relative root surface area between 0 and 450µM$Al^{3+}$ for all the genotypes. Ojo and Bello (2010) grew fifteen genotypes of soybean at eight levels of aluminium activity in hydroponics and attributed the growth restriction in the genotypes to the phytotoxic effects of aluminium in the media. The highly significant genotypic and genotype x aluminium interaction effects observed for all the traits in this study is consistent with previous findings (Villagarcia *et al.,* 2001; Ojo and Bello, 2010) and is an indication of genetic diversity for aluminium stress tolerance in the soybean population used in this study. It is also an indication of genotypic variation in response to the imposition of aluminium stress. The wider range in sensitivity for root dry weight, shoot dry weight and relative root surface area observed in the current work, compared to the findings of Villagarcia *et al.* (2001), could be due to differences in the populations and the environments in which the experiments were carried out. Villagarcia *et al.* (2001) conducted their experiments in the greenhouse at a constant temperature in a temperate country, using temperate genotypes, while the current work utilized tropically adapted genotypes in a humid tropical environment

without any control on temperature or relative humidity. Thus the highly significant genotype x aluminium x year interactions could be attributed to relative sensitivity of the genotypes to aluminium stress in response to environmental fluctuations. According to Wang *et al.* (2006), aluminium toxicity is affected by temperature, among many other factors.

The higher mean PC observed for the root dry weight is an indication that this trait is less sensitive to the presence of aluminium in the sand culture compared to the other two traits (shoot dry weight and the relative root surface area). This relative sensitivity of traits to the presence of aluminium in the culture media was also observed by Villagarcia *et al.* (2001) who conclude that the relative root surface area is the most sensitive trait in discrimination of soybean genotypes for aluminium stress tolerance. Thus, concentrating on the shoot dry weight and the relative root surface area as a selection criterion in screening of soybean genotypes for aluminium stress tolerance is likely to achieve a faster progress in selection. The higher CV observed for all the traits at 450µM$Al^{3+}$compared to the control in the current study is suggest that progress in selection for tolerance to aluminium will be faster at this level of aluminium activity.

These results showed that genotypes (TGX 1897 – 17F, TGX 1878–7E, TGX 1893–7F, TGX 1894–3F, TGX 1896–3F and TGX 1844–18E) were identified as aluminium stress tolerant for all the traits measured in this study. The results of current work are consistent with the findings of Ojo *et al.* (2010). Three out of the six genotypes were earlier identified by Ojo *et al.* (2010) as acid (aluminium) stress tolerant for mature plant traits (number of pods/plant, 100-seed weight and grain yield) on acid soil in Nigeria. This study demonstrated that sand culture could be used in a preliminary screening of soybeans to identify aluminium tolerant genotypes. The technology will minimize the cost of field experimentation by reducing the number of genotypes selected for field evaluation. The six identified aluminium stress tolerant genotypes identified in this study could further be explored in the development of acid/aluminium tolerant variety through genetic manipulations and testing in multi-locational field trials on the acid soils of Nigeria.

## REFERENCES


Ball S, MullaT, Konzack CF 1993. Spatial heterogeneity affects variety trial interpretation. *Crop Science*33: 931 – 935.

Bianchi-Hall CM, Carter TE Jr., Rufty TW, Arellano C, Boerma HR, Ashley DA, Burton JW, 1998.Heritability and resource allocation of aluminium tolerance derived from soybean PI416937.*Crop Science*38: 513 – 522.

Bianchi-Hall CM, Carter TE Jr., Bailey MA, Mian MAR, Rufty TW, Ashley DA, Boerma HR, Arellano C,Hussey RS, Parrott WA, 2000. Aluminium tolerance associated with quantitative traits loci derived from soybean PI416937 in hydroponics. *Crop Science* 40: 538 – 545.

Blum A, 1986. Plant Breeding for Stress Environments. CRC Press, USA. 223Pp.

Campbell KAG and Carter TE Jr., 1990. Aluminium tolerance in soybean: 1. Genotypic correlation and repeatability of solution culture and green house screening methods. *Crop science*30: 1049 – 1054.

Carley HE and Watson RW, 1966. A new gravimetric method for estimating root-surface areas. *Soil Science* 102 : 289 – 291.

de la Fuente JM, Ramirez – Rodriguez V, Cabrera – Ponce JL, Herrera – Estrella L 1997. Aluminium tolerance in transgenic plants by alteration of citrate synthesis. Science 276 (5318):1566 – 1568.

Ermolayev V, Weschke W, Manteufel R, 2003. Comparison of Al-induced gene expression insensitive and tolerant soybean cultivars. *Journal of Experimental Biology*54 (393): 2745 - 2756.

FAO Statistics Agriculture Data 2005.

Foy CD, Fleming AL, Armiger WH, 1969. Aluminium tolerance of soybean varieties in relation to calcium nutrition. *Agronomy Journal*61: 505 – 511.

Giller KE and Dashiell KE, 2007. *Glycine max* (L.) Merrill. In: van der Vossen HAM and Mkamilo GS (Eds.) Plant Resources of Tropical Africa 14. Vegetable oils. PROTA Foundation, Wagenigen. Netherlands/Backhuys Publishers, Leiden, Netherlands/CTA, Wagenigen, Netherlands. pp 78 – 74.

Hanson WD, 1991. Root characteristics associated with divergent selection for seedling aluminium tolerance in soybean. *Crop Science*31: 125 – 129.

Hanson WD, and Kamprath EJ, 1979. Selection for aluminium tolerance in soybeans based on

seedling-root growth. *Agronomy Journal* 71: 581 – 586.

Howell RW and Bernard RL, 1961. Phosphorus response of soybean varieties. *Crop Science*1: 311 – 313.

Kochian LV, 1995. Cellular mechanisms of aluminium toxicity and resistance in plants. *Annual Review of Plant Physiology and Plant Molecular Biology*46: 237 – 260.

Liu K, 1997. Soybeans: chemistry, technology, and utilization. Gaithersburg, MD: Aspen Publishers Inc. Press, 1–22.

Obi IU, 1986. Statistical Methods of Detecting Differences between Treatment Means. Snapp Press (Nig) Ltd., Nigeria. 45 Pp.

Obi IU, 2000. Introduction to Factorial Experiments for Agricultural, Biological and Social Sciences Research. Optimal International Ltd. 2nd Ed., Nigeria. 92 Pp.

Ojo GOS, 2010.Genotypic Variation and Diallel Analysis for Aluminium Stress Tolerance in Soybeans (*Glycine max* (L.) Merrill). PhD Thesis, 2010, University of Agriculture, Makurdi, Nigeria.

Ojo GOS and Bello LL, 2010. Determination of appropriate level of aluminum activity in hydroponics for the screening of tropically adapted soybean varieties. *Journal of Animal and Plant Science* 8 (2): 971 – 980.

Ojo GOS, Bello LL, Adeyemo MO, 2010. Genotypic variation for acid stress tolerance in soybean in the humid rain forest acid soil of South-Eastern Nigeria. *Journal of Applied Biosciences*36: 2360-2366.

Osedeke VE and Ojeniyi SO, 2005. Evaluation of the Forest Zone of Southeast Nigeria for Soybean Production. *Nigerian Journal of Soil Science*15: 129 – 132.

Spehar CR, 1994. Aluminium tolerance of soybean genotypes in short term experiments. *Euphytica*76: 73 – 80.

Urrea-Gomez R, Ceballos H, Pandey S, Bahia-Filho AFC, Leon LA, 1996. A greenhouse screening technique for acid soil tolerance in maize. Agronomy Journal 88: 806 – 812.

Villagarcia M, Carter TE Jr., Rufty TW, Niewoehner AS, Jennette MW, Arellano C, 2001. Genotypic rankings for aluminium tolerance of soybean roots grown in hydroponics and sand culture. *Crop Science*41 (5): 1499 – 1507.

Wang JP, Raman H, Read B, Zhou MX, Mendham NJ, Venkatanagappa S, 2006a. Validation of an Alt locus for aluminium tolerance scored with ferrochrome cyanine R staining method in barley cultivar Honen (*Hordeumvulgare* L.) Aust J Agric Res.57 (1):113–118.

Wang JP, Raman H, Zhang G, Mendham N, Zhou MX, 2006b. Aluminium tolerance in barley (*Hordeumvulgare* L.): physiological mechanisms, genetics and screening methods. J Zhejiang University Sci. B.7 (10):769 – 787.

Whitten M, 1997. Subsurface acidification: Estimation of Lime Requirements from Lime Dissolution Rates in the Field. In Williamson DR Ed. Proceedings of the 4th Triennial Western Australian Soil Science Conference. Pp 128 – 131.