SELECTION FOR ALUMINUM TOLERANCE IN TROPICAL SOYBEANS[1]

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RESUMO

SELEÇÃO PARA TOLERÂNCIA AO ALUMÍNIO EM SOJA TROPICAL

A acidez do solo é fator limitante para a maioria das plantas cultivadas no Cerrado Brasileiro. A toxidez causada por alumínio (Al) é especialmente séria na subsuperfície, que permanece ácida após o uso de corretivos, por impedir o crescimento radicular e causar suscetibilidade à seca e desbalanceamento nutricional. Aqui objetivou-se a seleção de genótipos de soja com maior tolerância ao Al, pela associação de experimentos em hidroponia e no campo. Cruzamentos incluindo genótipos selecionados no Cerrado foram realizados. Sementes de indivíduos contrastantes, selecionados em hidroponia na geração F2 pelo crescimento radicular, foram obtidas para avaliação de progênies em F3, no campo, e em F4, novamente em hidroponia. Rendimento de grãos e de biomassa das progênies selecionadas foram superiores aos genitores, no experimento em solo ácido. Esses resultados foram confirmados pelo desempenho em hidroponia, indicando que o método de seleção pode ser empregado com êxito em programas de melhoramento para adaptação de cultivos a condições de acidez subsuperficial do solo.

PALAVRAS-CHAVE: acidez sub-superficial, *Glycine max*, estresse, genótipo, melhoramento de plantas.

ABSTRACT

Soil acidity is a limiting factor for most of the cultivated plants in the Brazilian Savannah. Toxicity caused by aluminum (Al) is especially serious in the acid subsurface, which remains acidic after soil has been amended, by hindering root growth and causing drought susceptibility and nutritional unbalance. This research aimed at selecting soybean with increased tolerance to Al through association of hydroponics and field experiments. Crosses including savannah adapted genotypes were obtained. Seeds of contrasting individuals, selected in hydroponics at F2 generation for root growth, were obtained for progeny evaluation at F3, in the field, and at F4 in hydroponics. Grain production and total dry matter of selected progenies were superior to the parentals, in the acid soil experiment. These results were confirmed by performance in hydroponics, indicating the method may be successfully employed in breeding programs for crop adaptation to subsurface acid soil conditions.

KEY WORDS: subsurface acidity, *Glycine max*, Al stress, plant breeding.

INTRODUCTION

Genetic improvement of summer crops represents one of the great research contributions to agricultural development in the low latitude Brazilian savannahs (Cerrados). One factor that has hindered cultivation, until 30 years ago was the predominance of low fertility acid soils, rich in aluminum (Al). Ammending techniques have been developed, with simultaneous soybean genotype selection for long-juvenile character, resulting in commercial grain production (Spehar 1994a).

Soybean breeding for low latitudes started in the 1970´s by introduction, hybridisation, and selection from natural crosses and mutations, to attain adapted cultivars (Spehar 1994b). There were three main hybridisation cycles. The first was conducted by Instituto Agronômico de Campinas (IAC), for long-juvenile phase. In the second, disease resistance and high grain yield were incorporated. The third, a joint effort led by the Brazilian organization for agricultural – Embrapa, culminated with Doko and BR-9 Savana cultivar releases (Spehar 1994a). At present,

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commercial cultivars are selected to solve specific biotic and mineral problems of Al and nutritional unbalance, emphasising sustainable production (Spehar 1998b).

High Al cation exchange capacity (CEC) saturation occur in more than half of the cultivated area in Brazil. The ploughed layer benefits from amendments, while the acid subsurface soil contains Al, impeding deep root growth of susceptible plants, turning them liable proneto water stress and mineral nutrition unbalance (Spehar 1994b).

The presence of Al and the occurrence of dry spells during the reproductive phase can cause negative impact on grain yield. Cultivated plants, adapted to these environments, possess variable response to stress (Foy *et al.* 1992, Spehar 1994c, 1996). The challenge is to improve them by associating Al tolerance to superior agronomic performance.

Identification of Al tolerance, in field trials, may be affected by uncontrolled factors which are frequently confounded with treatments. Experiments in controlled environment, with problem soils and nutrient solution, have been used in physiology studies, variety classification and in the genetics of mineral stress tolerance (Foy *et al.* 1992, Spehar 1994b). Genetic differences for tolerance to Al have been found through root growth and organic compounds formation in hydroponics (Spehar & Makita 1994, Ma *et al.* 2004).

The use of hydroponics is of great interest in plant selection, by measuring the effect of toxic Al on aboveground plant parts and root growth (Delhaize & Ryan 1995). Hydroponics allows control of environmental variables and nutrient-Al interactions, increasing the precision of tests (Foy *et al.* 1978, Camargo 1985, Spehar 1994a). The method presents the advantage of being rapid and non-destructive, allowing to grow tolerant individuals for generation advance, progeny tests and variety acquisition (Spehar & Makita 1994).

In order to make field evaluations efficient, we need high Al contents of, uniformly distributed, and with suitable supplies of Ca, Mg, P, K, and micronutrients in soil, at levels that allow the increase of response magnitude. A difficulty posed by these experiments is to define Al saturation to which genotypes are submitted. The accepted level for commercial soybean production must be under 5 g 100 g^{-1} in the soil ploughed layer (Sousa *et al.* 1993). Saturation level up to 45 g 100 g^{-1} was shown the most efficient to select tolerant genotypes in soybeans (Hanson & Kamprath 1979). Spehar (1994c), using soil with 29 g 100 g^{-1} of Al saturation in 0 - 20 cm layer, and 33 g 100 g^{-1} in the subsurface layer, found genotypic differences for grain yield.

Al toxicity is to be reduced, or higher levels are needed to produce the same effects, under high water content in the soil profile (Camargo & Furlani 1989). Within limits, water and Al stresses can be combined to facilitate selection in field experiments (Goldman *et al.* 1989).

Root studies in hydroponics are aimed to determine the effect of the Al on cell division and elongation, while evaluations in the field reflect the continuous action of the element on the above aboveground parts, roots and absorption of nutrients. In this case, tolerance is assessed by grain yield and dry mater (Baligar 1997).

This work aimed to select soybean genotypes for Al tolerance through hydroponics and field evaluations on acid soil.

MATERIAL AND METHODS

Hybridization and generation advance

Fourteen savannah-adapted genotypes, except the Braxton of American origin, presenting increasing levels of tolerance to Al, were hybridised. They were chosen for their genetic background, in order to increase the recovering probability of favourable recombinants (Spehar 1996). Progenies were obtained for the hybrids: BR-1 x Dourados Mn, BR-4 x Dourados (a), BR-4 x Dourados (b), BR-4 x Dourados (c), BR-38 x BR-9 (Savana) (a), BR-38 x BR-9 (Savana) (b), BR83-147 x UFV-9, BR 38 x UFV-9, Braxton x BR-37, Dourados x Dourados Mn, Dourados Mn x BR-16, Dourados Mn x Emgopa 305, Dourados Mn x UFV Araguaia, Emgopa 305 x UFV-4, UFV Araguaia x BR-1.

The seeds (F_1) were grown in pots containing a mixture of soil and compost, with nutrient and water supply sufficient for full plant development. During growth, the hybrid plants were separated from the self-pollinated by morphological markers (Spehar, 1996). The glass house, set at 25 ± 2ºC temperature, had light supplementation to increase day length by two hours, for maximum vegetative growth, before flowering induction. The plants were exposed to short days, resulting in large number of F_2 seeds at harvest (Spehar & Souza, 1999). These seeds were identified and stored in a cold room at 5 ± 1ºC.

The F_3 progenies were obtained by advancing selected plantlets from hydroponics tests, whereas F_4 progenies were produced by sampling F_3 plants in field plots, using modified pedigre method or single seed decent.

F_2 progeny evaluation in hydroponics

For each of the 14 progenies, two lots of 60 seeds were wrapped in rolls of filter paper. The rolls were placed vertically in of 1,000 mL beakers, containing 100 mL of distilled water, to produce straight roots at germination. The vessels were covered with plastic film, to prevent moisture loss, and placed in a dark germinating chamber at the temperature of 25 ± 1°C. After 72 hours, sprouts were classified by root length; saving those between 25 and 35mm. Thirty sprouts of each progeny were separated into three groups and placed initially in plastic supports floating on distilled water.

Each support, consisting of one set of all progenies, was transferred to a plastic tank of 256 x 316 x 115 mm, containing 5.0 L treatment solution of 2.0 mg. L^{-1} Al, in the form of $Al_2(SO_4)_3 – 18H_2O$ and 160.0 mg L^{-1} Ca in the form of $Ca(NO_3)_2 . 4H_2O$. The Ca ion was added for pH buffering, root growth and Al absorption (Sartain & Kamprath 1978, Hanson & Kamprath 1979, Sapra *et al.* 1982, Garland *et al.* 1990). The pH was maintained at 4.0 by adding H2SO4 N, every 24 h, to assure availability of Al+3, the most toxic form (Kinraide 2003).

The tanks, covered with plastic film to prevent water evaporation, were placed in a growth chamber illuminated with 550 nm and 635 nm wavelengths, and temperature of 25 ± 1ºC, and relative humidity near 75 mL .100 mL^{-1}. For aeration and steering, pipes connected to a compressor were placed at the bottom, inside each tank. After 48-h exposure to treatment solution, final length of the roots was measured. Root growth (RG) was calculated according to the formula RG = FL – IL, where IL is initial length and FL final length.

The experiment was carried out in a randomized complete blocks design with three repetitions, each plot containing ten plantlets. The block contained 14 progenies and control. For each cross, two plantlets with smallest growth and two with longest roots were transferred to pots for generation advance in glass house, under extended day length. At physiological maturity, seeds were harvested, identified and stored in cold room with temperature of 5 ± 1ºC. Fifty-six F_3 progenies were obtained.

F_3 progeny evaluation in the field

The experiment was conducted in an oxisol (Ferralsol FAO), previously under Cerrado vegetation, in Planaltina-DF, Brazil (15º35'30"S, 47º42'30"W, and 1,000 m.a.s.l.). Soil physical characteristics are 34g.100 g^{-1} sand, 19 g 100 g^{-1} silt, 45 g 100 g^{-1} clay and 2 g 100 g^{-1} organic matter (OM). Before setting the experiment, a blank essaywas conducted to assess soil uniformity. Cultivar BR-9 (Savana) was grown for being sensitive to differences in soil fertility. Prior to the experiment, soil samples were collected in the depths of 0 to 20 cm and 20 to 40 cm, to perform chemical analyses (Table 1).

Lime was applied to the rate of 1,000-kg.ha^{-1} (100% $CaCO_3$ equivalent), 60 days before sowing. This brought aluminum saturation to nearly 45 g 100 g^{-1}, suitable for tolerance screening (Hanson & Kamprath 1979, Spehar 1994c). Five days before sowing, a mixture of 150 kg ha^{-1} P2O5 (triple superphosphate phosphate), 120 kg ha^{-1} K2O (potassium chloride), 2 kg ha^{-1} boron (borax), 5 kg ha^{-1} zinc (zinc sulphate), 2 kg ha^{-1} copper (copper sulphate), 250 mg ha^{-1} molybdenum (sodium molybdate), 50 kg ha^{-1} cobalt (cobalt sulphate) and 30 kg ha^{-1} sulphur (calcium sulphate) was broadcast (Sousa *et al.* 1993). The amendments were incorporated into the soil with the aid of rotovator for homogenous distribution. The final soil chemical composition is presented in Table 2.

The experiment was installed on hill plots, 50 cm long, where 30 seeds were sown per progeny. The distance between plots was 70 cm and between blocks was 80 cm (Spehar 1998a). All plots were thinned to fourteen individuals fifteen days after emergence. The experimental design was of augmented blocks, with ten replications to check

Tabela 1. Soil chemical analysis after blank essay with BR-9 Brasilian Savanah cultivar.

Depth (cm)	pH	Al	H+Al	Ca	Mg	OM
	H_2O	cmol$_c$.kg^{-1}				g 100g^{-1}
0-20	4.34	1.64	8.26	0.30	0.17	2.84
20-40	4.38	1.46	7.18	0.15	0.06	2.22
-	P mg ha^{-1}	Cu mg ha^{-1}	Fe mg ha^{-1}	Mn mg ha^{-1}	Zn mg ha^{-1}	K mg ha^{-1}
0-20	1.04	0.85	97.50	4.85	0.45	116.50
20-40	0.64	0.80	98.50	4.35	0.40	84.00

Tabela 2. Chemical analysis of amended soil in the experimental area.

Depth (cm)	pH H_2O	Al	H+Al	Ca	Mg	OM
		$\text{cmol}_c.\text{kg}^{-1}$				g 100g^{-1}
0-20	4.94	1.15	7.60	0.69	0.38	2.94
20-40	4.49	1.27	7.05	0.23	0.21	2.43
-	P mg ha^{-1}	Cu mg ha^{-1}	Fe mg ha^{-1}	Mn mg ha^{-1}	Zn mg ha^{-1}	K mg ha^{-1}
0-20	3.13	1.10	85.00	4.60	2.50	160.50
20-40	1.14	0.95	78.00	3.75	2.15	118.50

parent varieties (tolerant IAC-9 and intolerant UFV-1), and one for each of the 56 F_3 progenies.

At 50 days, the seventh and eighth fully expanded leaf, counting from the bottom first trifoliate, were harvested to determine the area (Spehar 1996). At physiological maturity, the plots were harvested and measurements performed: plant and first pod height, total dry mater (TDM), grain yield (GY) and days to maturity. Harvest index (HI) was calculated through the formula HI = GY / TDM*100.

Rainfall during the experiment was 490 mm. At the reproductive phase there was a dry spell with only 40 mm precipitation. The transpiration in the same period, measured in class A tank, was superior to 190 mm. To avoid severe drought effect and differences levelling off, the area was irrigated in four periods, with 20 mm each.

F_4 progeny evaluation in hydroponics

Plantlets in F_4 generation of 16 progenies that had with outstanding performance in field were chosen with respective genitors and checks of tolerance and intolerance, were grown in similar procedure for the F_2 generation. Correlation analysis of was performed.

RESULTS AND DISCUSSION

The mean root growth (mm) for F_2 generation hybrids and the extreme performers for tolerance and intolerance is presented in Table 3. Differences detected for crosses involving the same genitors may be related to genetic variation within genotype (Spehar & Souza 1999). The presence of plants with superior values, on average, suggests that these are segregates with high frequency of favourable genes to Al tolerance (Spehar 1996).

In general, tolerant F_2 individuals in hydroponics yielded F_3 progenies with higher grain production and dry mater than the respective genitors

Tabela 3. Average root growth (mm) for F_2 soybean progenies, with maximum and minimum values, at 2.0 mg ha^{-1} Al plus 160.0 mg ha^{-1} Ca, during 48 h

Hybrid	RG (mm) = FL – IL		
	Root Growth [1]	Maximum	Minimum
UFV Araguaia x BR-1	39.26 a	59	22
Braxton x BR-37 (a)	38.67 ab	65	19
BR-1 x Dourados	36.87 abc	61	23
BR-4 x Dourados (c) [2]	45.75 abcd	66	12
Dourados x Dourados Mn	34.00 abcde	66	16
BR-38 x BR-9 (Savana) (b) [2]	33.00 abcde	49	21
BR-4 x Dourados (b)	28.47 abcde	44	20
Dourados Mn x BR-16	24.27 abcdef	47	17
Dourados Mn x UFV Araguaia	24.13 abcdef	36	17
Dourados Mn x EMGOPA 305	23.60 bcdef	41	18
BR83-147 x UFV-9 [2]	22.75 cdef	43	2
Braxton x BR-37 (b)	22.27 def	48	11
BR-4 x Dourados (a) [2]	18.87 ef	41	3
EMGOPA 305 x UFV-4	12.40 f	25	7
CV (%)	37.06	–	–

[1]- Means followed by the same letter do not differ statistically (Duncan $p < 0.05$).

[2]- Genotypes that had been evaluated in hydroponics in F_4 generation.

Tabela 4. Leaf area (LA), plant height (PH), first pod height (FP), dry mater (DM), grain yield (GY) and harvest index (HI) of F3 progenies on high Al soil in the field.

Progeny	Trait[1]					
	LA (cm^2)	PH (mm)	FP (mm)	DM (g)	GY (g)	HI (g 100 g^{-1})
BR83-147 x UFV-9(t1)	495.0 a	273.3 c	43.7 c	23.6 a	13.2 a	56.0 a
BR83-147 x UFV-9(t2)	363.0 a	363.3 bc	55.0 bc	20.0 ab	11.1 ab	55.4 a
BR83-147 x UFV-9(i1)	-	436.7 abc	65.0 abc	21.1 ab	11.6 ab	54.9 a
BR83-147 x UFV-9(i2)	-	271.7 c	58.3 bc	9.2 b	4.7 c	51.4 a
BR83-147 (p1)	506.2 a	466.0 ab	79.9 ba	18.2 ab	9.2 abc	50.6 a
UFV-9 (p2)	504.5 a	565.5 a	97.5 a	21.6 a	9.4 abc	44.5 a
IAC-9 (ct)	459.0 a	363.0 bc	67.8 bac	13.8 ab	7.2 bc	52.2 a
UFV-1 (ci)	463.0 a	520.9 ab	100.2 a	15.8 ab	7.7 bc	49.9 a
C.V. (%)	14.69	15.47	17.79	28.81	23.66	9.84
BR-4 x Dourados (t1)	527.0 a	423.3 abc	71.3 ab	24.6 a	14.1 a	57.2 a
BR-4 x Dourados (t2)	437.0 abc	381.3 bc	88.3 ab	27.0 a	12.2 ab	45.1 bc
BR-4 x Dourados (i1)	349.0 bc	333.7 bc	105.7 a	8.6 c	4.8 c	55.8 ab
BR-4 x Dourados (i2)	298.0 c	291.7 c	61.7 b	12.7 bc	6.7 c	52.7 abc
BR-4 (p1)	355.1 bc	290.7 c	61.0 b	10.1 c	5.2 c	51.3 abc
Dourados (p2)	531.1 a	471.3 ab	105.3 a	19.1 abc	9.2 bc	47.9 abc
IAC-9 (ct)	504.5 ab	565.5 a	97.5 ab	21.6 ab	9.4 bc	44.5 c
UFV-1 (ci)	459.0 abc	363.0 bc	67.8 ab	13.8 bc	7.2 c	52.2 abc
C.V. (%)	14.67	16.68	18.74	26.83	24.67	9.40
BR-4 x Dourados (t1)	732.0 a	483.3 ab	72.3 abc	18.5 ab	9.2 ab	49.7 ab
BR-4 x Dourados (t2)	351.0 c	359.3 bc	85.0 abc	13.8 ab	8.0 ab	58.1 a
BR-4 x Dourados (i1)	343.0 c	275.0 c	74.0 abc	8.9 b	5.3 b	59.0 a
BR-4 x Dourados (i2)	-	343.7 bc	53.3 c	18.8 ab	10.7 a	56.8 a
BR-4 (p1)	355.1 c	290.7 c	61.0 bc	10.1 b	5.2 b	51.3 ab
Dourados (p2)	531.1 b	471.3 ab	105.3 a	19.1 ab	9.2 ab	47.9 ab
IAC-9 (ct)	504.5 b	565.5 a	97.5 ab	21.6 a	9.4 ab	44.5 b
UFV-1 (ci)	459.0 bc	363.0 bc	67.8 abc	13.8 ab	7.2 ab	52.2 ab
C.V.	14.40	16.65	18.97	27.33	25.00	9.34
BR-38 x UFV-9 (t1)	469.0 ab	346.7 b	43.3 c	16.9 ab	8.2 a	48.6 a
BR-38 x UFV-9 (t2)	597.0 a	355.0 b	88.3 b	15.8 ab	7.8 a	49.5 a
BR-38 x UFV-9 (i1)	399.00 b	286.70 b	42.30 c	9.5 b	5.1 a	53.1 a
BR-38 x UFV-9 (i2)	-	381.70 b	91.00 b	10.1 b	5.2 a	51.6 a
BR-38 (p1)	419.75 ab	355.12 b	67.36 bc	11.5 ab	5.6 a	48.7 a
IAC-9 (p2)	504.57 ab	565.50 a	97.58 b	21.6 a	9.4 a	44.5 a
IAC-9 (ct)	504.57 ab	565.50 a	97.58 b	21.6 a	9.4 a	44.5 a
UFV-1 (ci)	459.00 ab	363.04 b	67.87 bc	13.8 ab	7.2 a	52.2 a
C.V. (%)	16.00	11.77	17.59	28.02	25.61	8.89

[1]- Means followed by the same letter in same column are not statistically different (Duncan $p < 0.05$).

[2]- t1 and t2: Al-tolerant F2 plantlets; i1 and i2: Al-intolerant plantlets; p1 and p2: parents; ct: control tolerant; ci: control intolerant.

(Table 4). This suggests complementary gene effect. The quantitative nature of tolerance to Al has already been described (Granados *et al.* 1993, Spehar 1996) and the present results seem to confirm it. The inconsistency of some results in Table 4 may be attributed to sampling size. In each hill there were 14 plants and this could have been a restriction to select the more favourable combinations, i.e., there was exclusion of individuals with higher gene frequency for tolerance. A larger number of plants per progeny should be grown in the field experiment to increase selection efficiency in hydroponics.

Tolerant progenies, in the F_4 generation, resulted superior to genitors and varieties IAC-9 (control tolerant) and UFV-1 (control intolerant) (Table 5), confirming favourable combinations, detected by field tests. Significant correlation values for root growth between generations F_2 and F_4, in two progenies, shows genetic gain has been attained by selection in hydroponics, at high Al level (Spehar 1996). The low values for the other two can be justified by possible absence of tolerant individuals due to small sample size in hill plots. These have shown to be effective on genotype screening, where frequency of homozygous is high (Spehar 1998a). The high coefficient of variation (CV) values are an indication of non-repeatable trends by the segregates, contributing to increase the experimental error. Alternatively, selection can be conducted from F_4 generation, when the level of homozygous is increased, by testing large number of individuals in hydroponics, to identify the best combinations.

Variable performance in progenies from the same crosses suggests that the difference in Al tolerance must be explored initially within variety, to identify individuals with high gene frequency (Spehar 1996). The selected lines shall be used in crossings, increasing the possibility to obtain superior genotypes, when a limited number of individuals per sample are used.

If tolerance to aluminum is conferred by genes of major effects, complemented by others of minor expression, genetic gain from wide crosses is expected to be high. The results presented here illustrate this assertive. Recovery of plants that accumulate favourable genes can be achieved by combined hydroponics and field selection (Spehar & Souza 1999). Increased tolerance has been reflected by root growth and Al-activated citrate in root in barley (Ma *et al.* 2004). Whether more tolerant soybean genotypes should produce correspondingly higher amounts Al-neutralising substances in roots is a matter to be addressed in future experiments. The method is easy to conduct and can be roulinety employed on soybean breeding program for acid soil environment to achieve yield stability.

Tabela 5. Average root growth in hydroponics and correlation (R^2) for F_2 and F_4 generation.

Progeny/Generation[2]	F_2	F_4[1]	R^2
BR83-147 x UFV-9(t1)	43	20.0 ab	0.94*
BR83-147 x UFV-9(t2)	39	22.0 a	
BR83-147 x UFV-9(i1)	5	17.7 ab	
BR83-147 x UFV-9(i2)	2	15.6 abc	
BR83-147 (p1)	-	7.2 c	
UFV-9 (p2)	-	19.9 ab	
IAC-9 (ct)	-	12.9 bc	
UFV-1 (ci)	-	13.5 abc	
C.V. (%)	-	25.15	-
BR-4 x Dourados (t1)	49	30.8 ab	0.74*
BR-4 x Dourados (t2)	46	36.5 a	
BR-4 x Dourados (i1)	24	29.8 ab	
BR-4 x Dourados (i2)	21	25.8 bc	
BR-4 (p1)	-	20.9 cd	
Dourados (p2)	-	19.9 cd	
IAC-9 (ct)	-	20.5 cd	
UFV-1 (ct)	-	12.9 d	
C.V. (%)	-	31.0	-
BR-4 x Dourados (t1)	41	19.9 ab	0.13
BR-4 x Dourados (t2)	39	20.2 ab	
BR-4 x Dourados (i1)	4	20.6 a	
BR-4 x Dourados (i2)	3	17.9 ab	
BR-4 (p1)	-	15.8 abc	
Dourados (p2)	-	10.5 c	
IAC-9 (ct)	-	19.9 ab	
UFV-1 (ci)	-	12.9 bc	
C.V. (%)	-	24.65	-
BR-38 x IAC-9 (t1)	66	22.5 a	0.47
BR-38 x IAC-9 (t2)	49	20.3 ab	
BR-38 x IAC-9 (i1)	15	22.2 a	
BR-38 x IAC-9 (i2)	12	18.6 abc	
BR-38 (p1)	-	15.8 abc	
IAC-9 (p2)	-	11.4 c	
IAC-9 (ct)	-	11.4 c	
UFV-1 (ci)	-	12.9 bc	
C.V. (%)	-	26.77	-

[1]- Means followed by the same letter are not statistically different (Duncan $p<0.05$).

[2]- t1 and t2: Al-tolerant F2 plantlets; i1 and i2: Al-intolerant plantlets; p1 and p2: parents; ct: control tolerant; ci: control intolerant.

CONCLUSIONS

1. Combination of hydroponics and acid soil field selection is efficient to found tropical soybean genotypes with enhanced aluminum tolerance.
2. Crosses among varieties BR83-147, UFV-9, BR-4 and Dourados yield Al-tolerant progenies, making them useful in breeding programmnes.

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