Genetics of Aluminum Tolerance in Maize Evaluated in Nutrient Solution with and without Control Experiments

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Introduction

The soils of the tropical savannas are characterized by low fertility, pH, and phosophorus (P) availability, as well as high P absorption capacity and toxic levels of aluminum. (Foy 1988). These naturally degraded soils have been one of the principal constraints affecting development and food production in many countries throughout the tropics, representing 73% of the world's population. In Brazil, acid soils cover 205 million hectares; 112 million hectares are considered suitable for agriculture (Olmos and Camargo 1976). Aluminum (Al) toxicity has been recognized as a major constraint of plant productivity on acid soils, which accounts for more than 40% of the earth's arable land (Ma et al. 2001). Application of lime generally corrects the top layer of the soil but not subsoil acidity. Breeding programs in savannah areas have been able to develop modern cultivars with tolerance to aluminum toxicity and improved P acquisition efficiency. These cultivars have roots that can penetrate the acid subsoil with high levels of aluminum saturation, improving both water and nutrient use. For almost three decades, EMBRAPA (Brazil's Maize and Sorghum Research Center) has conducted a maize breeding program for adaptation to acid soils with emphasis on aluminum tolerance and phosphorus use efficiency (Parentoni 2001). Nutrient solution experiments are used to separate the effect of Al toxicity from all other deficiencies present in acid soils. Data from Al tolerance in a nutrient solution have been used for traditional breeding programs as well as to map aluminum tolerant genes in maize using molecular markers (Ninamango-Cardenas 2003). Nutrient solution experiments can be done using a complete nutrient solution with aluminum, or a control experiment (using a complete nutrient solution without aluminum). The objective of this study was to investigate the effects of the use of control experiments in the genetics of Al tolerance.

Methods

Nine maize inbred lines with different levels of Al tolerance (five tolerant, four susceptible) were selected as parents for a diallel study. Thirty-six F_1s and 9 parents were evaluated in a complete nutrient solution (Magnavaca et al. 1987) without aluminum (control), and in a complete nutrient solution with 222 μM of aluminum. The initial seminal root length (ISRL) of the seedlings was measured before transferring them to the nutrient solutions (with and without Al). After six days growth in each nutrient solutions under greenhouse conditions, the final seminal root length (FSRL) was measured for each plant. The phenotypic index used was relative seminal root length (RSRL) measured as [(FSRL - ISRL)/ISRL]. The RSRL was obtained for all treatments. The ratio between RSRL values obtained in the solution with and without Al was also obtained. Diallel analysis for the trait RSRL was done on the three sets of data. Griffing´s (1956) Method II fixed model (parents and F_1s) was used. The effects of general combining ability (GCA) and specific combining ability (SCA) for RSRL were estimated in the three sets of data. The additive component (ϕ g) and non additive component (ϕs) for RSRL in each of the three situations were estimated as follows: (ϕ g) = (MS GCA - MSE) / p+2, where MS GCA is the mean square values for GCA; MSE is the mean square error; and p is the number of parents in the diallel; (ϕs) = MS SCA - MSE, where MS SCA is the mean square values for specific combining ability. The ratio (ϕ g)/(ϕs), indicating the relative importance of additive versus non-additive effects for the trait RSRL, was obtained. This ratio was estimated in each of the three situations. The correlation coefficient between GCA and inbred per se RSRL for the nine inbreeds in each of the three situations was also recorded.

Results

The ANOVA showed that the effects of treatment, GCA, and SCA for the variable RSRL were significant ($p<0.01$) for the three situations: solution with no Al-control; solution with 222 µM of Al; and 222 µM of Al divided by control (Table 1). The ratio (ϕ g)/(ϕs) for each of the three situations was 0.08, 0.50, and 2.67 respectively (Table 1). The GCA and inbred per se RSRL values for the nine parents are shown on Table 2. Inbred lines 1 to 5 showed good levels of Al tolerance (inbred per se RSRL values with Al/control ranged from 56.7 to 87.5%). Inbreds 6 to 9 were Al susceptible (per se RSRL ranged from 23 to 34.8%). The highest Al tolerant inbred line (inbred 2, derived from Cateto germplasm, per se RSRL = 87.5%) also showed the highest value of GCA for RSRL (GCA Al/control = 27.42%). Correlation coefficients of GCA for RSRL of the nine inbreds and per se values of RSRL were -0.50 (control solution), +0.64 (solution with 222 µM of Al), and +0.93 (solution with Al divided by control).

Conclusions

The use of control experiments (no Al) to correct the values of RSRL obtained from a nutrient solution with Al, increases the ratio between additive and non additive effects (ϕ g/ ϕs) from 0.50 to 2.67, indicating that it would be desirable to always include control experiments to evaluate Al tolerance in a nutrient solution. The high correlation (r=0.93) found between inbred line per se and inbred GCA, using RSRL from Al solution/control solution, indicates that in this situation, per se evaluation of inbred line Al tolerance in a nutrient solution could be a good predictor of inbred GCA for Al tolerance in crosses. This experiment will be repeated using diallels with a different group of contrasting Al tolerant maize lines as parents to verify these results in a different set of genotypes. This finding could greatly reduce the costs of Al tolerance evaluation in nutrient solutions in allogamous crops like maize, by reducing the number of entries to be evaluated (only parents instead of F_1s).

References

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Table 1. ANOVA for the variable relative seminal root length (RSRL) for a diallel between 9 maize inbred lines evaluated in nutrient solutions with no aluminum (control experiment) and 222 µM of aluminum, and for the RSRL ratio obtained by Al divided by the control, EMBRAPA, 2003.

Source of variation‡	df	Control exp	222 µM of Al	Ratio of RSRL
TRA	44	0.823**	0.603**	1469.07**
GCA	8	0.796**	1.814**	6767.88**
SCA	36	0.829**	0.334**	291.55**
Error	88	0.226	0.014	63.75
ϕ g		0.05	0.16	609.46
ϕs		0.60	0.32	227.80
ϕ g/ ϕs		0.08	0.50	2.67

‡Treatments (TRA), general combining ability (GCA), specific combining ability (SCA), and error. Values for additive effects (ϕ g), non additive effects (ϕs), and ratio (ϕ g/ ϕs) for each situation. **: Sig. slope at $p<0.01$.

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