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Characterisation of maize cultivars in their adaptation to acid soils on the single plant level

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Abstract

Yield of maize is considerably reduced on acid, Al-toxic soils. A methodology was developed allowing the non-destructive screening of individual maize seedlings (*Zea mays* L.) for Al resistance in nutrient solution and their subsequent transfer to the field for yield assessment. Seedlings with roots exposed to 25 µM Al in nutrient solution were transplanted to an acid Al-toxic soil and those not treated with Al to a non-acid soil in Colombia. Plant growth as well as grain yield was significantly reduced on the acid Al-toxic site. Aluminium-induced callose formation in nutrient solution was significantly negatively related to relative grain yield (r = - 0.79*) and above-ground dry matter (r = - 0.84*) of the maize cultivars at maturity.

Introduction

In most acid soils throughout the world, aluminium (Al) is the most growth and yield limiting factor (von Uexküll and Mutert, 1995). An economically and environmentally acceptable alternative to overcome this problem is to develop plants tolerant to subsoil acidity (Foy, 1976). Aluminium-induced callose formation in root apices has been proposed as a marker of Al sensitivity in maize (Horst *et al.*, 1997). However, it often proved difficult to establish correlations between results obtained in complete nutrient solutions and soil studies (Edmeades *et al.*, 1995). Therefore, the relationship between Al-induced callose formation in nutrient solution and the performance on an acid site was investigated on a single plant level.

Materials and methods

Experiments were conducted at CIMMYT/CIAT, Cali, Colombia. Nine maize cultivars differing in Al resistance and adaptation to acid Al-toxic soils were used. Two of them, 66x68 and 21x28, were crosses from inbred lines, Guacuani was a local variety. The other cultivars have been used in physiological studies on Al toxicity. Seeds were sown into paper beakers filled with peat substrate and sealed with a wax layer at the bottom. The substrate was moistened with nutrient solution. The plant roots penetrated the wax layers into plastic boxes (22 L) filled with nutrient solution of low ionic strength (Horst *et al.*, 1997). Eight days after sowing, concentrations of 0 µM or 25 µM Al were adjusted in the nutrient solution (pH = 4.3). After 12 h of Al treatment callose formation in root apices was determined as described by Horst *et al.* (1997). Thereafter, seedlings without Al supply were transplanted to a non-acid site, those treated with Al to an acid Al-toxic site. At maturity, single plants were harvested. The grain yield, above-ground dry matter, plant and ear height were determined. A more detailed description of the transplanting method and the soil properties is given in Collet (2000).

Results and discussion

Individual plants could be successfully transplanted from nutrient solution into the field after sampling of root apices for the determination of Al-induced callose formation. Nearly all of the transplanted seedlings reached maturity. Transplanting resulted in a lower plant height but did not consistently influence grain yield production (Fig. 1). Clear differences between the cultivars existed at the acid as well as at the non-acid site. Considering the small effect on plant performance of transplanting compared to the effect of soil acidity, transplanting proved to be useful in validating screening methods in hydroponics based on Al-induced callose formation in root tips.

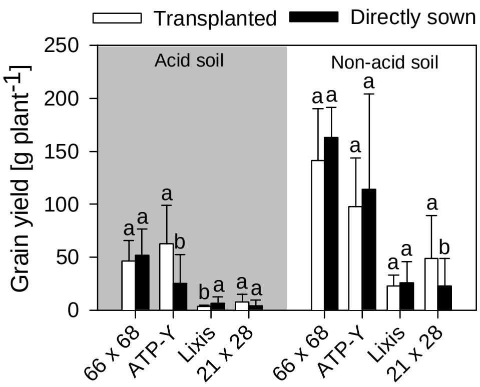

Figure 1. Grain yield of maize cultivars transplanted or sown to an acid and non-acid soil in Colombia.

On the acid Al-toxic soil plant height, ear height, above-ground dry matter and grain yield were significantly reduced (Tab. 1). The time to 50 % silking was retarded. Consequently, the interval between 50 % male and 50 % female flowering was extended as shown by the anthesis silking interval (ASI). The grain yield on the Al-toxic site was not correlated with the grain yield on the non-acid site.

Table 1. Means of agronomic traits for 9 transplanted maize cultivars on an acid Al-toxic and non-acid soil. Comparisons of means were conducted for each variable between the two sites. Means showing different letters are significantly different according to Tukey test at $P < 0.05$, n = 12.

Parameter	Non-acid soil	Acid soil
Plant height [cm]	188.4±38.2 a	110.7±30.1 b
50% silking [d]	61.8±4.8 a	72.2±8.7 b
50% anthesis [d]	61.8±4.4 a	70.2±8.6 b
ASI [d]	0±1.8 a	2.3±2.7 b
Ear height [cm]	100.3±30.4 a	40.2±20.4 b
Ears per plant	0.9±0.2 a	0.9±0.1 a
Above-ground dry matter [g]	301.5±141.3 a	95.6±60.5 b
Grain yield [g]	110.3±71.5 a	39.8±30.3 b

Aluminium-induced callose formation differed significantly between the cultivars. In agreement with previous results, Al-induced callose formation classified cultivar Lixis as Al-sensitive and ATP-Y as Al-resistant (Horst *et al.*, 1997). However, low callose formation of the cross 21x28 was in contrast to its poor performance on acid soil in this and previous studies (de León, personal communication). Because low callose formation was accompanied by an unusual root growth in nutrient solution this cultivar was not included into the regression analysis.

Aluminium-induced callose formation was not correlated to plant height at early stages after transplanting to the field. Since Al primarily affects the root tips, effects on shoot development may express only at later stages as a result of altered water and nutrient uptake as well as phytohormone production. This suggestion was confirmed by the significant correlations between Al-induced callose formation and relative grain yield and relative above-ground dry matter at maturity (Fig. 2; r = - 0.79*, r = - 0.84**).

Callose formation in root tips after 12 h Al treatment in nutrient solution was a reliable indicator of Al sensitivity of the maize cultivars. It may also be used as a sensitive indicator for adaptation of maize cultivars to an acid soil with Al toxicity as the most limiting factor. The correlations found here were even stronger than between root length assessed in nutrient solution and grain yield on acid soils (Kasim *et al.*, 1990; Magnavaca and Bahia Filho, 1993).

The established methodology should be especially useful in studies of inheritance of Al resistance where seed supply is small and it is desirable to save individual plants after screening in nutrient solution for further observations and/or seed multiplication in the field.

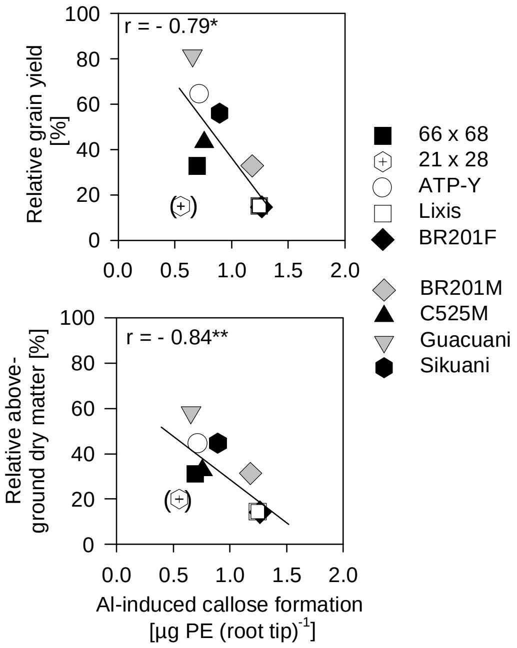

Figure 2. Aluminium-induced callose formation related to relative ear height, relative above-ground dry matter and relative grain yield of transplanted maize cultivars. Cross 21x28 excluded from correlation analysis.

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