Variability in K and Na Uptake in Wild and Commercial *Gossypium hirsutum* Seedlings under Saline Conditions

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ABSTRACT

Differences in K^+ and Na^+ uptake and compartmentation are related to salinity tolerance but the value of ion uptake as a trait for discriminating salt-tolerant genotypes is controversial. This report presents a survey of 15 wild and feral genotypes collected from salt-affected areas and 27 commercial cultivars in which K^+ and Na^+ concentration were determined in leaves, stems and roots after growing seedlings in nutrient solutions with 0 or 200 mM NaCl under controlled conditions. Salinity reduced growth, plant water content and K^+ levels in cotton seedlings. Genotypic variation in K^+ and Na^+ uptake resulted in differences in accumulation of these ions in leaves and stems and differences in Na^+ accumulation in roots. Some exotic genotypes showed differences in leaf and stem K^+/Na^+ ratios but no significant differences in root K^+/Na^+ ratios occurred among genotypes. When seedlings were grown in salinised solutions, genotypic differences in leaf Na^+ concentration were negatively correlated with leaf or shoot growth only when growth was expressed as dry matter. However, leaf Na^+ was positively correlated with leaf water content and shoot/root ratio. Stem, but not leaf, K^+ was positively correlated with leaf or shoot growth. Although genotypic differences in ion uptake were detected, no main ion effect on seedling growth was observed. Further studies are required to evaluate the performance of genotypes with contrasting ion uptake patterns at later growth stages.

Introduction

Salinity is a major factor affecting vegetative growth and yield in the land reclaimed from salt-marshes of the Guadalquivir River (Andalusia, SW Spain) and in some areas irrigated with brackish water. Cotton is rated as a salt tolerant crop with a threshold salinity level of 7.7 millimhos EC_e/cm for initial yield decline, with an EC_e of 17.0 millimhos/cm resulting in a 50% reduction in yield for the genotype tested (Maas, 1986). Cotton cultivars with higher salinity tolerance could have a major effect in these areas (Fowler, 1986), improving yield stability, especially when increasing salinity in water and soils during severe droughts depress economic yield.

Salinity limits plant growth by affecting water and nutrient uptake or by specific ion toxic effects (Grattan and Grieve, 1992; Shannon *et al.*, 1994). In many glycophytes, the maintenance of a higher K^+/Na^+ ratio in the shoots by excluding Na^+ and accumulating K^+ is associated with salt tolerance (Gorham, 1992). Mechanisms that lead to selective K^+ transfer from roots to shoots are a main factor for avoiding Na^+ accumulation in leaves (Jeschke, 1984). In other species, uptake and effective compartmentation of Na^+ in shoots provides some growth advantages over avoidance mechanisms (Sabbah and Tal, 1995; Leidi and Sáiz, 1997).

Differences in salt tolerance of upland cotton genotypes at various growth stages were observed by Läuchli *et al.* (1981) and higher salt tolerance in Pima cotton than in upland cotton has been reported (Fowler, 1986). Gorham and Young (1996) examined the effect of salinity on wild species of *Gossypium* and *G. hirsutum* and found differences in relative growth and Na^+ accumulation. In a recent report on *G. hirsutum*, salinity tolerance was related to lower Cl^- uptake instead of lower Na^+ or K^+ uptake (Qadir and Shams, 1997). Differential plant growth behaviour related to K^+/Na^+ selective uptake was found in upland cotton (Läuchli and Stelter, 1982; Leidi and Sáiz, 1997), but salt-tolerance is a complex response, further complicated by the interaction between different adaptive mechanisms and the environment (Leidi and Gorham, 1998). A partial substitution of Na^+ for K^+ in the nutrition of cotton (Joham, 1986) and efficient mechanisms of Na^+ compartmentation might increase cotton salt-tolerance (Leidi and Sáiz, 1997).

The aim of this work was to seek growth and differential uptake of K^+ and Na^+ in genotype seedlings, preparatory to seeking different adaptive responses to saline conditions across a broad genetic background.

Materials and Methods

Cotton (*Gossypium hirsutum* L.) seeds of commercial cultivars and wild and feral genotypes were germinated at 30ºC. Uniform 3-day-old seedlings were transplanted to aerated modified nutrient solutions based on Hewitt's Long Ashton solution (Hewitt, 1966; Leidi *et al.*, 1991) to provide 4 mM NO_3^- and 7 mM Ca^{2+}. The concentration of Ca^{2+} was in the optimum range for cotton growth in saline nutrient solutions (Gorham and Bridges, 1995). In the saline treatment, 200 mM NaCl was introduced to the nutrient solutions in four increments (50 mM NaCl every 12 h) after the plants were 6 days old. Solutions were renewed weekly. At harvest, the plants were separated into leaves, stems and petioles and roots and weighed. Roots were washed thoroughly in tap water and blotted dry before weighing. All plant parts were dried at 70ºC for 48h, followed by chemical analysis. K^+ and Na^+ were extracted from samples with hot water and concentrations determined using a flame photometer. Plant ion concentrations were expressed on the basis of tissue water or dry matter.

Results and Discussion

Differences in seedling vigour were a significant confounding factor in genotype comparisons, mainly when considering the wild and feral genotypes. By expressing the shoot growth data as percentage of control values (Figure 1), the genotypic variability in tolerance to salt-stress can be reasonably compared (Gorham and Young, 1996). Salinity reduced shoot growth more than 60% in some genotypes (e.g. Coro, Stv506, Exp24) but only 30% in other genotypes (Ck310, Z407, Albor, T-833). Root growth was less inhibited than shoot growth by salt-stress as previously shown (Leidi *et al.*, 1991), thus the shoot/root ratio was reduced (data not shown).

When seedling growth in salinity was expressed relative to the control treatment, leaf K^+ concentration was negatively correlated with shoot and root growth (r=-0.62, P<0.001 and r=-0.40, P<0.01, respectively, n=42). Leaf Na^+ concentration was not significantly correlated to relative shoot or root growth (r=-0.25 and r=-0.23 respectively). However, the situation changed when values were expressed as total growth. In this case, the concentration of Na^+ and K^+ in leaves was negatively correlated with shoot growth (r=-0.77 and r=-0.46 respectively, p<0.001, n=84) and shoot/root ratio (r=-0.62 and r=-0.51 respectively, p<0.001, n=84) when both control and saline treatments were considered. Within the salt-stress treatment, Na^+ concentration across genotypes was negatively associated with shoot growth (r=-0.41, P<0.01, n=42) but positively correlated with shoot/root ratio (r=0.42, P<0.01, n=42). An interesting feature was the positive correlation of stem K^+ concentration with shoot and root growth (r=0.58 and r=0.66 respectively, P<0.001, n=42).

Leaf Na^+ concentration (on dry matter basis) in salt-grown seedlings was positively correlated with leaf water content (r=0.54, P<0.001, n=84). No association was found between K^+ concentration and tissue water content.

In salt-stressed seedlings, no correlation was observed between leaf or stem Na^+ and K^+ (Figure 2). Na^+ acts as a competitor of K^+ uptake suggesting similar uptake mechanisms (Niu *et al.*, 1995), and the reduction of K^+ uptake in cotton by high Na^+ in the medium has been reported (Kent and Läuchli, 1985; Leidi *et al.*, 1991). Examination of the variation in cation concentration in leaves and stems (Figure 2) revealed that only two genotypes appeared to have differential selectivity. A negative correlation between K^+ and Na^+ concentration (dry matter basis) was observed in roots when considering both control and saline treatments (r=-0.42, P<0.001, n=84), but not when looking at the genotypic variation of ion concentration in the salt-treated seedlings (r=0.53, P<0.001, n=42).

The highest Na^+ accumulation in leaves was recorded in a wild genotype (T-2201) (263 mM) and an experimental line (Exp35) (217 mM). The lowest leaf Na^+ concentration (68 mM) was observed for Pym792, a cultivar already described as a Na-excluder (Leidi and Sáiz, 1997). Important variation in the accumulation of Na^+ occurred in stems (Figure 2) with some genotypes having stem Na^+ concentrations over 300 mM (Pym792, Ck310, T-996, T-1625), while others had below 80 mM Na^+ (Navb, T-2290).

Under salt-stress, the highest K^+ concentration in leaves and stems was observed in Pym792 (246 mM) and Z407 (316 mM) respectively. In contrast, the lowest K^+ concentration was recorded in wild genotypes, with values below 100 mM in leaves (T-2201, T-2296) and stems (T-2201, T-2194).

The K^+/Na^+ ratio in leaves and stems was correlated but no association was found between K^+/Na^+ ratio in stems and roots (Figure 3). Differences in selectivity in the process of uptake and transfer of cations probably led to the observed variation in K^+/Na^+ ratio in leaves. Interestingly, no correlation was observed for the leaf K^+/Na^+ ratio with growth parameters but the stem K^+/Na^+ ratio was correlated with shoot and root growth (r=0.61 and r=0.62 respectively, P<0.001, n=42).

Conclusions

The variability detected in K^+ and Na^+ uptake and distribution between leaves, stem and roots did not show a strong correlation with salt-stress tolerance at the seedling stage that could be used as a selection trait. However, genotypes with contrasting patterns of cation selectivity and accumulation may be useful in further studies to characterize the effects of salinity on basic mechanisms of selectivity in the processes of cation uptake and compartmentation.

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Figure 1. Relative shoot growth of cotton seedlings of 43 genotypes grown in medium with 200 mM NaCl expressed as percentage of growth in medium with no NaCl.

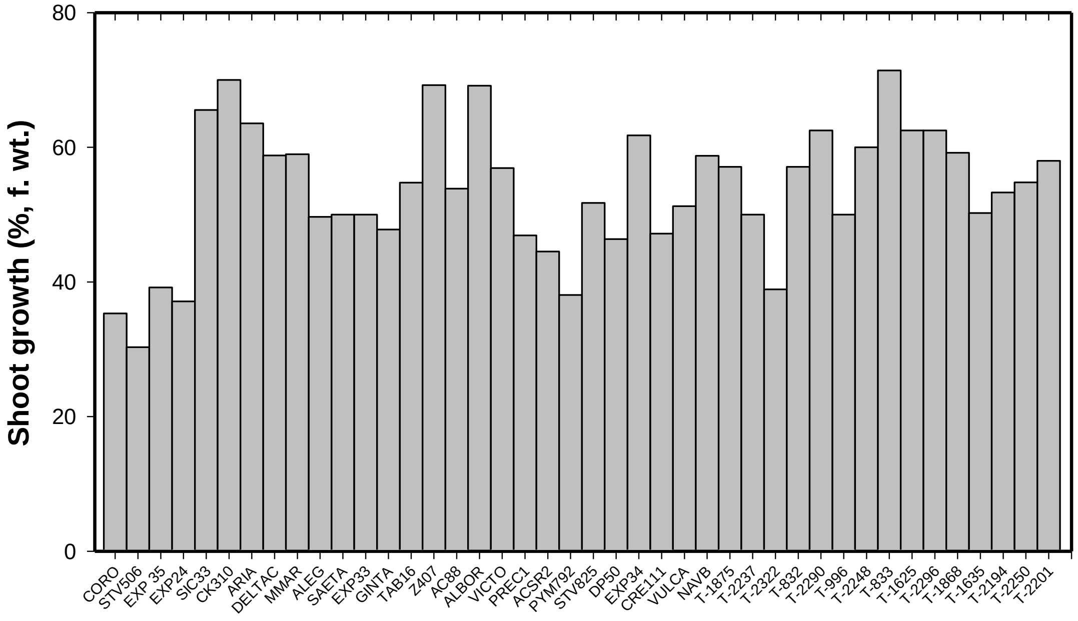

Figure 2. Relationship between the concentration of K^+ and Na^+ in leaves and stems of cotton genotypes grown in salinised nutrient solution (200 mM NaCl.

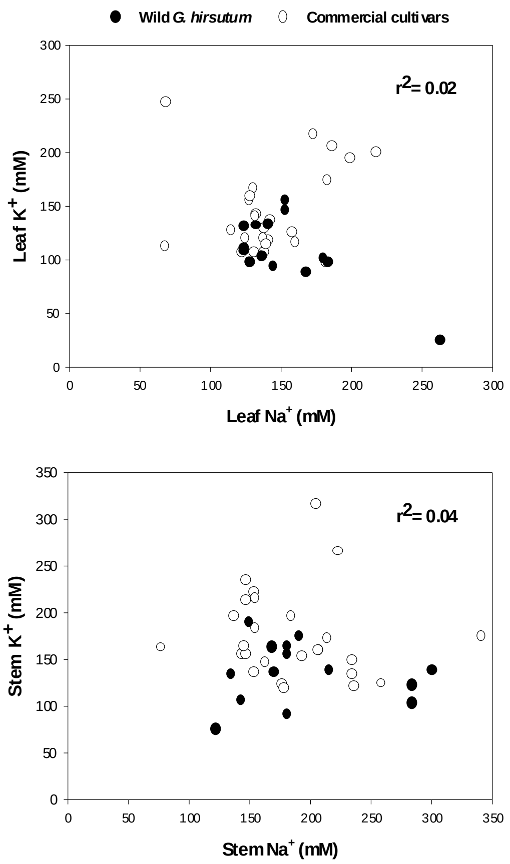

Figure 3. Variability in K^+/Na^+ ratio of leaves, stems and roots in cotton genotypes grown in salinised nutrient solution (200mM NaCl).