Varietal differences in salinity tolerance and mineral nutrition in tomatoes (Solanum lycopersicum)

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Introduction
Salt accumulation in soils of arid and semiarid regions of the world is a major problem of irrigated agriculture (Dasgan et al, 2002). About 15 million hectares are affected by salinity in the Maghreb and the Middle East (Hachicha et al. 1994). Plant adaptation to saline environments occurs via activation of biochemical and physiological mechanisms that lead to an efficient regulation of both ion and water homeostasis (Hasegawa et al., 2000). These include regulation of growth rates (Maggio et al. 2002a, 2002b), osmotic adjustment (Morgan, 1984), ion compartmentation (Zhu, 2002) and control of the antioxidative machinery (Smirnoff, 1993). Plant species and cultivars within a crop species differ greatly in their response to salinity (Marschner, 1995). Genetic variability within a species is a valuable tool for screening and breeding for higher salt tolerance. Tomato, one of the important and widespread crops in the world, is sensitive to moderate levels of salt in the soil. So, many authors have reported large variation among tomato genotypes in their response to salinity (Cuartero et al. 2006). The aim of the present study is to compare the growth and mineral nutrition of four varieties of tomato, Marmande, Coeur de Boeuf, Roma, and a “cherry”- type tomato variety Coktail, exposed to NaCl 100 mM at the early stage of development.

Materials and methods
Four varieties of tomato (Solanum lycopersicum) were used as plant material: Marmande (Vilmorin, France), Coeur de Boeuf (Italie), Roma (Italie) and a “cherry”- type tomato variety Cocktail (France). Seeds were surface-sterilized with 20% sodium hypochlorite solution for 10 min and then rinsed with distilled water. Seeds were germinated in the dark at 25°C on filter paper wetted with distilled water. 10 days after, the germinated seedlings were transferred to nutrient solution. The experiment was carried in a conditioned room under artificial light (150 µmol.m⁻².s⁻¹; 16 h photoperiod), at 25°C day/20°C night and air humidity 60-80%. 10 days after the transfer, the plants were at the third leaf stage. NaCl was added in increments of 25 mM per day up to a final concentration of 100 mM. After the salinization had been reached to 100 mM NaCI, the plants were grown for 14 days under 100 mM salt stress condition. At harvest, the plants were separated into roots, stems and leaves, bagged and dried at 80°C for at least 48 h. Dried leaf, stem and root tissues were extracted in 0.1 N HNO₃ for 48h. K⁺ and Na⁺ were determined by flame spectrophotometry and Cl⁻ by coulometry. The sensitivity index (SI), i.e., the difference between dry matter production of salt-treated plants and the control, expressed in percent of the latter, was calculated according to the following expression: SI NaCl= 100 x [(WNaCl - Wcontrol) /Wcontrol]. This parameter was more negative when the plant was sensitive to NaCl (Saadallah et al. 2001). Fluxes (J) of Na⁺ and Cl⁻ were calculated similarly to Pitman (1975) Results in this study are the mean of 29 replications. The data were statistically analyzed using ANOVA and means were compared according to Ducan post-hoc test (Statistica™ software).

Results and discussion
The four varieties showed significant difference when cultivated in control medium and the difference became more significant when cultivated in the presence of NaCl. Control plants of the four varieties expressed different growth potentialities (Fig. 1).
Indeed, Marmande was significantly more productive compared to the other varieties. Adding NaCl in culture medium significantly decreased the whole plant growth of all varieties. Cocktail presents the better behaviour under salinity stress: the whole plant growth of this variety decreased by 25 % compared to the control. Whereas the diminution noted at the other varieties was comprised from 41 to 48 % compared to the control, as follows Marmande<Roma<Cœur de Boeuf (Fig. 2).

Fig. 1. Dry weight of roots, stems, leaves, and whole plant of tomato plants after 14 days of NaCl (0 and 100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.

Fig. 2. Total dry weight (% of control) of tomato plants after 14 days of NaCl (100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.
In all varieties, this reduction of growth does not relate to the roots, but is explained by the strong sensitivity to salt of the aerial parts and particularly of the leaves, which seem the origin of sensitivity to salt stress. Indeed, the sensitivity index (SI), calculated on the basis of the dry matter of the leaves, is very close to that calculated on the basis of dry matter mass of the whole plant (Table 1). Cocktail presents the least negative sensitivity index and was considered more tolerant than the others varieties. Coeur de Boeuf presented the less SI and was considered as the highest sensitive variety.

Table 1. Variability of biomass production sensitivity index (SI) in tomatoes exposed to salt stress. The negative values (-) correspond to a reduction in the dry matter compared to the control and the positive values (+) represent a stimulation in the growth

<table>
<thead>
<tr>
<th>Variety</th>
<th>Whole plant</th>
<th>Roots</th>
<th>Stems</th>
<th>Leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cocktail</td>
<td>-25</td>
<td>-7</td>
<td>-32</td>
<td>-26</td>
</tr>
<tr>
<td>Marmande</td>
<td>-41</td>
<td>-3</td>
<td>-54</td>
<td>-42</td>
</tr>
<tr>
<td>Roma</td>
<td>-45</td>
<td>-9</td>
<td>-64</td>
<td>-46</td>
</tr>
<tr>
<td>Cœur de bœuf</td>
<td>-48</td>
<td>-16</td>
<td>-60</td>
<td>-50</td>
</tr>
</tbody>
</table>

According to Cruz and Cuartero (1990), the growth of the aerial parts of tomato is more affected by salinity than that of the roots. As a result, shoot/root dry weight ratio can be a significant parameter in the evaluation of the tolerance to salt at tomato. Cocktail is more tolerant to salt than the 3 other varieties, since it presents the least reduction in shoot/root dry weight ratio (Fig.3).

In the four cultivars, the decrease in dry weight production, observed after 14 days in the presence of NaCl 100 mM, was associated with a high accumulation of Na⁺ and Cl⁻ (Fig. 4 and 5) in different organs, whereas K⁺ contents decreased significantly (Fig. 6). In the different varieties and independently of the presence of NaCl in medium, stems were the more reached organs in K⁺. Salinity decreased K⁺ contents in all organs and the reduction was significant in shoots. Greenway and Munns (1980) suggested that the susceptibility of many
glycophytes to salt is due to an insufficient ion supply. Indeed, in tomato, salt reduces $K^+$ uptake (Alian et al. 2000).

Fig. 4. $Na^+$ contents of roots, stems and leaves of tomato plants after 14 days of NaCl (100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.

Fig. 5. $Cl^-$ contents of roots, stems and leaves of tomato plants after 14 days of NaCl (100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.
Na⁺ tissue contents increased by adding NaCl in the culture medium (Fig. 4). Stem Na⁺ contents were higher than those in roots and leaves. Although some differences were observed between varieties: Na⁺ contents leaf was higher in Cocktail than in the other varieties, whereas the less leaf Na⁺ contents were observed in Coeur de Boeuf. As Na⁺, Cl⁻ contents in all varieties were higher in stems than leaves and roots, Cl⁻ contents of organs are similar in Marmande, Roma and Coeur de Boeuf. Netherless, Cocktail presented the lower Cl⁻ contents in stems. Cocktail was distinguished from the other varieties by a higher Na⁺ uptake and transport (Fig. 4).

![Graph showing K⁺ contents of roots, stems, and leaves of tomato plants after 14 days of NaCl treatment.](image)

Fig. 6. K⁺ contents of roots, stems and leaves of tomato plants after 14 days of NaCl (0 and 100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.

In general, the tomato cultivars showed a restriction in the accumulation of Na⁺ in the leaves and are strongly selective in favour for K⁺ when they are exposed to salt stress (Dasgan et al., 2002). Nevertheless, the Cocktail variety, considered as most tolerant to salinity, presents a higher transport of Na⁺ towards the aerial parts; on the contrary Coeur de Boeuf which accumulated less Na⁺ in the aerial parts was more sensitive to salt. Alian et al. (2000) also showed that the Fireball variety of tomato, more tolerant to salinity than other varieties, was characterized by a strong accumulation of Na⁺ in the roots and leaves. One important strategy of several species to tolerate salinity was to use NaCl as an osmoticum and to compartmentalize the Na⁺ and Cl⁻ ions primarily in the leaf vacuoles. Figure 7 shows that Coktail, considered as the most tolerant variety to salt, has the lowest K/Na selectivity. It is
possible that this variety is genetically close to the wild tomato species, such as _Lycopersicon cheesmanii_ and _L. pennellii_, which fruit has the size of a “cherry”-type tomato variety Cocktail and which are known by their tolerance to salinity (Rick 1986). According to Cuartero et al. (1999), these species are characterized by a less K/Na ratio.

Perez-Alfocea et al. (2000) showed that, even with a low K/Na selectivity, the tolerant tomato to salt were distinguished under salt stress by a good redistribution of K⁺ starting from the old leaves towards the young leaves. Thus, it was suggested in this study that the tolerance of Cocktail to salinity was related to this aptitude.

Tolerance to salt is also related to the capacity of the plant to control the absorption and the export of Cl⁻ to the aerial parts. Levitt (1980) considered the accumulation of Cl⁻ in the aerial parts as the main reason of toxicity of the NaCl, corroborating that in presence of salt, the resistant cultivars accumulate less Cl⁻ than the sensitive ones. In our study, it is notable that in Cocktail, the most tolerant to salinity, the flow of export of Cl⁻ towards the leaves was more lower compared to the 3 other varieties (Table 2). A positive linear relationship was observed between NaCl sensitivity of whole plant and the Cl⁻ contents in the stems (Fig. 8).

Table 2. The transport of Cl⁻ at aerial organs level in tomato treated with 100 mM NaCl. Each point is the mean of 29 replicates. Error bars at 5%.

<table>
<thead>
<tr>
<th>Fluxes of ion Cl⁻</th>
<th>Varieties</th>
</tr>
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<tbody>
<tr>
<td>J mmol.g⁻¹ root DW d⁻¹</td>
<td>Cocktail</td>
</tr>
<tr>
<td></td>
<td>1.30 ± 0.27</td>
</tr>
</tbody>
</table>

Fig. 7. K/(K+Na) ratio in roots, stems and leaves of tomato plants after 14 days of NaCl (100 mM) treatment. Each point is the mean of 29 replicates. Error bars at 5%.
This correlation indicated that the tolerance of the plant is controlled by the capacity of plant to limit the transport and the accumulation of Cl\(^-\) in the aerials part, particularly in the stem. M’Charek et al. (2005) showed that the best tolerance to salt of Amico tomato was associated with its aptitude to limit the transport and the accumulation of Cl\(^-\) in the aerial organs. It is probably on this basis that the tolerance to salt in tomato can be improved by using the graft combination. The grafting method could be a useful tool for increasing the resistance of tomato to salinity (Martínez-Rodriguez et al. 2008).

**Conclusion**

At the seedling stage, we observed a variation among tomato plants in their response to salinity. Cocktail is more tolerant to NaCl than the other varieties. This higher salt tolerance is associated with its ability to use Na\(^+\) for osmotic adjustment and to limit the absorption and the transport of Cl\(^-\) to the shoots. Na\(^+\) accumulation varied among the varieties as follows: Roma< Coeur de Boeuf<Marmande<Cocktail. Thus Cocktail, which is the most tolerant variety, was distinguished from the other varieties by a higher Na\(^+\) uptake and transport and a least K/Na selectivity. Cocktail was also distinguished from the other varieties by a lower Cl\(^-\) uptake and transport. This variability within varieties of tomato is a valuable tool for screening and breeding for higher salt tolerance.

**References**


