Growth, flowering and leaf properties of pear cultivars grafted on two Asian pear rootstock seedlings under NaCl irrigation

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Abstract

The growth responses of grafted young pear trees under salinity were studied. Chinese, Japanese and European pear cultivars (Yari, Kosui and La France) were grafted onto 3-year-old *Pyrus betulifolia* Bunge (BET) and *P. pyrifolia* (Burm f.) Nakai (PYR) seedlings. They were grown in pots with sand and irrigated with 20% Hoagland’s plus 0, 25 or 50 mM NaCl solution. All scions grafted onto BET grew well even under 50 mM NaCl irrigation, while those grafted onto PYR suffered from NaCl deficiency heavily. Flower bud formation was stimulated by NaCl treatment in every scion–rootstock combination. Bloom date and number of flowers per cluster were not affected by NaCl treatment. Mineral analysis suggested that BET’s salt tolerance is due to the ability of this cultivar to restrict Na and Cl ion transport to leaves. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Salinity tolerance; *Pyrus* spp.; Sodium chloride; Flower bud formation

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1. Introduction

Pear trees are generally classified as salt-sensitive (Francois and Maas, 1994; Pasternak and De Malach, 1994). The plants are damaged by a relatively low salinity for long-terms (Myers et al., 1995).

Salt tolerance of a plant can be strengthened by choosing appropriate rootstocks. Evaluation of salt-tolerant stocks have been attempted in major fruit crops (Cooper and Gorton, 1952; Bernstein et al., 1969) but for pear, salinity study in terms of rootstocks is still limited. Among 22 primary species in the genus *Pyrus* (Lombard and Westwood, 1987), Francois (1982) reported *P. kawakamii* was tolerant to salinity among tested ornamental tree species. There may be more salt-tolerant species which can be used as a salt-tolerant rootstock for pear production.

The present work examines the vegetative and reproductive growth and foliar mineral concentrations of pear under varying NaCl conditions using combinations of two rootstocks onto three scion cultivars. The rootstocks, *P. betulifolia* Bunge (BET) and *P. pyrifolia* (Burm. f) Nakai, are both commercially important rootstocks in Asia but differ in susceptibility to NaCl irrigation (Okubo and Sakuratani, 2000). For scions, commercial varieties of Chinese pear, Japanese pear or European pear cultivars were grafted onto these rootstocks. This is because combinations of scion and rootstock can affect the growth habits and fruit productivity (Lombard and Westwood, 1976; Chaplin and Westwood, 1980).

2. Materials and methods

2.1. Growing conditions

The experimental site was located at Kyoto University Orchard, Osaka, Japan (34.5°N, 135.4°E). The experiment was conducted under a well-ventilated plastic-roofed greenhouse where monthly mean temperature ranged from 6°C (January) to 30°C (August) in 1994. Daily mean solar irradiation in summer (June–September) was 16 mJ m⁻² outside the polyplastic-roof and approximately 80% of sunlight permeated the greenhouse.

2.2. Plant material

Stems of Chinese pear (*P. ussuriensis* Maxim cv. Yari), Japanese pear (*P. pyrifolia* (Burm f.) Nakai cv. Kosui) and European pear (*P. communis* L. cv. La France) were obtained from producing trees in Kyoto University Orchard in December, 1993. They were wrapped with polyplastic film and stored at 5°C. In early March, 1994, seedlings of 3-year-old *P. betulifolia* Bunge strain ‘Blue’ (BET) and *P. pyrifolia* (Burm f.) Nakai (PYR) produced by a commercial nursery
were planted into 10 l clay pots containing coarse river sand with field capacity of 18.8% (w/w). The scions were grafted on the rootstocks in early April and grown outdoors. All the scions were grafted at approximately 5 cm above the soil surface. Grafting was successful for all the scion–rootstock combinations. Actively growing plants were selected on the basis of stem length and absence of disease symptoms and placed in the greenhouse. The plants were single-stem-trained and irrigated with 1/10-strength Hoagland’s nutrient solution (Hoagland and Arnon, 1938).

From 22 May, plants were irrigated with solutions consisting of 0, 25 or 50 mM NaCl plus 1/5-strength of the Hoagland’s solution. Each plant was irrigated with 500 ml of solution every morning for 10 weeks. Surplus solution was drained naturally from the bottom of pots to avoid build-up of salts in the growth media. During the NaCl treatment period, dead plants were removed from the plot and excluded from experiment thereafter. After 10 weeks of NaCl irrigation, all plants alive were irrigated with 1/10-strength Hoagland’s solution again without NaCl until defoliation in the following November. Length of stems and number of leaves were recorded every other week. Number of flower buds and flowers per cluster and the bloom date were recorded in the following April.

2.3. Leaf property determination

After sunset on weeks 3, 6, 9, 15 and 24 following the commencement of NaCl irrigation, two fully expanded leaves located at approximately 30 cm from the shoot tip were collected. Leaf water potential was determined immediately after collection with a leaf psychrometer (SC-10A; Decagon, USA). The same leaves were then wiped gently with cotton wool made wet with deionized water and oven-dried at 80°C for 24 h. For cation determination, leaves were ground and 100 mg of each tissue sample was dry ashed at 600°C for 6 h. These samples were then soaked with 0.5 N HCl + 1% volume LaCl₃ and Na concentration determined with an atomic absorption spectrophotometer (AA630-12; Shimadzu, Japan). For Cl ion, 100 mg of ground tissue sample was soaked in 50 ml deionized water, shaken 3 times for 1 h and then filtered with 0.5 μm filter (MX-13K; Showa Denko, Japan). Chloride concentration of the extracted fraction was determined by an ion chromatograph (System 430; Waters, USA) with a column (IC-524; Showa Denko, Japan).

3. Results

3.1. Plant growth

Stem elongation of the plants was reduced by NaCl irrigation in both rootstocks (Fig. 1). The reduction in elongation rate was observed at 25 mM NaCl irrigation
and it was maximum at 50 mM NaCl irrigation. Stem elongation of PYR-based plants were halved and one Yari, one Kosui and three La France plants had died by 50 mM NaCl by week 10. None of the BET-based plants died. Stem elongation of BET-based plants was also reduced by NaCl but the reduction in elongation rates were in most instances less than observed in PYR-based plants at week 28 (27 and 59% reduction in BET and PYR of 50 mM plots, respectively). Stems of all plants except Yari on PYR continued elongation after NaCl application but the lengths of stems were not recovered to the levels of control until week 28. The plant fresh weight measured after defoliation was also reduced by NaCl irrigation (Fig. 2). The weight of BET-based plants was higher than PYR-based plants although the weight relative to 0 mM NaCl treatment varied with scion cultivar.

In PYR-based plants, number of leaves were reduced by NaCl (Fig. 3). The leaves showed dark-brownish scorch during NaCl irrigation and severe defoliation was observed thereafter. Defoliation was maximum in PYR-based plants subjected to 50 mM NaCl and number of leaves continued to decrease after NaCl irrigation was discontinued. Number of leaves on BET-based plants was also reduced by NaCl but no leaf scorch was observed in all plots. After NaCl treatment was discontinued, leaf number increased in all the BET-based plots.
The reduction in leaf number in the salt treated plots as compared to those of control was greater in PYR-based plots. Flower buds were scarce in Yari but a slight increase in number of buds was observed in 50 mM BET and 25 mM PYR plots (Fig. 4). Effects of NaCl

![Graph showing fresh weight of three pear cultivars Yari (A), Kosui (B) and La France (C) grafted on P. betulifolia (BET) or P. pyrifolia (PYR) subjected to 0, 25 or 50 mM NaCl irrigation for 10 weeks. Values and bars are mean ± S.E. of five replicates except for those grafted on PYR and subjected with 50 mM NaCl, where the number of replicates were four for Yari, four for Kosui and three for La France, respectively.]

![Graph showing number of leaves on stems of three pear cultivars Yari (A and B), Kosui (C and D) and La France (E and F) grafted onto P. betulifolia (BET) or P. pyrifolia (PYR) rootstocks subjected to 0 (○), 25 (●) or 50 mM (△) NaCl irrigation. NaCl treatment (S) was performed continuously for 10 weeks. Values are mean of five replicates. Within plots, values followed by the same letter are not significantly different (P > 0.05) by Scheffe’s multiple comparison test (for clarity, only significances for weeks 10 and 18 are shown).]
appeared most significantly on Kosui and the number of flower buds was significantly increased. Flower bud formation of La France was enhanced in 25 mM BET but not in PYR-based plants. The NaCl treatment had no effect on bloom date nor number of flowers per cluster.

3.2. Leaf water potential

Leaf water potential (LWP) was reduced by 50 mM NaCl beginning in week 3 (Table 1). At week 6, LWP of Yari scion tended to be lower in both BET and PYR rootstocks. At week 9, LWP of plants irrigated with 50 mM was still lower than controls. The marked decrease in LWP was observed in PYR-based plants with 50 mM NaCl as compared to BET-based ones. By week 15 (5 weeks after NaCl treatment had been discontinued), no clear effect of NaCl irrigation could be observed on LWP.

3.3. Leaf mineral composition

Leaf Na concentration was elevated by 50 mM NaCl irrigation in all scions grafted onto PYR (Fig. 5). The Na concentration was prominent at week 9 in all scions and reached 1, 0.5 and 1.5% on dry weight basis in Yari, Kosui and La France, respectively. No significant difference was observed between leaves from 0 and 25 mM treatments. After NaCl treatments were discontinued, Na concentrations of the leaves sampled after NaCl treatments were lower than before and at the same levels as controls. In contrast, effect of NaCl irrigation on leaf Na concentrations was negligible in all scion cultivars grafted onto BET rootstock, although leaf Na concentration increased slightly in Kosui trees subjected to 50 mM NaCl irrigation.
Leaf Cl concentration of PYR-based plants was significantly elevated by week 3 (Fig. 6). In Yari, leaf Cl concentration was elevated even by 25 mM treatment. In Kosui and La France with 50 mM, leaf Cl concentration was prominent at week 9 and the maximum Cl concentrations in plants with 50 mM treatment were 2.8 and 1% for Kosui and La France, respectively. Leaf Cl concentration in the 25 mM treatment was equivalent to that of control in Kosui and La France. Like

Table 1
Midnight leaf water potential (MPa) of three pear cultivars Yari, Kosui and La France grafted onto P. betulifolia or P. pyrifolia rootstocks subjected to 0, 25, or 50 mM NaCl irrigation for 10 weeks (n.s.: not significant)\(^a\)

<table>
<thead>
<tr>
<th>Scion cv.</th>
<th>NaCl (mM)</th>
<th>Week 3</th>
<th>Week 6</th>
<th>Week 9</th>
<th>Week 15</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yari</td>
<td>0</td>
<td>–1.3 a</td>
<td>–1.2 n.s.</td>
<td>–1.1 a</td>
<td>–1.1 n.s.</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>–1.3 a</td>
<td>–1.5</td>
<td>–1.4 ab</td>
<td>–1.1</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>–1.8 b</td>
<td>–1.5</td>
<td>–1.6 b</td>
<td>–1.1</td>
</tr>
<tr>
<td>Kosui</td>
<td>0</td>
<td>–1.0 a</td>
<td>–1.0 a</td>
<td>–1.2 a</td>
<td>–1.0 n.s.</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>–1.1 a</td>
<td>–1.2 ab</td>
<td>–1.4 ab</td>
<td>–1.2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>–1.7 b</td>
<td>–1.7 b</td>
<td>–1.7 b</td>
<td>–1.3</td>
</tr>
<tr>
<td>La France</td>
<td>0</td>
<td>–1.0 a</td>
<td>–0.8 n.s.</td>
<td>–1.3 a</td>
<td>–1.0 n.s.</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>–1.2 ab</td>
<td>–1.3</td>
<td>–1.2 a</td>
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<td></td>
<td>50</td>
<td>–1.5 b</td>
<td>–1.5</td>
<td>–1.7 b</td>
<td>–1.3</td>
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<tr>
<td>(P. ) pyrifolia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yari</td>
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<td>–1.0 a</td>
<td>–1.4 a</td>
<td>–1.2 a</td>
<td>–1.4 n.s.</td>
</tr>
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<td>–1.4 a</td>
<td>–1.3 ab</td>
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<td>–1.9 b</td>
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<td>–1.4</td>
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<tr>
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<tr>
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<td>–1.5 ab</td>
<td>–1.2</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>–1.6 c</td>
<td>–1.7 b</td>
<td>–2.1 b</td>
<td>–1.5</td>
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<tr>
<td>La France</td>
<td>0</td>
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<td>–1.1 a</td>
<td>–1.2 a</td>
<td>–1.4 n.s.</td>
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<tr>
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<td>–1.1 a</td>
<td>–1.6 ab</td>
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<td>–1.4</td>
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<td>–2.3 b</td>
<td>–1.2</td>
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Analysis of variance

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<th>n.s.</th>
<th>*</th>
<th>***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scion (B)</td>
<td>n.s.</td>
<td>n.s.</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>NaCl (C)</td>
<td>***</td>
<td>***</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>A × B</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>A × C</td>
<td>n.s.</td>
<td>n.s.</td>
<td>*</td>
<td>n.s.</td>
</tr>
<tr>
<td>B × C</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>A × B × C</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

\(^a\) Within columns, values followed by the same letter are not significantly different (\(P > 0.05\)) using Scheffe’s multiple comparison test.

\(^*\) \(P < 0.05\).

\(^{**}\) \(P < 0.01\).

\(^{***}\) \(P < 0.001\).
Fig. 5. Sodium concentration in leaves of three pear cultivars Yari (A and B), Kosui (C and D) and La France (E and F) grafted onto *P. betulifolia* (BET) or *P. pyrifolia* (PYR) rootstocks subjected to 0 (○), 25 (●) or 50 mM (△) NaCl irrigation. NaCl treatment (S) was performed continuously for 10 weeks. Values are mean of five replicates. Within plots, values followed by the same letter are not significantly different (*P* > 0.05) by Scheffe’s multiple comparison test (for clarity, only significant weeks are shown).

Fig. 6. Chloride concentration in leaves of three pear cultivars Yari (A and B), Kosui (C and D) and La France (E and F) grafted onto *P. betulifolia* (BET) or *P. pyrifolia* (PYR) rootstocks subjected to 0 (○), 25 (●) or 50 mM (△) NaCl irrigation. NaCl treatment (S) was performed continuously for 10 weeks. Values are mean of five replicates. Within plots, values followed by the same letter are not significantly different (*P* > 0.05) by Scheffe’s multiple comparison test (for clarity, only significant weeks are shown).
Na, Cl concentrations in the leaves collected after NaCl irrigation had been discontinued was to the same level as in control leaves. Leaf Cl also increased in scions grafted on BET rootstocks. Nevertheless, the increment as compared to 0 mM treatments was negligible in BET.

4. Discussion

The stem elongation of pear trees on both BET and PYR rootstocks was reduced at 25 mM NaCl irrigation. Previous reports on young apple trees under sand culture had also shown linear reduction in the shoot lengths by NaCl irrigation (Motosugi et al., 1987; Solyu and Lüdders, 1988). The occurrence of defoliation and plant death was greater in PYR-based scions, indicating that PYR may be more sensitive to NaCl than BET rootstocks. Francois (1982) irrigated saline water of up to 9 dS/m (approximately 90 mM) to _P. kawakamii_ for 3 years and reported no growth reduction and slight leaf necrosis. On the other hand, Myers et al. (1995) reported leaf damages and plant death of Williams pear by 2.1 dS/m (approximately 21 mM) saline water irrigation but the damages appeared after 6 years. The difference in the susceptibility to irrigated NaCl concentrations seems due to the tree size, as a large amount of Na and Cl ions are accumulated in woody part and restricted to be loaded to leaves (Ziska et al., 1991; Boland et al., 1996). Present experiment suggests BET can be more tolerant to salinity than PYR but it is still unknown whether BET also fail or withstand long-term salinity. The leaf Na and Cl concentrations usually associated with leaf damages are reported 0.25–0.5% Na (110–220 mmol/kg DW) and 0.5–1.0% Cl (140–280 mmol/kg DW) for Williams pear (Myers et al., 1995), 0.5% Na and 1.0% Cl for Fuji apple (Motosugi et al., 1987). PYR-based trees subjected with 50 mM NaCl contained more than 0.5% Na and 1.0% Cl in the present experiment. The lethal NaCl concentrations at which leaf injury is produced may be equal for scion cultivars.

Apple tree cultivars Fuji (Motosugi et al., 1987) and Golden Delicious (Solyu and Lüdders, 1988) grafted onto several rootstocks all suffered from severe leaf injury when irrigated with 20 or 25 mM NaCl. Similarly, in the present experiment, the plants grafted onto PYR showed leaf burn at 25 mM NaCl irrigation. The results of mineral analysis suggest that excessive Na and/or Cl ions at toxic concentrations seem to be the primary cause of leaf burn and defoliation. Salt was excluded from leaves effectively only at 25 mM NaCl in PYR. On the other hand, BET-based plants seems to exclude salts at 50 mM NaCl, too. Present experiment suggest there is a difference in the salt accumulation between BET and PYR, as the leaf Na and Cl were maintained at low concentration in BET. Similar ion exclusion was reported in _P. kawakamii_ (Francois, 1982).

Susceptibility of a plant to salinity is controlled by several factors other than Na and Cl. Greenway and Munns (1980) noted the importance of cation exchange
and the ratio Na/Ca of irrigated water can also affect on a plant’s salinity tolerance. Calcium ions absorbed into plant body are responsible for cell membrane permeability. The irrigation in this experiment was performed using 1/5-strength Hoagland’s solution, thus the Na/Ca ratio in irrigated solution was 0, 15, and 30 for 0, 25, and 50 mM treatments on a molar basis, respectively. Supplemental Ca may improve salt tolerance of the pear. On the other hand, additional Ca had no ameliorating effect on growth and leaf Na concentrations of young citrus (Walker and Douglas, 1983) and blueberry (Wright et al., 1992) irrigated with up to 100 mM NaCl. Wright et al. (1992) suggested Ca may ameliorate salinity effects in case of long-term salinity at low concentration. Distinctive trends in major mineral cation (K, Ca and Mg) and anion (NO₃ and SO₄) concentrations were not observed among scion and rootstock options (data not shown). Selective ion absorption against elevated NaCl may become a major concern at higher salt concentrations and/or non-optimal nutrient levels.

Myers et al. (1995) reported the decrease in LWP in the salinised mature pear trees was slight but insignificant, while in the present experiment the LWP measured in midnight decreased significantly during the NaCl irrigation period. Effects of salinity on the LWP seems to be due to the fact that the long-term salinity and short-term salinity affect plants differently as noted by Munns and Termaat (1986). The plant mass can work as buffer in case of mature trees and changes in soil water potential can be less reflected to LWP. The significant difference in LWP between the rootstocks at week 9 may reflect there is a difference in mechanism to recover from salinity. LWP of salt-treated plants had no lower values than those of controls after NaCl irrigation was discontinued. This fact suggests the leaves which expanded after release from NaCl irrigation did not suffer from stress any more.

Flower bud formation on pear stems was promoted by NaCl irrigation in every scion–rootstock combination, even though stem extension was suppressed. Increase in blossom density is also observed on mature ‘Bartlett’ and ‘Williams’ trees under drought (Mitchell et al., 1984) and salinity (Myers et al., 1995). Increased flower bud formation and acceleration of fruit maturation is commonly observed in salinised fruit trees, such as avocado (Downton, 1978) and guava (Walker et al., 1979). In case of pear trees, formation of flower clusters on the basal buds is scarce and this limits fruit yield. Short-term NaCl irrigation at low level may promote flower bud without salinity injury, since spurs of pear can be maintained development for several years.

References


