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Short Notes

High-density 'Spadona' pear orchard shows reduced tree sensitivity to fire blight damage due to decreased tree vigour

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Summary. Fire blight, caused by *Erwinia amylovora*, is a severe disease of pear (*Pyrus communis*). Highly vigorous trees are more sensitive to *E. amylovora* damage after summer pruning. Trees grown in high-density orchards have lower vigour than those in low-density orchards, reducing required inputs for pruning and tying, and increasing per hectare yields orchard profitability. Tree damage due to fire blight was assessed in high-density pear orchards *vs.* the common Israeli low-density orchards. Pear trees were planted at high densities using the spindle system (2500 trees ha^{-1} for 'Spadona' and 1250 trees ha^{-1} for 'Coscia'), or at low density (1000 trees ha^{-1}) using palmeta ('Spadona') or open vase ('Coscia') systems. Four years after planting, both orchards were similarly infected with fire blight (11–50 infected blossoms per tree), but 1 year after infection, trees in the high density orchard had fewer infections in the main limbs or trunk bases compared to the low-density orchard. At 3 years after initial infection, no trees had died in the high density orchard, whereas in the low density 'Spadona' orchard, 10% of the trees were wilted. For the more tolerant 'Coscia', infection did not progress at either orchard density. These results indicate that in fire blight-susceptible pear cultivars, a high density planting system, associated with reduced tree vigour, presents a decreased risk of fire blight damage.

Keywords. *Erwinia amylovora*, fire blight, high-density orchard, *Pyrus communis*.

INTRODUCTION

Fire blight caused by *Erwinia amylovora* is the most severe disease of pear (*Pyrus communis*) trees and apple and other deciduous trees in the Rosacea. The bacteria enter host trees through flower nectarthodes (natural openings through which the nectar is secreted) or through wounds in young shoots caused by hail (Johnson, 2000; Bubán and Orosz-Kovács, 2003).

Erwinia amylovora can infect host leaves, blossoms, fruit, shoots and trunks (van der Zwet, and Beer 1995). Infections in the main limbs or trunk bases can ultimately lead to tree death in subsequent years (Vanneste and Eden-Green, 2000).

The most common pear varieties in Israeli pear orchards are cvs 'Spadona' and 'Coscia'. Since the introduction of fire blight in Israel in 1985, some studies have concentrated on the sensitive 'Spadona'. Shtienberg *et al.* (2003) showed that summer pruning of 'Spadona' trees encouraged growth of vegetative tissues while also ridding the trees of infected branches. However, this procedure can lead to rapid movement of the bacteria in the infected trees, potentially reaching the main limbs and endangering tree life. Shtienberg *et al.* (2003) also showed that trees with high vigour are more sensitive to *E. amylovora* than low vigour trees following pruning.

Irrespective of sensitivity to fire blight, the number of fruit trees planted per hectare has increased in the past 50 years worldwide, Israel included. Trees in high density orchards are considered to have lower vigour relative to those in low density orchards, thus reducing the manpower required for pruning and tying. Despite lower yields per tree, total yields per hectare are enhanced, significantly increasing orchard profitability (Robinson *et al*., 2004a and b). An increase in number of trees per unit area can be achieved using new dwarf rootstocks and novel crop design methods (Ferree and Warrington, 2003). In Israel, most of the old pear orchards are planted in the "Spanish method", which makes use of stronger rootstocks and generous applications of fertilizers, thereby improving yield per hectare but also potentially encouraging *E. amylovora's* movement in the tree branches.

The present study tested whether high density pear orchards planted using the spindle system had reduced fire blight damage in infected trees compared to a low density planting system.

MATERIALS AND METHODS

Pear tree experiment design

Pear plots were planted in 2013 specifically for this experiment, in the Hula valley orchard research station (coordinates: 33.1522059, 35.6242158). 'Spadona' plants were grafted on BA-29 10 rootstock, and Coscia plants were on Betulifolia rootstocks (Table 1). The maximum height of all trees was restricted to 2.5 m. Rows were planted for each of the cultivars in (i) a high density row system using the spindle tree design, or (ii) a low density system using palmeta (in 'spadona') or open vase design (in 'Coscia', see Table 1 and Figure 1).Rows were planted 4 m apart. Each row contained only one cultivar and one tree design.

For each cultivar, the same rootstock, nutrition, and growth hormone regulators were equally applied to low and high density trees. This aimed to eliminate any effect of rootstock or other treatments on the progression of fire blight in the trees, leaving only the effects of orchard density and individual tree design.

Tree vigour was estimated by measuring the main bark circumference. This measurement was performed in November 2017, 2018 and 2019 on six healthy trees for each design system, per cultivar, as described by Stern and Doron (2009) and Stern *et al.* (2013). The same trees were measured each year, 10 cm above their grafting sutures.

Disease assessments

Erwinia amylovora infections were estimated in spring 2017 in 4-year-old orchards, as numbers of infected blossoms per tree grouped into: 0, one to five, six to ten or 11–50 infected blossoms per tree. All trees in each treatment were evaluated (Table 1).

Fire blight progression was estimated in August/September each year for disease infection progress for 1 year prior, and estimates were classified into four groups: (i) no sign of disease progress (healthy tree); (ii) infected tree where infection was clearly identified in either the main limb or (iii) the trunk base; (iv) dead tree. All trees in each treatment (Table 1) were evaluated.

Statistical analyses

Statistical analyses were applied using JMP 13 software. T-tests were performed to compare tree circumferences between treatments. Chi-square tests (likelihood

Table 1. Experimental plot design (see also Figure 1).

Cultivar	Rootstock	Density	Tree Design	Distance between trees (m)	Number of trees per treatment	Number of trees ha^{-1}
Spadona	BA-29 10	High	Spindle	1.0	99	2500
		Low	Palmeta	2.5	40	1000
Coscia	Betulifolia	High	Spindle	1.0	93	2500
		Low	Open vase	2.0	50	1250

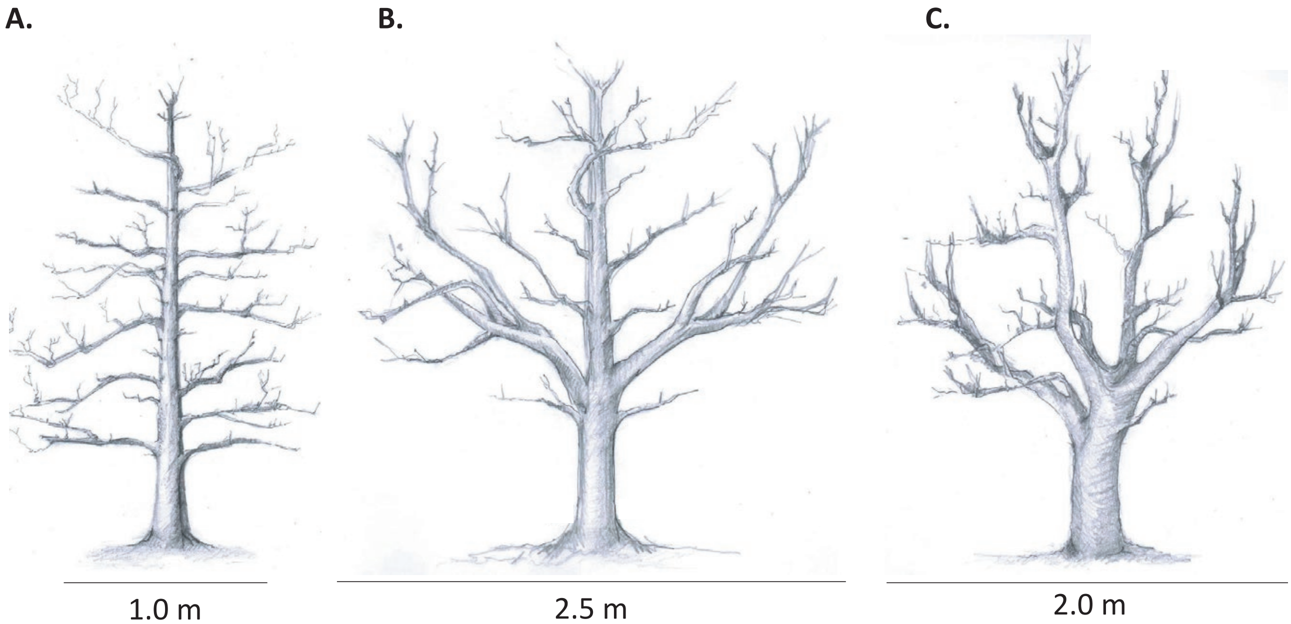

Figure 1. The tree design systems tested in this study. Schematic drawings of 7-year-old trees are shown. (A) 'Spadona' and 'Coscia' high-density system, spindle design; (B) 'Spadona' low-density system, palmeta design; (C) 'Coscia' low-density system, open vase design. Illustration: Reut Yelin-Alush.

ratio in contingency analysis) were used to compare infected trees within different categories, calculated as percentage of trees either without or with (i) infection in the main limb, (ii) infection in the trunk base, or (iii) dead trees. Tree was the experimental unit.

RESULTS

Trunk circumference for each rootstock–cultivar combination reflects tree vigour, where a large circumference reflects greater vegetative growth than a small circumference (Stern and Doron, 2009; Stern *et al.*, 2013). In 'Spadona' grown in the palmeta tree design, trunk circumference was greatest (Figure 2A, B and C), with annual sequential differences accumulating to 23.2% in the sixth year (t = 4.90, $P = 0.0008$; Figure 2C), compared with 'Spadona' grown in the spindle design. In 'Coscia', the differences between trunk circumference in the spindle vs. open vase designs were smaller, with only up to 12.6% cumulative difference in the sixth year (t = -3.18, $P = 0.0098$; Figure 2C).

Disease assessments

Natural fire blight infections occurred in spring 2017 when the trees were 4 years old, with more than 97.4% of the trees infected at 11–50 blossoms per tree, in both 'Spadona' and 'Coscia'. In 'Spadona', the disease progressed to 41.0% infected trees in the palmeta tree design, but only 13.1% infected trees in the spindle design. The differences between the design infection levels were statistically significant ($\chi^2 = 12.105$, $P = 0.0005$; Figure 3A). Infections continued to progress in the 5-year-old trees, to 75.0% of the palmeta trees and 50.5% of the spindle trees ($\chi^2 = 7.25$, P = 0.0069; Figure 3A). Infections in the trunk bases, threatening tree life, was detected in 56.4% of the palmeta trees and 26.3% of the spindle trees ($\chi^2 = 10.893$, P < 0.001; Figure 3B). Dead trees were only found for 'Spadona' grown in the palmeta design, with 5.0% of the 6-year-old trees dying ($\chi^2 = 5.055$, P = 0.0246) and 10.0% of the 7-year-old trees dying ($\chi^2 = 10.263$, P = 0.0014; Figure 3C).

In cv. Coscia, in the summer of 2017, a few months after the initial *E. amylovora* infections, the proportions of trees with apparent infection in the trunk base or in the main limb was significantly higher for the open vase vs. spindle design in Ca 2.5-fold. These differences may have been random, but in the following spring of 2018, all lesions recovered and the infections did not progress (Figure 3D and E). In the spring of the fifth year (2018), trees grown in the spindle design had infection scars on the trunk bases (1.1% of the trees) or the main limbs (7.5% of the trees). However, these

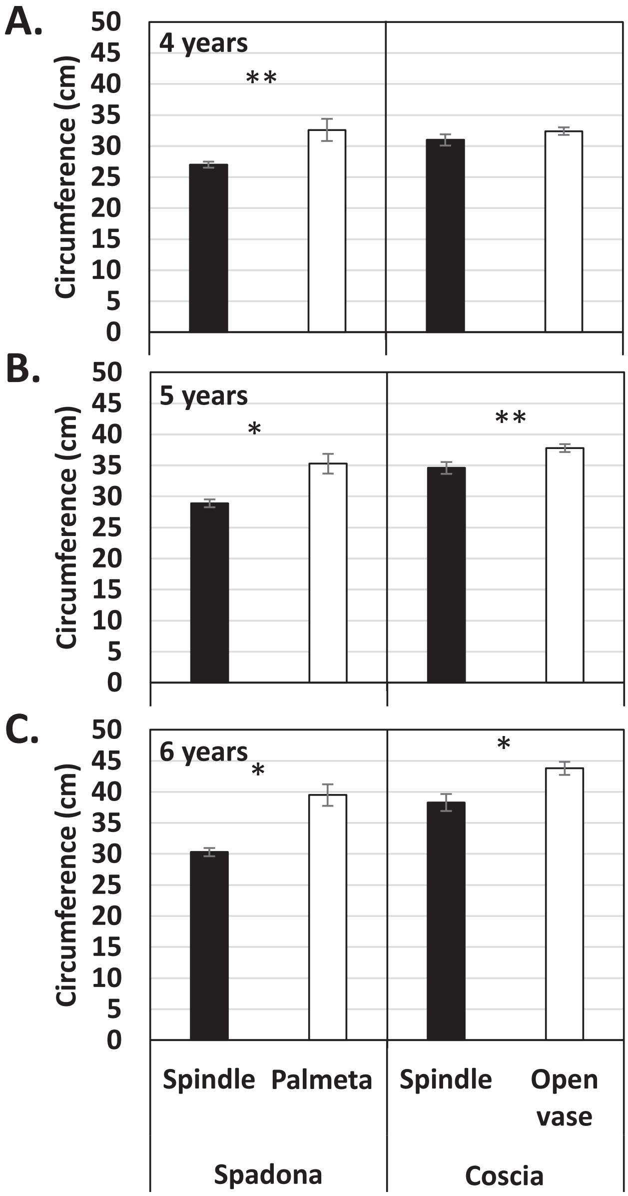

Figure 2. Mean trunk circumferences (cm) of 4-year-old (A), 5-year-old (B), or 6-year-old (C) pear trees. Trees were measured in November 2017 (A), 2018 (B), and 2019 (C), grown in a spindle design (low vigour, high density system for 'Spadona') , or Palmeta and open vase design (high vigour, low density system for 'Coscia'). Results are presented as averages ± SE. * indicates $P \leq 0.01$, and $**P \leq 0.05$, as shown by t-tests.

lesions were probably not active, because no disease progress was recorded in the following year (summer of 2018, Figure 3D and E). No 'Coscia' trees died from fire blight infections during the study.

DISCUSSION

High density pear orchards have many economic benefits over low density orchards, including greater yields, quicker returns on investment, more efficient utilization of pesticides and labour inputs, and improved fruit quality (Norelli *et al*., 2003; Majid *et al*., 2018). High density orchards can be profitable within the first 5 to 10 years from planting, which is less than for low density orchards (Robinson *et al*., 2004b). Although each low density tree gives less yield, there are significant positive effects on cumulative fruit yields per hectare. In the present study, tree population densities were varied using two different tree design systems, either spindle (in 'Coscia' and Spadona), palmeta (in 'Spadona') or open vase designs (in 'Coscia').

In 4- and 5-year-old 'Spadona' experimental plots, the spindle-shaped, low vigour trees had more restricted vegetative growth, measured as trunk circumference, than the palmeta trees. In the spindle-shaped trees, damage from fire blight infections was less in both the main limbs and the trunk bases, and no trees died after 7 years of growth and 4 years after severe infection. In contrast, in the palmeta, high vigour design system, in 10% of the trees the infection progress to the point of complete wilt. These results were not surprising, as Shtienberg *et al*. (2003) showed increased sensitivity of high vigour trees to fire blight progression in branches of 30 cm or longer. Similar results have also been obtained in apple. Norelli *et al*. (2000) reported that pruned and infected trees lost 10 times more yield than infected, unpruned trees, since pruning increased vegetative growth as well as the levels of primary metabolites and bacterial movement in the tree phloem.

In contrast to the present study results, however, Norelli *et al*. (2003) showed that high density orchards of apples grafted on a dwarf rootstock were very sensitive to fire blight. This sensitivity could have been due to the intensive summer pruning applied to the trees, as is common with this orchard design practice. Furthermore, summer pruning is used to improve fruit quantity and quality, and may also remove dead tissues and pathogen inoculum, and through reduced humidity, improve bactericide penetration into orchard canopies (Cooley *et al*., 2007). On the other hand, summer pruning can increase disease rates, if pruning is applied when disease risk is high (Cooley and Autio, 2011).

In Israel, 'Spadona' is the main cultivated pear variety, with 70 to 80% of sales, and 'Coscia' makes up the other 20 to 30% (http://agro.mashovgroup.net). 'Spadona' is considered to be more sensitive to fire blight damage than 'Coscia', so most fire blight studies in Israel have been

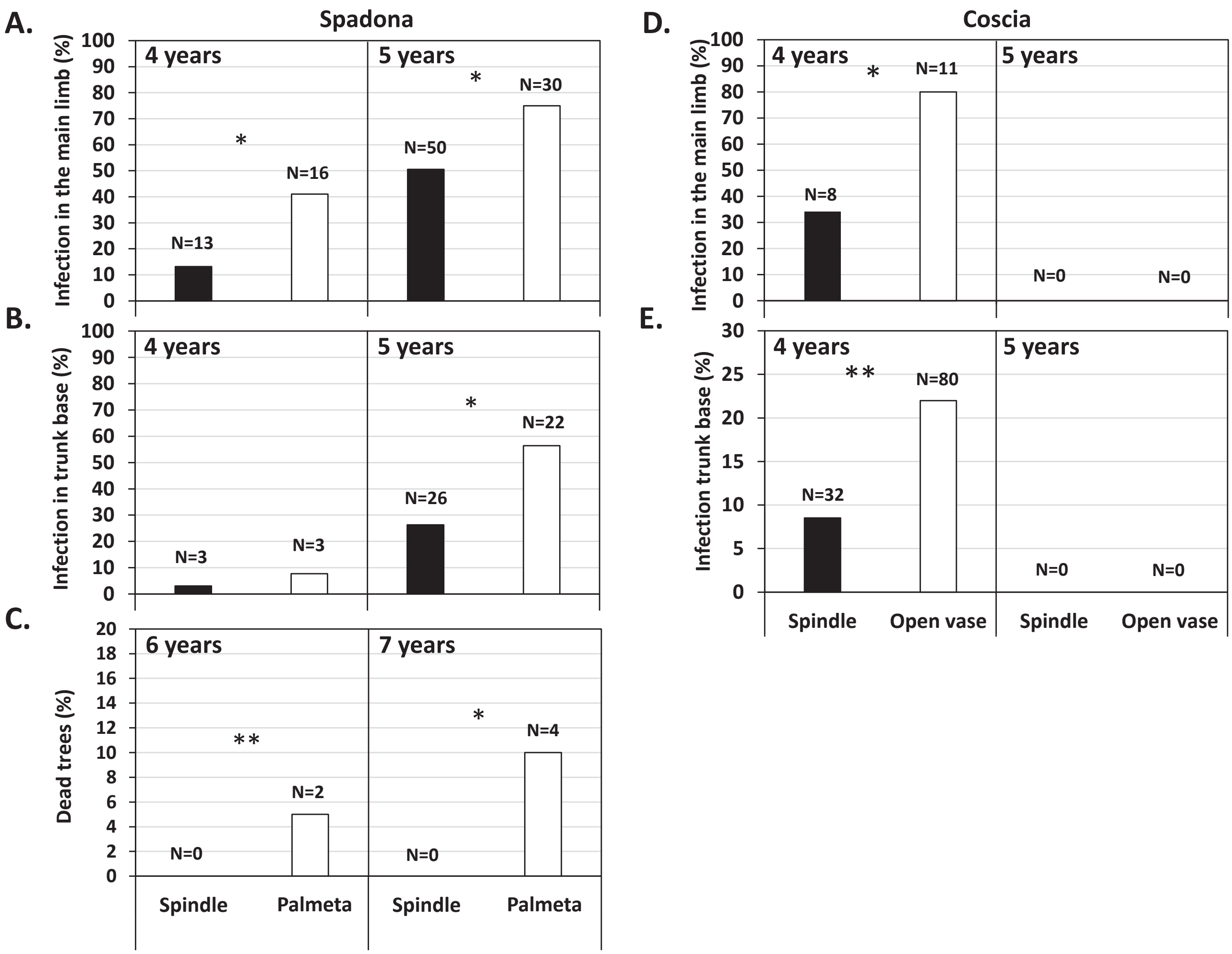

Figure 3. Mean proportions of pear trees infected with *Erwinia amylovora* out of all trees of different growth designs. A to C, 'Spadona' grown in spindle design (low vigour, high density) or palmeta design (high vigour, low density). D and E, 'Coscia' grown in spindle or open vase designs (high vigour, low density). A and D, Percent of trees with infections that reached the main limbs. B and E, percent of trees with infections that reached the trunk bases. C, percent of dead trees. Note that only 'Spadona' trees growing in the palmeta design (high vigour, low-density system) died due to fire blight. N = number of infected or dead trees. *$P < 0.01$, **$P < 0.05$ as indicated from contingency Chi-square analyses.

performed on 'Spadona' pear trees. The present study is the first to assess sensitivity of both of these cultivars under the same level of disease pressure, and to track disease severity over time. The 'Coscia' trees were naturally infected with fire blight at a level that was as severe as for 'Spadona', but the disease did not spread to the trunk bases or tree limbs in the subsequent year, and no fire blight symptoms appeared in the following 2 years. This was probably due to the more restricted innate vigour of 'Coscia'. Therefore, 'Coscia' tree design did not significantly affect *E. amylovora* progress in the trees.

In conclusions, 'Spadona' pear trees in high density (low vigour) plantings were less sensitive to fire blight damage than their low density, high vigour trees. Further agrotechnical methods to restrict tree vigour could be investigated for limiting infection in pear trees. In cv. Coscia, on the other hand, due to naturally low vigour, tree design had little impact on resistance to fire blight. Taken together, low-vigour, high-density orchard systems can be recommended for their increased profitability, and for their enhanced disease resistanceto fire blight.

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