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Morphological differences of vessels in the secondary xylem of columnar and standard apple trees

Diferencias morfológicas de los vasos en el xilema secundario de árboles de manzana estándar y columnar

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Abstract. The length, dimension and type of the vessel elements in the secondary xylem of columnar and standard apple trees were studied by isolation method and micrograph. Results showed that the shoot xylem vessel cells were reticulate and pitted in columnar and standard apples. Most of the end walls were simple perforation plates. Compared with columnar apple trees, standard apple trees showed more abnormal cells in the xylem vessel cells. The average diameter of the xylem vessel cells of shoots was significantly wider in columnar apple (43.27μm) than in standard apple, (32.64 μm). Length of the xylem vessel cells of shoots didn't have a consistent pattern in columnar and standard apple trees. Results of this study might help to explain why columnar apple trees had higher photosynthetic rates and light energy utilization ratios than standard apple trees. These traits might have contributed to early flowering and fruiting in columnar apple trees.

Keywords: Columnar apple; Isolation method; Vessel Element.

Resumen. La longitud, dimensión y tipo de los vasos en el xilema secundario de árboles de manzana estándar y columnar se estudiaron por el método de aislamiento y microfotografía. Los resultados mostraron que las células de los vasos del xilema del tallo fueron reticuladas y agujereadas en las manzanas estándar y columnar. La mayoría de las paredes del fondo fueron simples platos perforados. Comparado con los árboles de manzana columnar, los árboles de manzana estándar mostraron más células anormales en las células de los vasos del xilema. El diámetro promedio de las células de los vasos del xilema de tallos fue significativamente más amplio en la manzana columnar (43.27μm) que en la manzana estándar (32.64 μm). La longitud de las células de los vasos del xilema de tallos no tuvo un modelo consistente en las manzanas estándar y columnar. Los resultados de este estudio contribuirían a explicar porque los árboles de manzana columnar tienen mayores tasas fotosintéticas y relaciones de utilización de energía lumínica que los árboles de manzana estándar. Estas características deben haber contribuido a una floración y fructificación más temprana en los árboles de manzana columnar.

Palabras clave: Manzana columnar; Método de aislamiento; Vasos del xilema.

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INTRODUCTION

Tube is a major component of micro-vascular plant xylems, whose element structure can affect growth and development of plants through water and mineral transport. The first columnar apple variety ("McIntosh Wijcik") was a mutant of "McIntosh" discovered in Canada. It has many advantages, such as very short internodes, high germination rates, weak branching and rarely long lateral branches from trunk (Zhang et al., 2003). Columnar apple trees flower and fruit early. All this make columnar apple trees a valuable resource for improving apple genetics.

Former researches have investigated columnar apple in (1) breeding cultivars (Dai et al., 2003), (2) leaf anatomy (Liang et al., 2009), (3) photosynthetic characteristics (Zhang et al., 2010) and (4) linkage map construction based on molecular markers (Wang et al., 2002; Tian et al., 2005). The structure and evolution of secondary xylem vessels has been reported in peach (Guo et al., 2008), mango (Chen & Tang, 2005), Grevillea (Chen & Tang, 2004a), Aquilaria (Chen & Tang, 2004b), and Manilkara (Chen, 2007). However, there are a few reports on this regard on apples, especially in columnar apple. In this study, we compared the general inner structure of secondary xylem vessels of columnar apple with that of standard apple. Technologies of segregation methods and micro-photography were used. Our results might contribute to explain the earlier flowering and yield in columnar than in standard apple trees.

MATERIALS AND METHODS

Materials. Southern direction, 1.5m height and 2-year-old shoots were selected as experimental materials from the uniform growth plants in the Fengshi gardening field at Laixi county, Qingdao city in March 2011.

Sample 1: 'Fuji' × 'Telamon' standard apple; Sample 2: 'Gala' × 'Telamon' standard apple; Sample 3: 'Fuji' cultivar; Sample 4: 'Fuji' × 'Telamon' columnar apple; Sample 5: 'Gala' × 'Telamon' columnar apple; Sample 6: 'Telamon' cultivar. Samples 1, 2 and 3 were standard types, and samples 4, 5 and 6 were columnar types.

Experimental methods. After being washed, the same shoot positions were cut in pieces of about 1 cm, which were vertically cut into 2-3 mm cross-sectional strips, and isolated for 3-4 d at 30-40 °C in incubator (Chen & Xie, 2003). Temporary slides were made with 0.5% Safranin staining dye, and microscopic pictures of vessel elements were photographed with a Nikon E80i biological microscope. One hundred samples of each material were randomly observed; vessel length (excluding tail) and diameter were determined with Image-Pro Plus6.0. Valves were then averaged, and statistical analyses conducted using the data DPSv7.05 software.

RESULTS

Morphology of xylem vessel elements of apple shoots. Xylem vessel types of apple shoots were similar in columnar and standard apple trees under an optical microscope. There were two kinds of vessels: pitted vessel elements and reticulate vessel elements (Figs. 1 and 2). Reticulate vessel elements accounted for 69.7% in standard apple trees and 75.7% in columnar apple trees. Vertical connections of vessel elements were observed by vessel elements not completely isolated in this experiment. There were some abnormal vessel elements (vessel elements with an uneven diameter) (Fig. 3). Compared to the columnar apple, the standard apple types had more abnormal vessel elements: malformation rate of xylem vessel elements was 9.66% in standard apple and 5.75% in columnar apple.

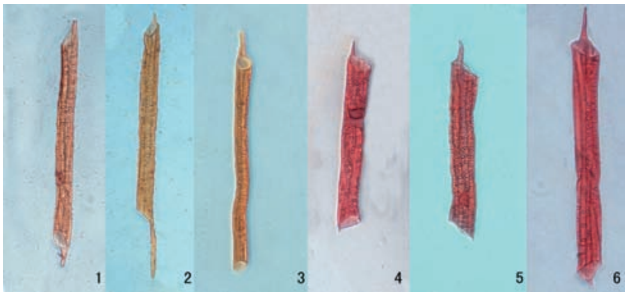

Fig. 1. The pitted vessel element shapes of shoot xylems.
1: 'Fuji' × 'Telamon' standard apple; 2: 'Gala' × 'Telamon' standard apple; 3: 'Fuji'; 4: 'Fuji' × 'Telamon' columnar apple; 5: 'Gala' × 'Telamon' columnar apple; 6: 'Telamon'.
Fig. 1. Las formas de los elementos de conducción agujereados de los xilemas del tallo.
1: manzana estándar 'Fuji' × 'Telamon'; 2: manzana estándar 'Gala' × 'Telamon'; 3: 'Fuji'; 4: manzana columnar 'Fuji' × 'Telamon'; 5: manzana columnar 'Gala' × 'Telamon'; 6: 'Telamon'.

Fig. 2. The reticulate vessel element shapes of shoot xylems.
1: 'Fuji' × 'Telamon' standard apple; 2: 'Gala' × 'Telamon' standard apple; 3: 'Fuji'; 4: 'Fuji' × 'Telamon' columnar apple; 5: 'Gala' × 'Telamon' columnar apple; 6: 'Telamon'.
Fig. 2. Las formas de los elementos de conducción reticulados de los xilemas del tallo.
1: manzana estándar 'Fuji' × 'Telamon'; 2: manzana estándar 'Gala' × 'Telamon'; 3:'Fuji'. 4: manzana columnar 'Fuji' × 'Telamon'; 5: manzana columnar 'Gala' × 'Telamon'; 6: 'Telamon'.

Fig. 3. Connection of vessel elements in vertical. 1 and 2: abnormal cells in the connection of vessel elements in vertical; 3 and 4: other abnormal cells.
Fig. 3. Conexión vertical de los elementos de conducción. 1 y 2: células anormales en la conexión vertical de los elementos de conducción; 3 y 4: otras células anormales.

Comparison of vessel length on two types of apple shoots. The average vessel lengths were mostly similar ($p>0.05$) in columnar and standard apple shoots (Table 1). However, the highest ($p<0.05$) and lowest ($p<0.05$) average vessel lengths were found in 'Telamon' columnar and 'Gala' × 'Telamon' columnar, respectively (Table 1).

Table 1. Vessel length of shoot xylems in columnar and standard apples.
Tabla 1. Longitud de los vasos del xilema del tallo en los genotipos de manzana columnar y estándar.

Number	Variety (Combination)	Type	Length of the vessel element (μm)		
			Average	Max	Min
1	Fuji × Telamon	Standard	243.359b	482.485	111.691
2	Gala × Telamon	Standard	253.875b	518.067	105.897
3	Fuji	Standard	260.776b	443.888	110.093
4	Fuji × Telamon	Columnar	240.747b	384.116	101.233
5	Gala × Telamon	Columnar	218.674c	470.394	103.748
6	Telamon	Columnar	293.383a	485.454	116.505

Different letters a, b and c represent significant differences at p=0.05.
Letras a, b y c representan diferencias significativas a p=0,05.

Comparison of vessel diameter on two types of apple shoots. The average vessel diameters of columnar apple shoots were significantly larger ($p<0.05$) than those on standard apple shoots. Significant differences ($p<0.05$) in vessel diameters were also found within the same type of apple shoots (Table 2).

Table 2. Comparison of vessel diameters on shoot xylems of columnar and standard apples.
Tabla 2. Comparación del diámetro de los vasos del xilema del tallo en genotipos de manzana columnar y estándar.

Number	Variety (Combination)	Type	Diameter of the vessel element (μm)		
			Average	Max	Min
1	Fuji × Telamon	Standard	35.345c	51.712	17.476
2	Gala × Telamon	Standard	32.255d	53.886	11.989
3	Fuji	Standard	30.318e	46.078	13.062
4	Fuji × Telamon	Columnar	43.830a	57.226	22.230
5	Gala × Telamon	Columnar	41.638b	59.653	26.096
6	Telamon	Columnar	44.345a	66.021	22.862

Different letters a, b, c, d and e represent significant differences at p=0.05.
Letras a, b, c, d y e representan diferencias significativas a p=0,05.

DISCUSSION

There were more reticulate vessel elements, thinner secondary walls and less abnormal vessel elements in columnar than standard apples. These characteristics made horizontal or vertical translocation of water and minerals relatively smoother in columnar than standard apple trees. Results of Zhang et al. (2010) and Zhang & Dai (2011) contributed to explain that these differences of xylem vessel size were involved in the greater capability of columnar apple for transporting water and minerals, and having a greater photosynthetic efficiency than standard apple; also, columnar apple showed earlier flowering and fruiting, and higher yields (Zhang et al., 2010; Zhang & Dai, 2011).

The larger the diameter of xylem vessels, the higher the transportation efficiency (Zimmermann, 1983). This theory is now generally accepted. However, there are still different points of view about the relationship between vessel length and water transport: Baas et al. (1983) believed that rather than the length of a single vessel element, it was the total xylem vessel length that related directly to water transport efficiency. Carlquist (1975) pointed out that the longer the xylem vessel, the smaller the resistance to water transport. The relationship between vessel element length and apple architecture type still needs further study.

The diameter of xylem vessels was larger in columnar than standard apple trees. This would help the capability of transporting water and minerals, and improving transport efficiency more in columnar than in standard apple. A greater water and mineral transport from roots to leaves will subsequently benefit photosynthesis. Our results also implied that columnar apple trees had a shoot microstructure to foster early flowering and fruiting (Zhang et al., 2010; Zhang & Dai, 2011).

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