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Root Architecture, Leaf Nutrient Levels and Photosynthesis of Columnar and Standard Apple Seedlings are different

Shaoxia Guo[1], Xin Sun[2], Yuanxia Liu[2], Jun Zhu[2], Lu Zhang[2],
Hongyi Dai[2], Yugang Zhang[2,3*]

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Abstract

The columnar apple tree is a valuable apple breeding resource, which differs from the standard apple tree in tree architecture. In this study, we used two-year-old F_1 seedlings of columnar and standard apple trees to study their differences in root architectures, nutrient uptake and photosynthesis. The results showed that 1) the numbers of root tips, forks and crossings of the columnar trees were significantly higher than those of the standard trees; 2) F_1 progenies of columnar genotypes had more average root tip numbers, total root lengths and root volumes than those of the two standard genotypes; 3) leaves of the columnar trees had significantly higher (1.77-2.34-fold) Ca, Mg, Fe, Zn and Cu concentrations than the leaves of standard trees, and macronutrient K concentration for standard trees was higher (1.03-1.1-fold) than for columnar trees; 4) leaves of the columnar trees had significantly higher chlorophyll a, chlorophyll b and chlorophyll a+b concentrations; 5) diurnal variations of both net photosynthetic rate (Pn) and transpiration rate (Tr) showed bimodal curves with a “siesta” phenomenon, and Pn and Tr of the two columnar genotypes were higher than those of the standard trees.

The columnar apple tree is a valuable apple breeding resource and has many characters different from the standard apple tree, such as natural single stem shape, compact structure, dwarf main stem, short internodes and fewer long-branches among other notable features. We previously conducted a series of preliminary experiments on columnar apple breeding (Dai et al., 2003) and studied the anatomical structures of roots, stems and leaves (Zhang et al., 2011b; Zhang et al., 2012a) and expression of genes related to its columnar features (Zhang et al., 2012b; Wang et al., 2014; Han et al., 2012; Bai et al., 2012).

Plant root morphology and architecture are closely related to water absorption and mineral uptake, and roots influence the tree structure and mechanical support for the tree (Li et al., 2016; Zhao et al., 2015; Smith et al., 2012). Many scholars have studied the root architectures and mineral absorption of maize (Cai et al., 2014), bluegrass (Sullivan et al., 2000) and wheat (Dong et al., 1995). In addition, the root architecture of white clover is also affected by *arbuscular mycorrhizal* fungi (Wu et al., 2014). The mineral nutrition of apple trees influences fruit quality and growth, and different rootstocks and interstocks have a major effect on nutrient content of apple fruits (Chen et al., 2010; Ma et al., 2010; Xue et al., 2012; Zhang et al., 2011a; Zhang et al., 2014). The columnar tree is a type of apple tree with high photosynthetic efficiency and is suitable for high-density planting and orchard mechanization,

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[1] College of Landscaping and forestry, Qingdao Agricultural University, Qingdao, 266109;
[2] College of Horticulture, Qingdao Agricultural University, Qingdao, 266109;
[3] Qingdao Key Laboratory of Genetic Improvement and Breeding in Horticultural Plants, Qingdao, 266109;
[*] Corresponding author: Email: ygzhang@qau.edu.cn

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which is in line with the patterns and trends of high-density planting. In this study, we used two types of hybrid columnar apple seedlings and two types of standard apple seedlings to evaluate differences in root architecture, mineral uptake and photosynthesis, with the hope of further understanding the relationship between tree architecture and tree physiological metabolism.

Materials and Methods

Materials. The experimental materials were 2-year-old hybrid seedlings of ACo, ASt, BCo and BSt, which were planted in the greenhouse of Jiaozhou Experiment Station of Qingdao Agricultural University (JESQAU). Seedlings were grown in 20 cm×30 cm nutrition pots, spaced 20 cm between pots, and the media was 2 natural soil: 1turfy soil: 1earlite: 1 vermiculite (by volume), and were fertilized with 50-80 g urea fetilizer per tree for three times during the growing season. ACo was the columnar F_1 progeny of 'Shinsekai' and '94-12'; BCo was the columnar F_1 progeny of 'Golden Delicious' and '94-12'; ASt was the standard F_1 progeny of 'Shinsekai' and '94-12'; and BSt was the standard F_1 progeny of 'Golden Delicious' and '94-12'. The '94-12' was a columnar apple strain bred by our group. 'Shinsekai' and 'Golden Delicious' are standard apple cultivars. After stratification, 1023 hybrid seeds of two combinations (A and B) were sown in the greenhouse. Two years later, when the seedlings could be distinguished as columnar or standard, a total of 6 seedlings per progeny were randomly selected and marked for the study. Therefore the experimental design was considered completely randomized.

Determination of photosynthetic parameters. Using the selected 24 seedlings, the fifth functional leaf from the top of each seedling was marked and measured every hour from 800 – 1800HR on three sunny days in the mid-June. The photosynthetic parameters including net photosynthetic rate (Pn, $\mu mol \cdot m^{-2} \cdot s^{-1}$), transpiration rate (Tr, $mmol \cdot m^{-2} \cdot s^{-1}$), stomatal conductance (Gs, $mmol \cdot m^{-2} \cdot s^{-1}$) and intercellular CO_2 concentration (Ci, $\mu mol \cdot mol^{-1}$) were measured using a CIRAS-3 portable photosynthesis meter (PP SYSTEMS). Following gas exchange measurements, half of the marked leaves were used to measure chlorophyll concentration, and the other half were used to measure mineral elements.

Determination of chlorophyll concentration. Pigments were extracted from 0.5 g of marked leaves using 80% acetone and a suitable amount of $CaCO_3$. Chlorophyll a and chlorophyll b concentrations were measured using a UV-2100 spectrophotometer as previously reported (Sun et al., 2010).

Measurement of leaf mineral elements. After drying at 80°C in an oven for three days, 0.5 g of marked leaves was used to measure P, K, Ca, Mg, Fe, Mn, Cu, Zn and Na concentrations using microwave digestion with HNO_3/ $HClO_4$ solution followed by inductively coupled plasma atomic emission spectrometry (ICP-OES) (Wei et al., 2011). Total N concentration was measured using the Kjeldahl method (Zhang et al, 2014).

Root architecture analysis. Six seedlings of ACo, ASt, BCo and BSt were selected in mid-June. Three days later after watering, they were harvested with intact root systems using a spade. After washing with distilled water, the intact root images were obtained using the flatbed scanner of V700/WinRHIZO analyzer (Seiko Epson Company) and analyzed using WinRHIZO root analysis software to obtain the root architecture parameters including length, area, volume, and number of root tips, number of branches and number of crossings.

Statistical analyses. Statistical analyses were performed using the SAS system software (SAS 9.3, SAS Institute, Cary, N.C.). Data for most response variables were analyzed with a one-way analysis of variance (ANOVA). Photosynthesis data were analyzed with repeated measures ANOVA with PROC MIXED and LSmeans were compared with DIFF.

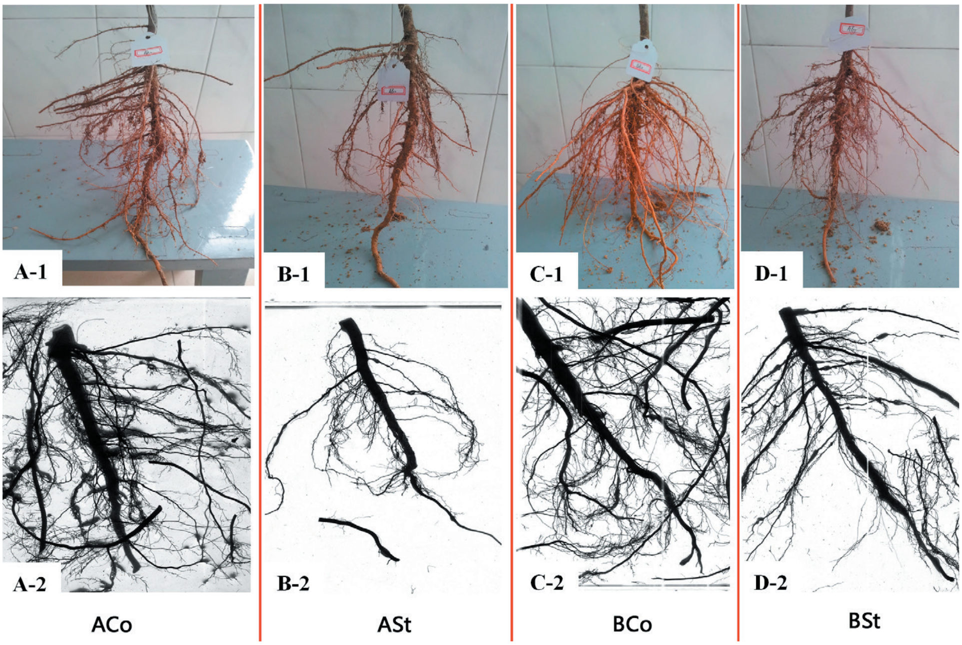

Fig. 1. Photographs (top) and scans (bottom) of root systems of four progenies of columnar and standard apple trees.

Results

Root architecture appearance. Root images clearly show differences in the root architectures between the standard and columnar apple trees (Fig.1). The two columnar F_1 progenies ACo and BCo (Figure 1-A, 1-C) had obviously more lateral roots and fibrous roots than the standard F_1 progenies ASt and BSt (Figure. 1-B, 1-D), although their taproots were not different. These phenomena in the fibrous roots were more clear in the scan images of root system (Figures A-2, B-2, C-2 and D-2), indicating that columnar apple trees had more developed fibrous roots than the standard apple trees.

Root architecture parameters. The two columnar F_1 progenies had significantly more root tips, forks and crossings than the two standard F_1 progenies (Table 1). The average numbers of root tips of the two columnar F_1 progenies ACo and BCo were 1.22- and 2.52-fold greater than those of the two stan-

Table 1. Numbers of the root tips, forks and crossings of roots for four progenies of columnar and standard apple trees.

Combination of F_1 progeny	F_1 progeny type	Root tip number	Root fork number	Root crossing number
'Shinsekai'	Columnar (ACo)	3873.7b[z]	9072.5b	1389.2b
× '94-12'	Standard (ASt)	3175.8d	6671.5d	1039.0d
'Golden Delicious'	Columnar (BCo)	5477.0a	13018.0a	2034.4a
× '94-12'	Standard (BSt)	3598.1c	8429.2c	1277.2c

[z] Means within columns followed by common letters do not differ at the 5% level of significance, by LSD.

dard F_1 progenies ASt and BSt, respectively. The number of root tips was highest for BCo (5477.0), and lowest for ASt (3175.80). The numbers of forks and crossings were proportional to the number of root tips among the same type of apple trees, and BCo had the highest number of forks and crossings among the four types.

The total root length also differed significantly for columnar and standard trees (Fig. 2). The total root lengths of the two columnar progenies ACo and BCo were 1.18- and 1.59-fold greater than the two standard F_1 progenies ASt and BSt, respectively. The total root length was highest for BCo, (1833.76 cm), and lowest for ASt (1020.11cm). Of the four types of seedlings, the length of roots with diameter of 0-0.5 mm accounted for 73.8%, 73.9%, 75.7% and 75.1% of the total root length for ACo, ASt, BCo and BSt, respectively, whereas the length of roots with diameter greater than 4.5 mm accounted for only 1.0-2.1% of the total root length.

The root surface areas of columnar and standard apple trees were significantly different (Fig. 3). The root surface areas of the two columnar progenies ACo and BCo were 1.16- and 1.45-fold greater than the two standard progenies ASt and BSt, respectively. The root surface area of BCo was the largest (290.04 cm^2), and that of ASt was the smallest (188.79 cm^2). Although the four types of seedlings had varied root surface areas in different ranges of root diameter, their performance was similar. In other words, the surface of roots with diameters of 0-0.5 mm was the largest, followed in turn by the roots with diameter of greater than 4.5 mm, 0.5-1.0 mm and 4.0-4.5 mm.

Root volume was larger for columnar trees than for standard trees (Fig. 4). The root volumes of the two columnar progenies ACo and BCo were 1.16- and 1.46-fold higher than for the two standard progenies ASt and BSt. BCo had the greatest root volume (18.10 cm^3), and BSt had the least root volume (12.39 cm^3).

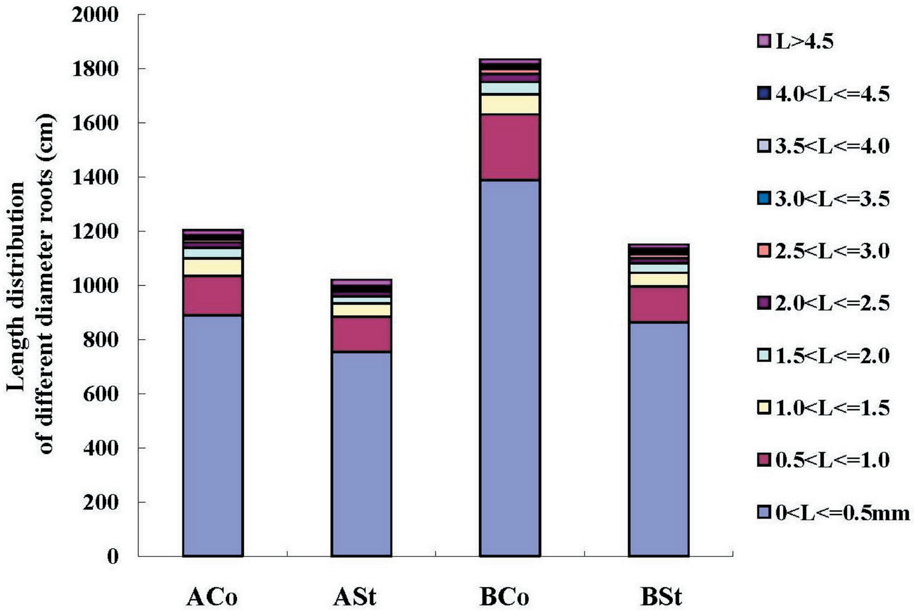

Fig. 2. Length of roots with different diameters for four progenies of columnar and standard apple trees.

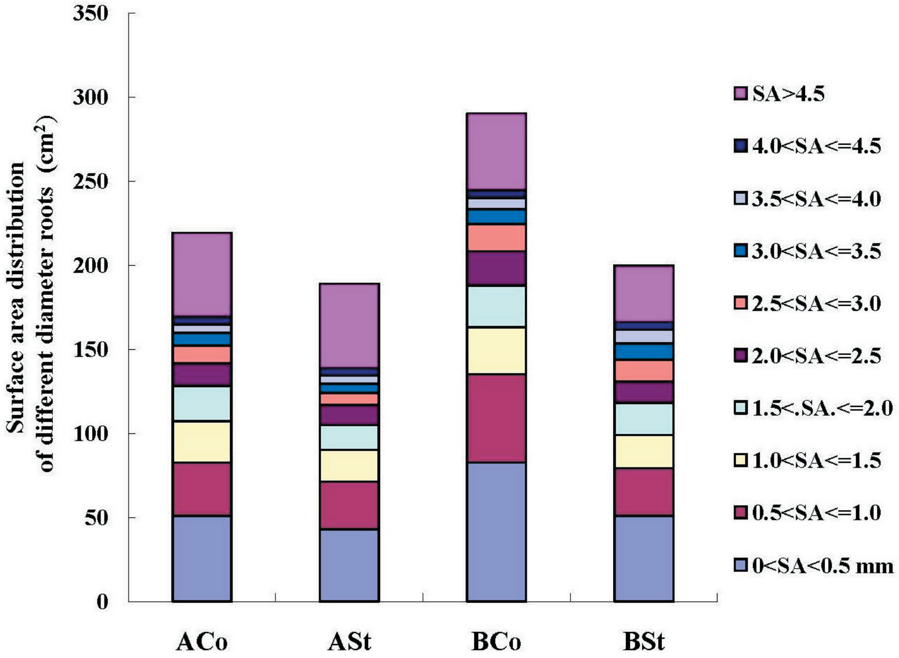

Fig. 3. Surface area of roots with different diameters for four progenies of columnar and standard apple trees.

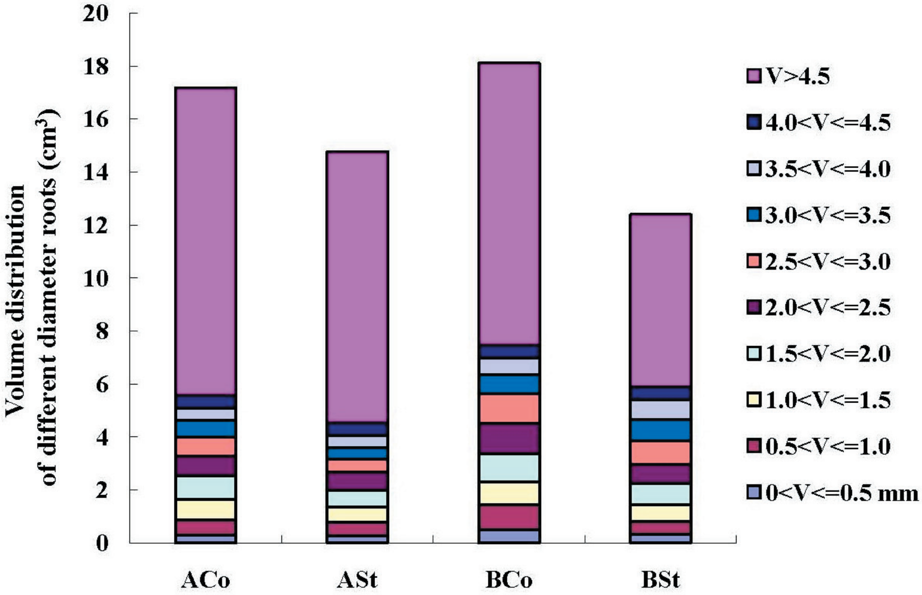

Fig. 4. Volume of different diameter roots of four progenies of columnar and standard apple trees.

Table 2. Leaf mineral concentrations for four progenies of columnar and standard trees

F1 progeny type	N	P	K (g·Kg^{-1})	Ca	Mg	Fe	Mn	Zn (mg·Kg^{-1})	Cu	Na
ACo	4.70b[z]	1.00b	1.47b	5.31b	0.57a	65.27b	27.40c	16.57a	6.60b	35.04bc
ASt	3.83c	1.43a	1.51a	2.27d	0.41b	60.03c	23.17d	14.45c	5.71c	30.33c
BCo	4.96b	1.43a	1.34c	6.88a	0.56a	70.44a	49.59a	16.67a	7.90a	36.33b
BSt	5.71a	1.43a	1.47b	3.89c	0.38b	61.07c	46.71b	14.79bc	6.29bc	41.48a

[z] Means within columns followed by common letters do not differ at the 5% level of significance, by LSD.

The volume of roots with diameter greater than 4.5 mm accounted for 67.6%, 69.2%, 58.8% and 52.5% of the total root volume of ACo, ASt, BCo and BSt, respectively. In addition, the root volume of columnar trees of the same diameter was 0.02-0.63 times greater than that of the standard trees.

Leaf mineral concentrations. The leaf mineral concentrations varied significantly between different types of apple trees (Table 2). The trends of macronutrients Ca and Mg as well as trace elements Fe and Cu were similar, with significantly higher concentrations in columnar leaves than in standard leaves. Ca concentration in columnar leaves was 1.77-2.34 times greater than in standard leaves. Mn and Zn concentrations were also higher in columnar leaves than in standard leaves. By contrast, the K concentration in standard leaves was 1.03-1.1-fold higher than in columnar leaves. The concentrations of N, P and Na were not significantly influenced by tree type. The order of N concentration was BSt> BCo> ACo> ASt whereas the order of P content was ASt = BCo = BSt> ACo.

Leaf chlorophyll concentrations. Chlorophyll concentrations were significantly influenced by tree architecture type (Table 3). The two columnar progenies had much higher chlorophyll a, chlorophyll b and chlorophyll a+b concentrations than the two standard progenies. In addition, the external leaf morphology and color also reflect the differences between columnar and standard trees. The average leaf mass and thickness were greater for columnar trees than for standard trees (data not shown) and the leaves were also darker green for columnar trees than for standard trees.

Diurnal variation of net photosynthetic rate (Pn) and transpiration rate (Tr). During the growing season, the diurnal net photosynthesis of new leaves showed similar bimodal curves with a "siesta" phenomenon at noon in all progeny (Table 4). Pn first peaked at1100HR, then declined until 1300-1400HR, and started to increase again, reaching a second peak at 1500HR. In the diurnal variation of the day, the two columnar progenies had significantly higher Pn than the two standard

Table 3. Leaf chlorophyll concentrations for four progenies of columnar and standard apple trees

Combination of F_1 progeny	F_1 progeny type	Chlorophyll a conc. (mg·g^{-1})	Chlorophyll b conc. (mg·g-1)	Chlorophyll a+b conc. (mg·g^{-1})
'Shinsekai' × '94-12'	Columnar (ACo)	1.352±0.069b[z]	0.447±0.016a	1.886±0.065b
	Standard (ASt)	0.987±0.122d	0.301±0.048c	1.272±0.213d
'Golden Delicious' × '94-12'	Columnar (BCo)	1.401±0.148a	0.481±0.035a	1.911±0.183a
	Standard (BSt)	1.190±0.138c	0.373±0.045b	1.591±0.165c

[z] Means within columns followed by common letters do not differ at the 5% level of significance, by LSD.

Table 4. Hourly photosynthetic rates (Pn, $\mu mol\cdot m^{-2}\cdot s^{-1}$) of four progenies of columnar and standard apple trees

F1 progeny	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
ACo	7.9±0.59b[z]	9.8±0.68c	14.4±0.84b	15.7±1.47b	13.8±1.08b	8.3±0.63b	6.8±0.48c	10.8±0.978c	7.7±0.57b	6.2±0.72b	4.8±0.38a
ASt	5.3±0.33d	8.6±0.86d	11.3±0.63c	12.9±1.09c	11.9±1.19c	6.8±0.78c	6.4±0.54c	9.5±0.95d	6.6±0.46c	5.1±0.51c	3.3±0.33bc
BCo	9.1±0.53a	12.8±0.74a	15.3±1.49a	18.6±1.38a	15.3±0.89a	12±1.40a	10.6±0.61a	15±1.37a	8.9±0.52a	7.6±0.44a	3.8±0.22b
BSt	6.2±0.36c	11.1±0.64b	14.2±0.82b	15.2±0.98b	13.9±0.81b	8.2±1.78b	7.6±0.54b	11±1.64bc	8.5±0.49a	7.4±0.43a	2.9±0.17c

[z] Means within columns followed by common letters do not differ at the 5% level of significance, by LSD.

Table 5. Hourly transpiration rates (Tr, $mmol\cdot m^{-2}\cdot s^{-1}$) of leaves of four progenies of columnar and standard apple trees

F1 progeny	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00
ACo	2.7±0.28b[z]	3.3±0.13b	3.7±0.35b	4.2±0.20b	3.6±0.24a	2.8±0.19ab	2.6±0.22b	3.3±0.23b	2.8±0.26a	2.1±0.19b	1.5±0.11c
ASt	2.4±0.23c	2.9±0.19c	3.2±0.27c	3.5±0.25d	3.1±0.22b	2.4±0.21c	2.1±0.17d	3.0±0.20c	2.1±0.14bc	2.1±0.18b	1.4±0.10c
BCo	3.1±0.27a	3.6±0.35a	4.0±0.18a	4.6±0.35a	3.6±0.16a	3.0±0.23a	2.9±0.26a	3.6±0.26a	2.8±0.25a	2.2±0.20a	1.8±0.15b
BSt	2.9±0.28ab	3.0±0.20c	3.5±0.22 b	3.9±0.29bc	2.7±0.26c	2.6±0.27b	2.4±0.18bc	3.2±0.26bc	2.3±0.20b	2.0±0.16b	2.0±0.17a

[z] Means within columns followed by common letters do not differ at the 5% level of significance, by LSD.

progenies. In addition, the decrease of Pn from the first peak to the "siesta" at noon was slower for columnar trees than for standard trees, and most obvious in BCo.

Net photosynthetic rate is usually positively related to transpiration rate. The diurnal Tr followed a similar pattern as Pn for both columnar and standard apple trees, showing bimodal curves with a "siesta" phenomenon (Table 5). In the diurnal variation of the day, the two columnar progenies had higher Tr than the two standard progenies.

Discussion

The columnar apple tree is a valuable resource for genetic improvement of new apple cultivars due to its special architecture, which is important for crop yield, quality, and cultivation. Tree architecture also affects root architecture, mineral uptake and photosynthesis of apple trees. Compared with standard trees, columnar trees had more fibrous roots. The average number of root tips and total root length of columnar trees were 1.22-1.52-fold and 1.18-1.59-fold greater than those of standard apple trees, respectively. The root tips contain a large amount of root hairs and are important for absorption of water and mineral elements. The fact that columnar trees had more root tips provides a foundation for its high efficient absorption of mineral elements. Analyses of root and stem architecture showed that the diameters of root and stem xylem vessels of the columnar trees were greater than those of the standard apple trees. In addition, columnar trees had normal stem xylem vessel morphology, whereas the standard trees had more deformed stem xylem vessels (Zhang et al., 2012a). Stem xylem vessels with larger diameter provide a basis for efficient transport of mineral elements in columnar trees (Zhang et al., 2011b). Many factors affect the absorption and uptake of mineral nutrition in plants (Zouar, et al., 2016; Quirantes, et al., 2016; Li et al., 2016). The leaf mineral Ca, Mg, Fe, Cu, Mn and Zn concentrations in the columnar trees were significantly higher than those in the standard trees, which might be related to the root architectures as well as the root and stem xylem vessels. In addition, relatively wider xylem vessels in columnar trees may have also enhanced the upward transportation ability, thus resulting in increased concentrations of leaf Ca, Mg, Fe, Cu and other mineral elements. By contrast, leaf K concentration in the columnar trees was significantly lower than that in the standard apple trees, which was possibly related to its own regulation. The detailed underlying mechanisms need to be further studied. The concentrations of N and P were similar for both tree types in this study. Xiao et al. (2014) showed that root architecture of young peach trees was significantly associated with nitrogen metabolism. Sullivan et al. (2000) showed that the blue-grass roots with larger surface area can absorb more nitrogen. Fan and Yang (2014) showed that *Malus hupehensis* seedlings with more lateral roots could absorb more P and K. Our results were inconsistent with the above-mentioned studies, presumably because of the difference in the test materials.

Chlorophyll concentrations were closely related to photosynthesis. The concentrations of chlorophyll a, chlorophyll b as well as chlorophyll a+b were significantly higher in columnar leaves than in standard leaves, in agreement with higher Pn and Tr rates in columnar leaves than in standard leaves. Columnar trees have higher luminous efficiency and leaf area index than standard trees (Zhang et al., 2011b). Higher Pn and Tr not only increased the transpiration force of columnar leaves, but also enhanced the absorption of water and mineral elements. Mg, Fe, Zn, Cu, Mn and other elements were closely related to photosynthesis. Deficiencies of these elements can significantly inhibit photosynthesis, which was also proved by the correlation between the concentrations of Mg, Fe, Zn, Cu, and Mn with chlorophyll concentrations (data not shown).

Different types of apple trees have different root architectures, which affect mineral uptake and leaf photosynthesis. The root system and leaves in columnar apple trees leads to more efficient photosynthesis as well as higher absorption and utilization of mineral elements than those of the standard apple trees.

Literature Cited

Bai, T.H., Y.D. Zhu, F. Fernández-Fernández, J. Keulemans, S. Brown, and K.N. Xu. 2012. Fine genetic mapping of the *Co* locus controlling columnar growth habit in apple. Mol. Genet. and Genomics. 287: 437-450.

Cai, H.G., J.Z. Liu, X.Z. Zhang, X.G. Yan, H.X. Zhang, J.C. Yuan, J.H. Gai, and J. Ren. 2014. Root morphology and its response to planting density in different genotypes with root architecture. J. Maize Sci.. 22: 81-85.

Chen, X.S., M.Y. Han, G.L. Su, F.Z. Liu, and H.R. Su. 2010. Discussion on today's world apple industry trends and the suggestions on sustainable and efficient development of apple industry in China. J. Fruit Sci. 27: 598-604.

Dai, H.Y., C.H. Wang, B. Chi, J. Zhu, R. Wang, G.X. Li, and L.L. Zhuang. 2003. Report on breeding columnar apple varieties. J. Fruit Sci. 20: 79-83.

Dong, B., Z. Rengel, and R.D. Graham. 1995. Root morphology of wheat genotypes differing in zinc efficiency. J. of Plant Nutr. 18: 2761-2773.

Fan, W.G. and H.Q. Yang. 2014. Response of root architecture, nutrients uptake and shoot growth of *Malus hupehensis* seedling to the shape of root zone. Scientia Agr. Sinica 47: 3907-3913.

Han, F.,H.Y. Dai, and Y.G. Zhang. 2012. Cloning and bioinformatic analysis of *MdSCR* gene of *GRAS* gene family in columnar apple. J. of Qingdao Agr. Univ.. 29: 196-200, 2012.

Li, X.X., Z.S. Zeng, and H. Liao. 2016. Improving crop nutrient efficiency through root architecture modifications. Journal of Integrative Plant Biol. 3:193-202.

Ma, B.K., J.Z. Xu, and J.S. Sun. 2010. Consideration for high density planting with dwarf rootstocks in apple in China. J. Fruit Sci. 27: 105-109.

Quirantes, M., F. Calvo, E. Romero, and R. Nogales. 2016. Soil-nutrient availability affected by different biomass-ash applications. J. Soil Sci. Plant Nutr.1:159-163.

Smith, S. and I.D. Smet. 2012. Root system architecture, insights from *Arabidopsis* and cereal crops. Philosophical Trans. Royal Soc. *B*. 367: 1441-1452.

Sullivan, W.M., Z.C. Jiang, and R.J. Hull. 2000. Root morphology and its relationship with nitrate uptake in Kentucky bluegrass. Crop Sci. 40: 765-772.

Sun, S., Z. Zhang, M. Lu, and G.M. Xing. 2010. Effects of cadmium stress on photosynthesis and active oxygen metabolism in the leaves of small watermelon seedlings. J. Nuclear Agr. Sci.. 24: 389-393.

Wang, C.H., M.D. Bai, Y.K. Tian, and W. Tian. 2014. Characterization of two genes encoding cytochrome P450 mono-oxygenases involved in gibberellin biosynthesis in apple (*Malus* × *domestica* Borkh.). J.

Hort. Sci. and Biotechnol. 89: 329-337.

Wei, Y.S., J.G. Ning, and M.Y. Zheng. 2011. Determination of mineral elements of *Rhodiola Kirilowii* by the method of microwave digestion and ICP-OES. Appl. Chem. Ind. 40: 728-730.

Wu, Q.S., F.Y. Yuan, Y.J. Fei, L. Li, Y.M. Huang, and C.Y. Liu. 2014. Effects of arbuscular mycorrhizal fungi on root system architecture and sugar contents of white clover. Acta Prataculturae Sinica 23: 199-204.

Xiao, Y.S., F.T. Peng, Y.F. Zhang, Y.J. Qi, G.F. Wang, X.L. Wang, and H.R. Shu. 2014. Effects of aeration cultivation on root architecture and nitrogen metabolism of young peach trees. Sci. Agr. Sinica 47: 995-2002.

Xue, X.M., C. Lu, J.Z. Wang, G.H. Yu, and P.G. Wang. 2012. Impacts of dwarf interstocks on growth and fruit quality of apple trees. Deciduous Fruits. 44: 5-7.

Zhang, Q., Q.P. Wei, R.S. Jiang, X.D. Liu, H.P. Liu, and X.W. Wang. 2011a. Correlation analysis of fruit mineral nutrition contents with several key quality indicators in "Fuji" apple. Acta Hort. Sinica 38: 1963-1968.

Zhang, X.Z., J.Y. Guo, Y.Z. Wang, C.L. Liu, and Y.B. Yuan. 2014. Effects of different rootstocks on mineral contents and fruit qualities of Fuji apple. J. Plant Nutr. and Fert. 20: 414-420.

Zhang, Y.G. and H.Y. Dai. 2011b. Comparison of photosynthetic and morphological characteristics, and microstructure of roots and shoots, between columnar apple and standard apple trees of hybrid seedlings. Phyton Intl. J. Ext. Bot. 80: 119-125.

Zhang, Y.G. and H.Y. Dai. 2012a. Morphological differences of the vessel in secondary xylem of columnar and standard apple trees. Phyton Intl. J. Expt. Bot. 81: 229-232.

Zhang, Y.G., J. Zhu, and H.Y. Dai. 2012b. Characterization of transcriptional differences between columnar and standard apple trees using RNA-Seq. Plant Mol. Biol. Rep. 30: 957-965.

Zhao, Y.Y., Z.H. Lu, J.B. Xia, and J.T. Liu. 2015. Root architecture and adaptive strategy of 3 shrubs in Shell Bay in Yellow River Delta. Acta Ecologica Sinica. 3:602-603.

Zouar, M., N. Elloumi, C.B. Ahmed, D. Delmail, B.B. Rouina, F.B. Abdallah, and P. Labrousse. 2016. Exogenous proline enhances growth, mineral uptake, antioxidant defense, and reduces cadmium-induced oxidative damage in young date palm (*Phoenix dactylifera* L.). Ecol. Eng. 86:202-209.

Correction

In volume 71(2), in the article by Do Su Park, Shimeles Tilahun, Jae Yun Heo, Kyong Cheul Park and Cheon Soon Jeong "Effect of 1-MCP on persimmon fruit quality and expression of ethylene response genes during ripening", the temperature at which persimmon fruit were ripened is incorrect in the captions for Figures 1 – 6. The ripening temperature was 25°C.