

# Influence of two training systems on growth, yield and fruit attributes of four apple cultivars grafted onto 'M.9' rootstock

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All relevant data are within the paper and its Supporting Information files.

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**Abstract:** This research was carried out to compare several attributes pertaining to the growth, fruit and yield of four apple cultivars, i.e. 'Golab-kohans', 'Fuji', 'Starking' and 'Delbar estival'. These cultivars were grafted onto M.9 rootstocks trained into 'Guttingen V-slender-spindle (or V-system) and 'Geneva Y-trellis (or Y-system) systems. Compared to the Y-system, it was observed that the V-system caused the trees to yield more fruits, dry matter, ash and total soluble solids (TSS). In contrast, the Y-system caused the trees to have broader trunk cross sectional areas (TCSA), along with higher yield, fruit weight, fruit diameter, fruit length and fruit firmness, compared to trees trained with the V-system. In summary, these results showed that both systems can be employed as promising approaches, but the 'Y-system' appears to be more productive than the 'V-system'. In addition, among the studied cultivars, it seems that the 'Delbar estival' and 'Fuji' were more adaptive to these intensive training systems, especially when considering the fruit traits.

## 1. Introduction

Intensive training systems are particular layouts that assist orchard managers in improving the productivity of orchards (Ferree and Warrington, 2003). The need to improve training and pruning methods can better fit the natural growing conditions, and this can be associated with higher fruiting performances by the fruit trees (Lauri, 2009). Thus, modern apple orchards are planned on the basis of higher tree density than that of traditional planting systems which use dwarfing apple rootstocks (Ferree and Warrington, 2003). Dwarfing rootstocks are increasingly becoming prevalent among the sectors of the fruit industry. They are an important factor that improve orchard productivity due to their significant effects on agro-morphological characteristics such as the yield

(Barritt *et al.*, 1995). The Guttingen-V system, the Y-system (Tatura), the Drilling system, and the Mikado system are the most popular V-shaped canopy systems, and are suggested as promising alternatives to high density orchards (Robinson, 2000). Dwarfing rootstocks, such as M.9 and M.27, are generally employed in V-shaped systems (Ferree and Warrington, 2003). V systems allow better light penetration than other training-shaped trees (Robinson, 2003). The 'Geneva Y-trellis' system is a V-shaped system which uses a Y shaped trellis to support the trees. The 'Guttingen V-slender-spindle' system includes individual conic-shaped trees allowing high tree densities within multiple rows. It has been reported that the Guttingen V causes the production of higher yield per hectare and thinner trunks, compared to the drilling system (Sosna and Czaplicka, 2008). Many investigations have shown that there are significant differences between local and foreign apple cultivars in terms of growth and productivity (Dadashpour *et al.*, 2010; Dadashpour *et al.*, 2011). Such reports also indicate the same with regard to apricot (Strikic *et al.*, 2007) when trained by intensive training systems. Recently, it has been reported that rootstocks and training forms have significant effects on the vegetative growth, yield and fruit traits of apple cultivars (Alizadeh and Pirmoradian, 2016). It has been reported that the efficiency of several parameters can be improved by more production or by the reduction in tree size (Fioravanco *et al.*, 2016). When apple scions are grafted onto dwarfing and semi-dwarfing rootstocks, they usually produce larger fruits and more yield, compared to when scions are grafted onto non-dwarfing rootstocks (Perry and Byler, 2001; Gjamovski and Kiprijanovski, 2011). Negligible differences have been reported in the cumulative yield among 'slender spindle', 'Hybrid Tree Cone' ('HyTec') and 'vertical axis' (Crassweller and Smith, 2004). Rutkowski *et al.* (2009) studied nine training systems for apple trees, and reported that the growth and yield of trees may be more dependent on genetic traits, while the shapes of trees can modify the skeletal structure of an orchard. To this end, Gonkiewicz (2011) showed that trees having spindle shapes can produce the best yield and fruit weight among the studied pruning systems in sweet cherry. By studying the 'Fuji' apple, grafted onto the M.9 rootstock under five training systems, Ozkan *et al.* (2016) reported that there were significant differences among the studied training systems in relation to canopy volume, trunk-cross sectional area (TCSA), yield, yield efficiency and fruit size.

With 2.8% of the total harvestable area (134,000 ha) and 2.2% of the total production (1.7 million tons) in the world, Iran is among the largest producers of apple after China, USA, Turkey, Poland, India and Italy (Faostat, 2012). The majority of apple orchards in Iran are traditional ones. They are characterized by low tree densities and are commonly grown on seedling rootstocks. However, semi-intensive and intensive apple orchards are recently becoming popular among apple growers. 'Golden Delicious' and 'Red Delicious' are two apple cultivars that are planted in about 90% of cultivated areas. Meanwhile, the early ripening cultivar 'Golab-Kohans' is the most prevalent, native apple cultivar in Iran. It provides the summer demand for fresh apples in the market. Furthermore, 'Granny Smith', 'Fuji', 'Gala', 'Jonagold', and 'Braeburn' are increasingly becoming popular in the country (Gharaghani *et al.*, 2015).

As the apple industry in Iran is about to shift dramatically from traditional to modern production systems, e.g. semi-intensive and intensive orchard, it is important and necessary to study the performance of popular apple cultivars on different rootstocks, especially within the context of various training systems. Accordingly, the objective of this study was to evaluate two training systems, i.e. 'Guttingen V-slender-spindle' and 'Geneva Y-trellis', and compare their effects on growth characteristics, yield and fruit quality of four apple cultivars. Their scions were grafted onto M.9 rootstocks in the Alborz Province of Iran.

## 2. Materials and Methods

### *Plant materials and experimental design*

This research was conducted at an experimental field belonging to a horticultural research station, Karaj, Iran. The duration of the entire experiment took from 2007 to 2010. The average maximum temperature of the region is 13.7°C, with an annual rainfall of 254 mm. The soil in the region is classified as clay-loam. The experiments were arranged as split-plot (main plot: training system; split-plot: cultivar) according to a randomized complete block design (RCBD) with four replicates. Four apple cultivars were used, i.e. 'Delbar estival', 'Fuji', 'Golab-kohans' and 'Starking', and their scions were grafted onto dwarfing M.9 rootstocks. All trees were planted in March 2005, and trellis systems were established in June 2006. The trees were trained into two training systems, i.e. 'Guttingen V-slender-spindle' (V-system) (0.9×3.7 m or 3000 trees/ha) and 'Geneva Y-trellis'

(Y-system) (1.6×3.7 m or 1680 trees/ha), based on the relevant protocols described by previous research on apples (Robinson, 2003). Drip-irrigation was scheduled to operate twice a week. The soil was fertilized once in every season and was managed according to the common practice in the region. Trees received their first fertilizers in the second year after planting. They were pruned during the winters, but the amount of wood being removed by pruning was not documented. Fruit thinning was performed if necessary. The fruits were harvested manually. Twenty representative trees within each replicate were selected for sampling and data collection.

**Agro-morphological and yield traits**

To calculate the Trunk Cross Sectional Area (TCSA), the trunk circumference was measured (20 cm above the graft union) from both sides (north-south) with a hand caliper. This was performed at the end of the growing season in the November of 2007, 2008, 2009 and 2010. The average measurement of the two sides on the trunk were taken to make trunk diameter (R) and “Area= πr<sup>2</sup>”. A formula assisted in calculating the TCSA in cm<sup>2</sup>. In addition, the cumulative yield per tree and per hectare were recorded at harvest time (kg/tree and kg/ha). The yield efficiency was defined as “yield per tree divided by TCSA (kg/cm<sup>2</sup>)”.

**Fruit properties**

All attributes pertaining to fruit traits were measured using 5 randomly-sampled fruits from each test tree. Then, their average was recorded. The individual fruit length, the fruit diameter and the ratio of length to diameter (L/D) were calculated by a vernier caliper. The fruits fresh weight was determined using

a Mettler PC 8000 scale. In addition, fruit firmness was measured using a penetrometer (Instron Universal Machine, Model 1011) and recorded as kg.cm<sup>-2</sup>. Total soluble solids (TSS) were measured with a Bausch and Lomb Abbe 3L refractometer. Moreover, the dry matter content was determined after the fruits were exposed to a process of drying at 70°C for 48 h. One gram of dry matter was burnt to yield ash in a Gaallankamp furnace at 550°C for 6 h. Titratable acidity (TA) was determined using an Aminex HPX-87H column which operated at 65°C, while 4 mM sulfuric acid was used as an eluent.

**Data analysis**

The data were obtained by field measurements. Laboratory observations were processed by analysis of variance (ANOVA) using the SAS software and the Duncan mean separation test procedure.

**3. Results**

**Agro-morphological and yield traits**

In general, all cultivars had developed a sufficient stem diameter (data not shown). The analysis of variance signified substantial differences among the cultivars and training systems. Tree vigor was affected substantially by training systems. After four years, there were significant differences in TCSA among the four cultivars. ‘Golab-kohans’ exhibited the highest value of TCSA (17.12 cm<sup>2</sup>) (Table 1). The apple trees that were trained by the Y-system showed significantly higher TCSA values (16.41 cm<sup>2</sup>) compared to those trained by the V-system which formed thinner trunks (9.80 cm<sup>2</sup>) (Table 2). The interaction between

Table 1 - Means comparison of four apple cultivars about studied characteristics in Guttingen V and Geneva-Y trellis systems during 2007-2010

Cultivar	Fruit firmness (kg/cm <sup>2</sup> )	Fruit weight (gr)	Fruit diameter (cm)	Fruit length (cm)	L/D	TSS	TA (%)	Ash (%)	Dry matter (%)	Cumulative yield (Kg/tree)	Yield efficiency (Kg/cm <sup>2</sup> )	TCSA (cm)
Delbar estival	10.00 b	130.15 b	6.57 b	5.81 a	0.86 a	14.53 a	0.45 bc	0.40 b	20.63 bc	16.4 a	0.41 a	9.58 c
Fuji	14.52 a	148.40 a	6.94 a	5.78 ab	0.83 b	15.33 a	0.68 a	0.35 b	23.89 ab	14.72 ab	0.1 c	14.69 b
Golab-kohans	8.44 c	79.25 c	5.72 c	5.01 c	0.86 a	11.23 b	0.28 c	0.38 b	19.56 c	7.72 c	0.1 c	17.12 a
Starking	14.37 a	143.99 a	6.63 b	5.58 b	0.82 b	14.56 a	0.47 b	0.73 a	24.14 a	10.64 b	0.22 b	10.98 c

Means with same letters are not significantly different. (P>0.05) using Duncan Multiple Range Test.

Table 2 - Properties in Guttingen V and Geneva-Y trellis systems during 2007-2010

System	Fruit firmness (kg/cm <sup>2</sup> )	Fruit weight (gr)	Fruit diameter (cm)	Fruit length (cm)	L/D	TSS	TA (%)	Ash (%)	Cumulative yield (Kg/tree)	Cumulative yield (t/ha)	Yield efficiency (Kg/cm <sup>2</sup> )	TCSA (cm)
Guttingen V	10.53 b	122.45 b	6.36 b	5.39 b	0.84 a	14.17 a	0.46 a	0.5 a	7.88 b	23.640 b	0.25 a	9.80 b
Geneva-Y trellis	12.90 a	126.69 a	6.54 a	5.69 a	0.84 a	13.55 a	0.47 a	0.43 a	16.72 a	28.089 a	0.22 b	16.41 a

Means with same letters are not significantly different. (P>0.05) using Duncan Multiple Range Test.

training systems and cultivars showed that ‘Fuji’ had the largest trunk diameter and the largest TCSA (19.98 cm<sup>2</sup>) (Fig. 1A). Regardless of the training system, ‘Delbar estival’ produced the most cumulative yield (16.4 kg/tree) (Table 1). Table 2 shows that the Y-system results in a higher average value of cumulative yield per tree (16.72 kg/tree) and per hectare (28.08 t/ha) than that of the V-system (7.88 kg/tree and 23.64 t/ha, respectively).

The V-system contributed to a higher density of trees (3000 tree/ha), compared to the Y-system (1680 tree/ha). Results show that ‘Fuji’ and ‘Delbar estival’ exhibited the most cumulative yield per tree and per hectare, under the Y-system and the V-system, respectively (Figs. 1B and 1C). Concerning the yield efficiency, during the four years, regardless of the training system, the ‘Delbar estival’ yielded the highest amount of fruit per trunk cross sectional area (Table 1). In addition, the V-system showed a higher yield efficiency (0.25 kg/cm<sup>2</sup>), compared to the Y-system (0.22 kg/cm<sup>2</sup>). A smaller trunk diameter and a higher tree density per hectare can be reasons for the higher yield efficiency (Table 2). The interaction between training systems and cultivars functioned mostly in determining the yield efficiency (0.57 kg/cm<sup>2</sup>) in the ‘Delbar estival’ through the V-system (Fig. 1D).

#### Fruit properties

Results showed that the ‘Fuji’ cultivar yielded the heaviest fruit weight (148.40 gr), whereas ‘Golab-kohans’ had the lightest fruit (79.25 gr) (Table 1). Trees trained by the V-system (as a denser system in this study) developed fruits with an average lighter weight (122.45 gr), but the apples obtained from the Y-system were slightly heavier (126.69 gr) (Table 2). The ‘Starking’ cultivar exhibited the heaviest (159.69 gr) and longest fruit (6.1 cm) by the Y-system (Figs. 2A and 2B). In fact, the Y-system caused the ‘Starking’ to exhibit the maximum fruit length among the four cultivars. The Y-system contributed to the production of fruits that were significantly longer (5.69 cm) than those obtained by the V-system (5.39 cm) (Table 2). In addition, the ‘Fuji’ yielded the widest fruit (6.94 cm) among the four studied cultivars (Table 1). The Y-system caused a greater fruit diameter (6.54 cm) than the V-system (6.36 cm) (Table 2). Figure 2C shows that the maximum width of fruit (7.1 cm) was recorded in the ‘Fuji’ by the Y-system. The highest L/D ratio (0.87) belonged to the ‘Delbar estival’ by the Y-system. In general, the greatest value of fruit firmness was observed in ‘Fuji’

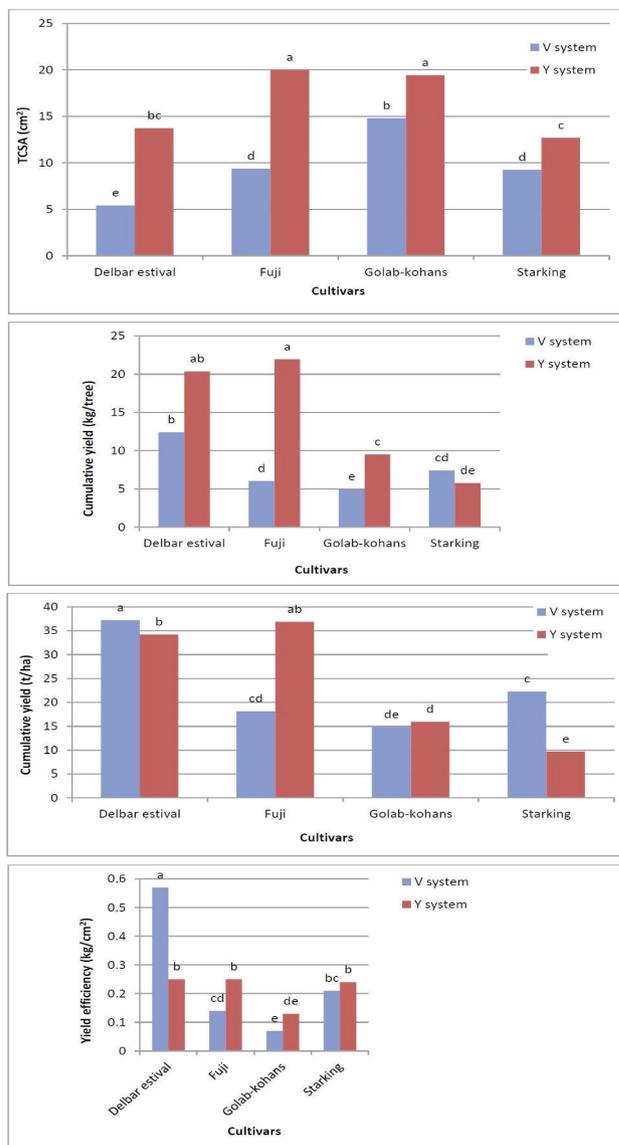


Fig. 1 Interaction of training systems (V-system and Y-system) and four cultivars (Delbar estival, Fuji, Golab-kohans, Starking) on fruit properties.

(14.52 kg.cm<sup>-2</sup>) and the lowest was observed in ‘Golab-kohans’ (8.44 kg.cm<sup>-2</sup>) (Table 1). Also, trees trained by the Y-system yielded fruits with the greatest value of firmness (12.90 kg/cm<sup>2</sup>), compared to the function of the V-system (10.53 kg/cm<sup>2</sup>) (Table 2). ‘Fuji’ yielded the firmest fruits (15.96 kg/cm<sup>2</sup>) by the Y-system (Fig. 2D). The highest TSS (15.33%) and TA (0.68%) were produced by ‘Fuji’, whereas the lowest TSS and TA were recorded in the fruits of ‘Golab-kohans’ (Table 1). The content of TA also differed because of the training systems. The Y-system caused higher TA values in fruits, compared to the V-system, but this difference was insignificant (Table 2) which suggests that the training system had no remarkable influence on the acidity of fruits in this

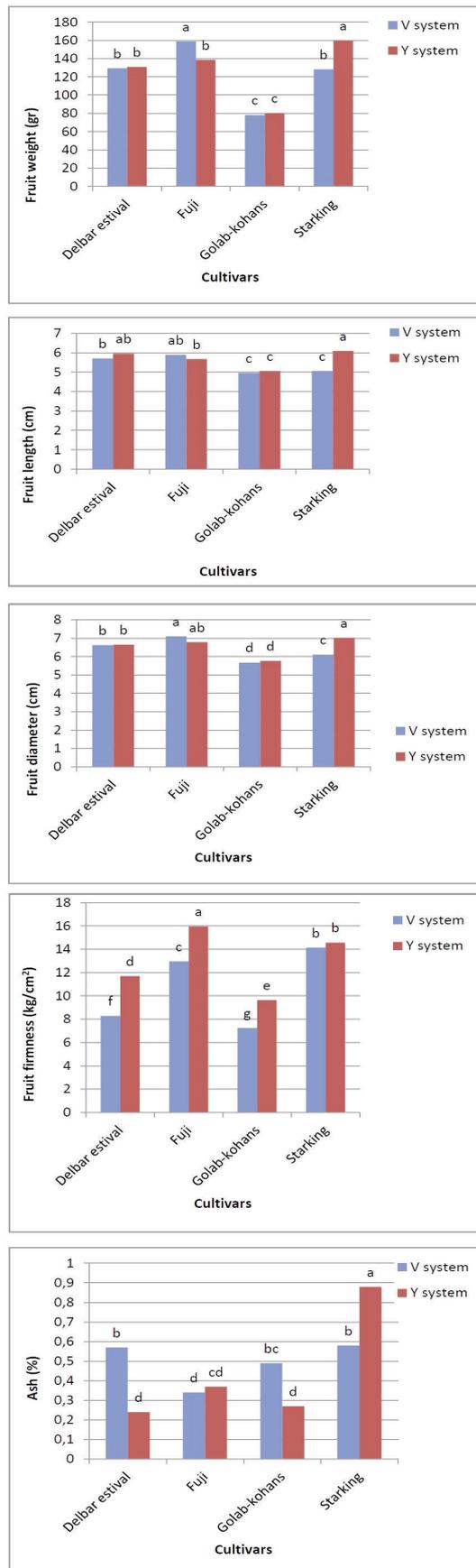


Fig. 2 - Interaction of training systems (V-system and Y-system) and four apple cultivars (Delbar estival, Fuji, Golab-kohans and Starking) on fruit properties.

research. The ‘Fuji’ yielded fruits with the highest amounts of TSS and TA by the Y-system and V-system, respectively. When comparing the cultivars, ‘Starking’ had the best results regarding the dry matter of fruits (24.14%) and ash (0.73%) (Table 1). Regardless of the cultivar, the fruits contained more dry matter when the trees were trained by the V-system, compared to training by the Y-system (Table 2). Additionally, ‘Starking’ yielded the highest amount of ash by interaction with training systems examined in this study (Fig. 2E).

#### 4. Discussion and Conclusions

The results herein suggest that the cultivars and training systems caused differences in the measured characteristics. The occurrence of more tree growth by ‘Golab-kohans’ may be due to a higher degree of shading in the canopy than in other cultivars (Lo Bianco *et al.*, 2007). In addition to the influence of rootstocks, cultivar vigor can be affected by training systems. A lower TCSA was observed in trees of the V-system. This can be attributed to the competition between adjacent trees which, in turn, was a result of shorter spacing between trees (0.9 m) in comparison with the Y-system (1.6 m). As reported by other researchers (Musacchi *et al.*, 2015; Sosna, 2017), planting the trees closer to each other might have negatively affected the stem diameter in this study. These results are in accordance with the latest findings in the available literature (Robinson, 2007; Ozkan *et al.*, 2016) in which intensive cultivations had remarkable effects on tree growth. The greater yield caused by the Y-system might be due to the larger (wider) tree canopy. This result is in agreement with recent reports which suggest that the number of trees per unit area has a great influence on the yield per tree and per hectare (Robinson, 2007; Ozkan *et al.*, 2016). In general, a more even distribution of fruit-bearing can be observed in apple trees with V-shaped canopies, as trained by the Y- and V-systems, compared to other popular training systems. This has been suggested before by similar research (Sosna, 2017). It is known that the yield efficiency depends on the tree’s vegetative vigor and fruit production. When the cultivar has good yield and high TCSA, a lower yield efficiency occurs compared to trees of other cultivars by the same yield and lower TCSA. A lower tree vigor, as caused by the V-system, did not result in a higher yield efficiency. This can be due to a lower yield per tree. In fact, results show that a high-

er yield efficiency can be attained by increasing the number of fruits in each tree or by controlling the tree vigor by dwarf rootstocks. Significant differences in yield efficiency were also reported in a previous study (Fioravanco *et al.*, 2016). It may be assumed that trees on dwarf rootstocks exhibit a weaker vegetative vigor and result in a higher amount of yield (Robinson, 2007). Nonetheless, the differences among cultivars in this study is likely due to the variations in morphological traits, which is in agreement with previous studies (Barritt *et al.*, 1995; Dadashpour *et al.*, 2010). No incremental trend was observed in the fruit weight during the four years, even by the influence of training systems. The contradictory effects of planting density on the fruit weight in this study are consistent with earlier reports (Ozkan *et al.*, 2012; Sosna, 2017). Nonetheless, fruit quality is influenced by many factors such as the specifications of a training system (Robinson *et al.*, 1991). Therefore, it is natural to expect variations in the type of influence caused by the two different training systems on the measured traits in fruits. The L/D ( $\geq 1$ ) is a criterion used for apple marketing, but all cultivars showed L/D  $< 1$  in this study. This observation is probably due to warmer nights in the climatic conditions of the experiment, resulting in insufficient cell elongation. This confirms the results of previous research (Dadashpour *et al.*, 2011). Based on the current discussion, the 'Delbar estival' probably has the highest marketable value in terms of its visual appearance among the cultivars. The denser cultivation of trees in the V-system contributed to the production of fruits with lower amounts of coloration, but this was not substantially different compared to the other training system. The good quality of apples obtained from the V-system was noticed in previous studies (Rutkowski *et al.*, 2009; Dadashpour *et al.*, 2012). It seems that the climatic temperature can affect the fruit firmness. In most of the cultivars, the softest fruits were observed in 2008 (as a cool year in this experiment). However, the relation between temperature and fruit firmness is not fully understood. The Y-system caused firmer fruits, compared to the V-system (Table 2), and this confirms that fruits harvested from the Y-system can be transported with less physical damage. Significant differences in apple firmness support recent findings (Talaie *et al.*, 2011). 'Golab-kohans' was the earliest ripening cultivar and produced the softest fruits (7.25 kg.cm<sup>-2</sup>) by the V-system (Fig. 2D). The 'Fuji' produced the firmest fruits, probably because of the small fruit size, thereby con-

firmed the findings of previous studies (Drake *et al.*, 1988; Dadashpour *et al.*, 2010). In addition, differences in fruit firmness might have been due to genetic variations among cultivars. In addition, it has been reported that fruit firmness is the first edible criterion affecting buyer acceptance (Harker *et al.*, 2008).

Considering the fruit sweetness, fruits and leaves that are exposed to higher light intensities may exhibit more TSS (Tustin *et al.*, 1988). Also, the different TSS contents among cultivars may result from variations in leaf area, as suggested by previous research (Hudina and Stamper, 2002) or by a presumably higher canopy shading of cultivars which produce fruits of lower TSS (Garriz *et al.*, 1996, 1998). Although the TSS was not significantly affected by the two training systems, the V-system caused slightly higher levels of TSS than the Y-system (Table 2). Among the cultivars, the 'Fuji' produced the sourest fruits. These results show that acidity, in general, varies with cultivar, confirming previous studies (Platon, 2007; Dadashpour *et al.*, 2010). The highest amount of TA was observed in fruits of the 'Fuji' cultivar. This may have resulted from less shading in the tree canopy or because of good nutritional conditions. In general, the 'Starking' cultivar produced the highest amount of dry matter, thereby confirming previous claims regarding the differences among cultivars in this regard (Lata, 2007; Palmer *et al.*, 2010). In addition, the dry matter content varies among cultivars, and different training systems cause variations in the dry matter. The dry matter can vary from fruit to fruit and from training system to training system, in agreement with a previous study (Palmer *et al.*, 2010).

In conclusion, the 'Delbar estival' exhibited better results under intensive training systems, whereas 'Golab-kohans' and 'Fuji' showed the best growth characteristics. In general, the Y-system was better than the V-system when considering the majority of characteristics. The two cultivars 'Fuji' and 'Delbar estival' were more adaptable to intensive training systems in Karaj's climatic conditions.

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