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The Training Systems Affect Fruit Quality, Yield, and Labor Efficiency in Peach (*P. persica* L. Batsch)

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Abstract. **In the Vase system, the most common training system for peach-growing countries for more than a century, light distribution to the canopy is uneven, and access to the canopy for pruning, thinning, and harvest labor is difficult. It is important to identify alternative systems to the Vase system considering the cultivar and growing environment to facilitate labor and enhance productivity and quality. In Türkiye, one of the important centers of peach growing worldwide, detailed research has yet to be published on the applicability of training systems alternative to the widely used Vase system. Therefore, this study aimed to evaluate the effect of different training systems (Vase, Catalan Vase, Quad-V, Tri-V) on growth, yield, fruit quality, and labor costs of peach cultivars (Extreme® 314, Extreme® 436, Extreme® 568). The experiment was conducted from 2017 to 2022. Although the distance between rows in all training systems is 5 m, the distance between trees on the row is determined as 4 m in Vase, 3 m in Catalan Vase, 2.5 m in Quad-V, and 2 m in Tri-V. In the experiment, vegetative development parameters, such as canopy volume, trunk sectional area, and the amount of winter pruning weights, differed according to the training system. In the final year, the Vase system, which produces the most pruning weight, generates 48.0% more pruning weight compared with the Tri-V system, which produces the least. Concerning yield per tree and hectare, trained to the Vase system yielded higher fruit per tree regardless of cultivar, while the Quad-V and Tri-V systems yielded more fruit per hectare. The training system and cultivar affected the fruit size; the largest fruits were obtained from the Extreme® 568 cultivar trained according to the Vase system. The most time needed for winter pruning was obtained from the Vase (79.4 min/tree) system, and the Tri-V (57.4 min/tree) and Quad-V (60.3 min/tree) systems required the least time. The Catalan Vase (31.1 min/tree) system required the least time for summer pruning. The most fruit harvest in an hour was obtained from the trees trained according to the Tri-V (164.5 kg/h) and Quad-V (132.02 kg/h) systems. These results suggest that Quad-V and Catalan Vase systems performed well and could be alternatives to the Vase system.**

Historically, peaches have been planted into low-density orchards, characterized by wide inter- and intrarow densities. Thus, the trees had a three-dimensional (3D) canopy and were tall and robust, resulting in very autonomous, productive, and long-lasting but with a very high labor requirement. As in several different fruit orchards, nowadays, peach tends to increase planting density and reduce the tree dimension. The aim is pursued with genetic and horticultural studies to select cultivars and rootstocks that are suited for high-density orchards, training, and pruning techniques that maintain the plant highly productive in a smaller volume with high-quality fruit (Anthony and Minas 2021; Grossman and DeJong 1998). The rootstocks do not induce complete dwarfing because most peach cultivars require 1-year-old proleptic shoots to maintain consistent production and fruit quality. Given the high plasticity inherent in peach trees, achieving these objectives is feasible with diverse training systems (Neri et al. 2022). Training systems affect the canopy shape, depth, and size of the tree, affecting the efficiency of labor and reducing the cost of production through better machine and labor access to the canopy while, at the same time, the spatial distribution of fruit and its quality characteristics (Faust 1989; Grossman and DeJong 1998; Gullo et al. 2014; Iglesias and Echeverria 2022). Peach training systems range from traditional 3D canopy architectures with multiple leaders per tree ideal for low- or medium-density plantings (e.g., Open vase (220 to 550 trees/ha), Delayed Vasette (600 to 800 trees/ha), Catalan Vase (667 trees/ha), Hex-V (750 trees/ha), and Quad-V (900 to 1000 trees/ha) to modern planar or flatted systems (mostly 2D designs) with single or numerous leaders per tree ideal for high-density plantings [e.g., Palmette/hedgerow (600 to 900 trees/ha), Y-shaped (900 to 2000 trees/ha), Fusetto (1250 to 2000 trees/ha), and Slender Spindle Axe (SSA) (1500 to 2445 trees/ha)] (Hoying et al. 2007; Mazzoni et al. 2022; Minas et al. 2018; Neri et al. 2010). Nevertheless, lower-density planting open vases have been the most common training system for peaches for more than a century because of the lack of efficient size-controlling, productive rootstocks comparable to M9 in apples (Iglesias 2022).

Medium-density planting systems in peach training systems are an excellent compromise for growers who want to maintain lower-density management, such as open vase. These orchard systems were developed to diffuse vigor, decrease tree height, reduce canopy complexity, and significantly facilitate pruning, thinning, and harvesting activities compared with the Vase system (Iglesias et al. 2023). The Catalan Vase is one of the medium-density systems and is derived from the vase characterized by a low scaffold (0.5 m aboveground), low tree height (2.5 m), and a mostly free-growing canopy during the initial years, creating a bush-type to enhance early bearing (Montserrat and Iglesias 2011; Neri and Massetani 2011). Also, the Quad-V system was developed to diffuse further the vigor of higher-density two-leader systems such as the parallel and perpendicular-V systems (i.e., KAC-V) (Day et al. 1993, 2005). In the Tri-V system, another system is planted at medium density, unlike the Quad-V system, where there is a single leader branch between the rows instead of two pairs of leader branches. Thus, the Tri-V system (900 to 1250 trees/ha) can be planted more frequently than the Quad-V (900 to 1000 trees/ha) (Hoying et al. 2007).

Türkiye has a climate zone and soil characteristics extremely suitable for peach cultivation. Recently, Türkiye has been one of the countries with significant development in peach production worldwide. In 2022, global peach production reached a total of 26 million tons, with China and Italy leading as the top two producers, and Türkiye, previously ranked fourth or fifth, has risen to third place among significant peach-producing countries with a production of 1 million tons (FAOSTAT 2022). However, Türkiye has fallen behind

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countries such as Italy, Greece, Spain, the United States, and Chile in yield. The relatively lower yield in Türkiye is that semidwarf or dwarf rootstocks and training systems that control canopy volume in peaches are not practiced, and producers have not broadly accepted these. It is essential to increase yield and fruit quality by reducing labor costs in parallel with the increase in production. In the past 10 years, increased labor costs worldwide and the inability to find laborers have become significant problems. The increase in fruit prices could not cover the cumulative increase in production costs (Anthony and Minas 2021; Foschi et al. 2012). The peach industry's survival depends on growing higher-quality fruits that can compete with national and international markets but use less labor (Neri et al. 2015). Türkiye has also been greatly affected by the labor problems experienced in the world. Therefore, training systems that reduce labor, facilitate all cultural processes, and increase fruit quality should also be used in Türkiye.

The effect of training systems on yield, fruit quality, and profitability in peaches has been previously reported (Corelli-Grappadelli and Marini 2008; Sutton et al. 2020). Because many different factors affect orchard performance, it is necessary to conduct long-term studies to find the best training system within the constraints imposed by the local climate (Badiu et al. 2015; Lordan et al. 2018; Weber 2001). In Türkiye, the labor-intensive Vase system is used, and there has been no published report on the applicability of an alternative modern training system to the Vase system. The improper horticultural practices of producers who do not know how to manage the modern systems, which have gained popularity worldwide, create prejudices among producers, and the systems are abandoned before their values are fully understood. An efficient orchard design combines the cultivar, rootstock, and training system. Cultivars vary in fruiting habits, directly affecting pruning (Iglesias and Echeverría 2009; Sutton et al. 2020). In this regard, this research aimed to compare medium-density, open-center training systems (Catalan Vase, Quad-V, Tri-V) with similar investment costs with Vase, using the newly released Extreme® 314, Extreme® 436, and Extreme® 568 cultivars, and also to reveal the applicability of these systems.

Materials and Methods

Study site. The study was conducted in the Agricultural Research Center of Bursa Uludag University from 2017 to 2022. The experimental plantation was located at an altitude of 104 m, with geographic coordinates of 40°14′ north latitude and 28°51′ east longitude in Bursa. According to the meteorological station, the average temperature was 15.9 °C, the highest average temperature was in July at 25.9 °C, and the lowest was in January with an average of 5.9 °C during the years 2017 to 2022 (METOS® by Pessl Instruments, Bursa, Türkiye). The soil structure was silty clay composed of 41% clay, 38% sand, and 20% silt; the soil pH (7.95) was light alkaline and had no saltiness. Lime content was midlow (10.2%), and the organic matter was considered low (1.5%).

Plant material and experimental design. Three peach cultivars developed from the Provedo breeding program in the Don Benito R&D center (Badajoz-Spain), Extreme® 314, Extreme® 436, and Extreme® 568 grafted on GxN15 (Garnem) (Garfi × Nemared) (Felipe 2009) rootstock were used as a material. Extreme® 314 is characterized as an open habitus, high-yielding, early maturing, dark red skin, yellow-fleshed cultivar; at the same time, Extreme® 436 is a semiopen habitus, high-yielding, midseason maturing, bright red skin, yellow-fleshed cultivar. Extreme® 568 has a semiopen habitus, a very productive cultivar with significant and same-sized red skin, yellow-fleshed fruits, and ripens late.

The fully feathered, 1-year-old grafted trees were planted in the spring of 2017, and heading cuts were made but not pruned after planting. The plants were trained using four training systems: Vase (V), Catalan Vase (CV), Quad-V (QV), and Tri-V (TV). The distance between rows was kept equal to 5.0 m, whereas distance between plants varied depending on the training system. In the Vase system, traditional spacing of 4 m was used as local growers do; for the Catalan Vase, 3.0 m spacing was preferred, as most Spanish growers opt for (Montserrat and Iglesias 2012; Neri et al. 2015). A spacing of 2.5 m was used in the Quad-V system, and in the Tri-V system, it was 2.0 m. With these planting distances, the number of plants per hectare was 500, 666, 800, and 1,000, respectively. Vase, Catalan Vase, Quad-V, and Tri-V systems were pruned according to DeJong et al. (2008), Montserrat and Iglesias (2012), Day et al. (2005), and Hoying et al. (2007), respectively. The Vase system was used as a control since it is the traditional training system. The trial was established in randomized blocks with four replications and five trees per replication.

Irrigation, pruning, fertilization, and disease control were regularly applied during the study. Irrigation was made by drip irrigation. According to nutrient levels and pH of the orchard's soil, Monoammonium Phosphate (MAP), urea, NPK (nitrogen, phosphorus, and potassium), and potassium sulfate fertilizers have been applied, and humic acid additions were a regular practice because the soil has a low organic matter content. During the research, a low-biuret urea (LBU) (2 kg/m^3) and boron and zinc fertilizers were applied as foliar spraying every October. Fruits were thinned 30 d after full blooming by hand, leaving one fruit for every 10 cm of shoot. The analyzed variables were separated into vegetative growth, productivity, fruit characteristics, and labor requirement groups.

Tree growth characteristics. Tree vegetative growth was measured each winter from 2017 to 2020. Trees were harvested from 2018 to 2022, but a spring frost eliminated the crop in 2021. Therefore, productivity, fruit characteristics, and labor requirements were analyzed in 2018, 2019, 2020, and 2022. To determine the vegetative growth of the plants, tree heights were measured from the first node to the tree's peak in the dormant period. Trunk diameters were measured 10 cm above the graft union, and the $\pi.r^2$ formula calculated trunk cross-sectional area (TCSA). For the canopy volume, the tree canopy radius (r) and the tree canopy (h) length were determined and calculated with the $2{\cdot}\pi{\cdot}r^2{\cdot}h/3$ formula (Rufato et al. 2006). Also, regarding vegetative growth, summer and winter pruning weights (kg) were weighed.

Labor analysis. Regarding labor requirement components, the minute per worker (research technicians) needed to accomplish each orchard operation (winter pruning, summer pruning, thinning, harvest) was calculated as recording the time required to perform each system operation.

Yield, cumulative yield, and yield efficiency. Regarding the productive measurements, yield per tree (kg) and per hectare (tonne) was determined from the harvest data. The fruit was hand-harvested in two pickings at the commercial maturity stage for each cultivar-training system combination.

Fruit characteristics. Fruit characteristics were evaluated in four replicates of 10 fruits per replicate randomly hand-picked at first pickings at the commercial maturity stage for each cultivar-training system combination. Extreme® 314, Extreme® 436, and Extreme® 568 cultivars were harvested when fruit firmness was about between 45 and 54 N, and when 80%, 70%, and 60% red ground color was observed on the fruit skin, respectively. Fruit characteristics such as fruit weight (g), fruit diameter (mm), and fruit firmness (N) were measured according to standard morphometric methods. Fruit firmness was measured on two paired sides of each fruit using a manual penetrometer (FT327, Italy) equipped with an 8-mm tip, and the data were expressed in Newtons (N). Fruit skin colors in lightness (L*), a*, and b* values were measured using a colorimeter, and the hue (H°) and chroma (C) were calculated (Chroma Meter CR-400; Minolta, Osaka, Japan). In addition, fruit chemical traits such as the soluble solid content (SSC) by a digital refractometer (Atago PR-101; Atago, Tokyo, Japan) and total acidity by titration (TA) with 0.1 N NaOH were determined in each replication. Also, the ripening index was estimated by the ratio of SSC and TA values (Iglesias and Echeverría 2009).

Data analysis. The obtained data were analyzed using the IBM SPSS 23.0 program (SPSS Inc., Chicago, IL, USA). Although the analysis of variance obtained significant ($P \leq 0.05$) values, the comparison of the mean values was compared with Duncan's multiple range test.

Results and Discussion

Tree growth characteristics. The training system significantly affected growth characteristics such as tree height, TCSA, and canopy volume (Table 1). The highest trees were obtained from the Extreme® 314, Extreme® 436, and Extreme® 568 cultivars trained to the Vase system, followed by the Tri-V system. Catalan Vase trees have formed the

Table 1. Tree height, canopy volume, and trunk cross-sectional area (TCSA) of peach cultivars trained to different training systems.

	Tree height (cm)				Canopy volume (m^3)				TCSA (cm^2)				
TS	2017	2018	2019	2020	2017	2018	2019	2020	2017	2018	2019	2020	2021
						Extreme® 314							
V	122.6[a,i]	195.3[a]	233.5[a]	257.2	0.81	5.3	14.0	23.8[ab]	5.5	20.3	57.7	104.2	132.6[ab]
CV	85.2[c]	149.8[b]	208.5[b]	254.2	0.61	4.0	13.8	25.7[a]	3.9	17.3	69.7	111.2	136.4[a]
QV	102.4[bc]	171.4[ab]	217.0[ab]	253.5	0.62	4.5	12.5	19.8[b]	4.4	18.6	58.8	95.6	118.2[b]
TV	116.2[ab]	187.0[a]	233.2[a]	263.4	0.75	4.5	12.0	20.8[b]	3.7	18.0	59.7	92.8	111.1[b]
Mean	106.6	175.8	223.0	257.0	0.70	4.61	13.1[A]	22.5[A]	4.42	18.6	61.5	100.8	124.6
						Extreme® 436							
V	124.6[a]	207.6[a]	235.1[a]	257.4	0.82	5.1	14.3[a]	23.4[a]	5.53[a]	21.7	58.5[b]	98.1[ab]	121.8[ab]
CV	84.9[c]	156.5[c]	214.2[b]	249.6	0.55	4.0	13.2[ab]	24.8[a]	3.55[b]	17.6	82.1[a]	122.4[a]	145.9[a]
QV	102.3[bc]	176.0[bc]	221.5[ab]	258.3	0.89	4.2	11.6[bc]	18.5[b]	3.72[b]	19.7	57.8[b]	79.9[b]	101.5[b]
TV	108.1[ab]	195.7[ab]	229.9[a]	257.6	0.66	4.0	10.0[c]	16.9[b]	3.64[b]	17.6	59.2[b]	85.5[b]	101.0[b]
Mean	118.6	184.0	225.1	255.7	0.73	4.40	12.3[AB]	20.9[A]	4.11	19.1	64.4	96.5	117.5
						Extreme® 568							
V	136.0[a]	198.5[a]	227.6[a]	253.0	1.02[a]	5.1[a]	13.9[a]	22.1[a]	6.11[a]	19.9	52.9[b]	94.8[ab]	120.5[a]
CV	82.2[c]	148.0[b]	208.0[b]	237.7	0.5[b]	3.3[b]	12.2[a]	21.3[a]	3.94[b]	16.9	65.7[a]	105.5[a]	129.0[a]
QV	109.0[b]	161.4[b]	212.2[ab]	251.9	0.6[b]	3.9[ab]	10.3[ab]	17.3[ab]	4.87[ab]	16.2	48.0[b]	83.2[ab]	104.8[ab]
TV	109.8[b]	175.9[ab]	210.8[ab]	252.1	0.6[b]	3.1[b]	7.6[b]	14.2[b]	3.64[b]	14.0	43.9[b]	70.7[b]	86.6[b]
Mean	109.3	170.9	214.6	248.7	0.69	3.87	11.0[B]	18.7[B]	4.64	16.8	52.6	88.5	110.2

[i] Different lowercase letters indicate differences between training systems according to cultivars, while uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

shortest trees with each cultivar. Day et al. (2005) stated that given the number of scaffolds diffusing the tree's vigor, tree heights will typically be lower, especially if the angle of the scaffolds is bent more toward the horizontal. However, the training systems had similar tree heights for all cultivars in the final year. The fact that the systems in the study were multileader systems with open canopy may have contributed to the difference in tree height that was only noticed in the early years. Furthermore, in the first 3 to 4 years, relatively higher-density systems (Quad-V, Tri-V) fill the space allocated to them, and afterward, lower-density plantings fill their allotted space, increasing leaf area, interception, and yield (Hampson et al. 1998; Palmer 1999). Likewise, Anthony and Minas (2021) reported that the goals of medium-density planting systems such as Catalan Vase, Quad-V, and Tri-V include increasing light interception, increasing yields, and reducing tree heights. Tree heights are essential for labor costs, especially pruning, thinning, and harvesting. Similar to the vase system, a ladder or platform is necessary when exceeding 4 m in height (DeJong et al. 2008). In the present study, the Vase system still needs to complete its allocated space; tree height and canopy volume will continue to increase. Regarding the canopy volume, differences between training systems became more distinguishable in 2020, and the highest volume was obtained from the Catalan Vase and Vase systems for all cultivars.

Iglesias et al. (2023) reported that in the Catalan Vase system, the highest canopy volume was reached in the fourth year. Consistent with this, the Catalan Vase, known as the compact version of the Vase system, gave the highest canopy volume in the fourth year of the study, indicating that the system fills the space allocated to it. In contrast, the Vase system still does not fill its own space and does not have the highest canopy volume. Among the cultivars, Extreme® 568 showed the lowest canopy volume values, especially when trained to the Tri-V (14.2 m^3) and Quad-V (17.3 m^3) systems. Regardless of cultivar, the lowest volume was obtained from the Tri-V system (17.3 m^3) as small as two-thirds of the Catalan Vase (23.9 m^3) (Table 1). Consistent with the present study, Lang (2022) stated that increasing the number of leaders per tree enhances overall canopy vigor due to a larger leaf area and a more extensive root system, which distribute and moderate the vigor of each leader proportionally when trees are planted in wider spaces. Hamana et al. (2016) reported that the trees trained by open-center training systems such as Vase and with lower planting densities grow much more vigorously and develop significant canopy volumes. Uberti et al. (2019) stated that 'Eragil' peach trees trained by the Vase system had 35% more canopy volumes than Y-Ipsilon and Central leader. Similarly, DeJong et al. (1999) and Day et al. (2005) reported that Quad-V simplified the architecture of a Vase system, promoting a compromise between the KAC-V and Vase systems.

The Extreme® 436 and Extreme® 568 cultivars that were trained according to the Tri-V system had lower TCSA in 2017, 2019, and 2020. Also, in 2021, for all cultivars, the lowest TCSA was recorded for the Tri-V system (111, 101, 86.6 cm^2), and the highest was obtained from the Catalan Vase (136.4, 145.9, 129.0 cm^2), with 27% more area than Tri-V (Table 1). Consistent with this, Iglesias et al. (2023) reported that compared with a single leader tree, 'Fantasia'/'Lovell' nectarine trees with eight leaders were 105% more vigorous as measured by TCSA, but each leader was 22% shorter and 63% less vigorous. There is a strong relationship between TCSA and tree sizes (Barden and Marini 2001). Trees planted with higher densities have smaller TCSA values than those of lower densities because of higher competition between plants for light, water, and minerals (Layne et al. 2002). Consistent with Layne et al. (2002) and Lang (2022), the higher-density planted Tri-V system had a smaller TCSA in the present study because closer tree spacing contributes to vigor control through root competition. Taylor (2003) reported that the Vase system provided 21.1% more TCSA than the Quad-V system. In the present study, the Vase system also had 16.7% more TCSA than Quad-V.

Training systems generally affected the weight of winter pruning based on the cultivars, but the cultivars did not have an effect. The cultivars trained to the Catalan Vase system produced less winter pruning weight in the first year but provided more from 2018. The Catalan Vase needed trimming in the first 2 years and no winter pruning in the first winter. However, in the second winter, all central growth required to be removed to achieve a widely open-center tree, and this removal increased the total amount of winter pruning weight. In contrast to other open-centered training systems, Quad-V and Tri-V systems have been staked to have oriented skeleton branches in the right direction, so this type of orientation and slightly more summer pruning activities have reduced winter pruning weights drastically. In 2020, Extreme® 436 trees trained to Vase (18.46 kg) produced the highest pruning weight, followed by trees trained to Catalan Vase (16.68 kg). This trend was similar in the Extreme® 568 cultivar (Table 2). In 2020, regardless of cultivars, the Tri-V (8.6 kg) system produced about half the amount of pruning weight compared with the Vase (16.6 kg). These results are compatible with the statement by Day et al. (2005), "Vase system requires strong annual pruning." In addition, as a well-known phenomenon, trees planted at lower densities have more light interception capacity and lower competition pressure for water and minerals with neighboring trees,

Table 2. Winter and summer pruning weight of peach cultivars trained to different training systems.

	Winter pruning wt (kg/tree)				Summer pruning wt (kg/tree)		
TS	2017	2018	2019	2020	2018	2019	2020
				Extreme® 314			
V	0.22[a,i]	0.85[b]	3.47	12.50[a]	0.39	1.39	4.55
CV	0.05[c]	1.71[a]	3.49	13.33[a]	0.29	1.73	4.68
QV	0.12[b]	1.28[ab]	3.19	13.72[a]	0.32	1.60	4.76
TV	0.19[a]	1.06[ab]	4.27	9.24[b]	0.37	1.68	5.49
Mean	0.14[A]	1.19	3.61	12.19	0.34	1.60	4.87
				Extreme® 436			
V	0.17[a]	0.93[ab]	4.34	18.46[a]	0.53	1.35	4.70
CV	0.07[c]	2.01[a]	4.40	16.68[ab]	0.42	1.87	5.87
QV	0.12[b]	1.23[ab]	3.64	13.17[ab]	0.47	1.63	4.56
TV	0.09[c]	0.82[b]	4.38	9.16[b]	0.45	1.16	5.33
Mean	0.12[B]	1.25	4.19	14.37	0.47	1.50	5.11
				Extreme® 568			
V	0.15[a]	1.16	4.49[a]	19.08[a]	0.48	1.35	5.35
CV	0.06[b]	1.44	4.63[a]	14.18[ab]	0.20	1.57	5.78
QV	0.15[a]	0.92	2.29[b]	11.16[bc]	0.47	1.35	4.94
TV	0.13[ab]	0.75	3.48[a]	7.63[c]	0.39	1.02	4.17
Mean	0.11[B]	1.04	3.72	13.01	0.38	1.32	5.06

[i] Different lowercase letters indicate differences between training systems according to cultivars, while uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

increasing photosynthetic activity and nutrient uptake, resulting in more vigorous growth and increased pruning requirement (Chalmers et al. 1981; Loreti et al. 1978; Parry 1978).

According to cultivars, no significant differences in summer pruning were observed in training systems (Table 2). Despite having smaller canopy volumes, the Quad-V and Tri-V systems produce a comparable amount of summer pruning weight compared with the larger volume Vase and Catalan Vase systems. This is due to the abundance of watersprouts at the central portion of the canopy and the need for extensive summer pruning in these systems (Day et al. 2005).

Labor analysis of training systems. The training system affected cumulative summer pruning labor. Catalan Vase (33.55, 30.70, 29.12 min/tree) required significantly less time for summer pruning for all cultivars (Table 3). Because for the first 2 years, all summer pruning activities for Catalan Vase included head trimming, while all other systems were needed to eliminate watersprouts and strong branches. Also, the main reason for this high requirement was the time-consuming obligation of stakes application and tying. Similarly, DeJong et al. (1999) reported that systems that reduce tree height increased hand labor efficiency. Consistent with DeJong et al. (1999), the study indicated that, notably in the first years, the labor required for summer pruning was lower in the shorter Catalan Vase system. The number of trees per hectare has increased summer pruning labor time per hectare in all years, especially in Tri-V and then Quad-V systems.

The training system affected winter pruning for all cultivars. The Vase system needed the most time for all cultivars. The least time spent Extreme® 568 trees trained to Tri-V (55.08 min/tree), followed by trees trained to Quad-V (60.31 min/tree). However, for the Extreme® 314 and Extreme® 436 cultivars, there was no difference in terms of Quad-V, Tri-V, and Catalan Vase systems (Table 3). As system definition, because there were needed minimal winter pruning for Catalan Vase in the first year but needed significantly more time in the second winter because of eliminating the central bush. Besides the Catalan Vase system, other systems required skeletal branch selection and elimination of most lateral fruiting branches.

Table 3. Cumulative labor needed for main cultural practices of peach cultivars trained to different systems.

	Summer pruning labor[i]		Winter pruning labor[i]		Thinning labor[ii]		Harvest labor[ii]	
TS	min/tree	h/ha	min/tree	h/ha	min/tree	h/ha	min/tree	h/ha
				Extreme® 314				
V	51.96[a,iii]	433.00[c]	78.55[a]	654.58[c]	102.1[a]	852.2[b]	44.88[a]	374.30[a]
CV	33.55[b]	369.05[d]	60.50[b]	665.50[c]	93.8[ab]	1042.6[a]	23.99[b]	266.40[b]
QV	44.86[ab]	598.13[b]	57.67[b]	768.93[b]	87.5[b]	1189.2[a]	23.40[b]	314.90[ab]
TV	46.02[ab]	767.00[a]	59.41[b]	990.16[a]	54.7[c]	560.5[b]	18.75[c]	313.20[ab]
Mean	44.09	541.79	64.03	769.92	84.52[B]	818.43[B]	27.75[B]	317.20[B]
				Extreme® 436				
V	58.27[a]	485.58[b]	77.76[a]	648.00[c]	140.2[a]	1169.1[ab]	54.41[a]	462.30[a]
CV	30.70[c]	337.70[c]	58.03[b]	638.33[c]	152.4[a]	1660.2[a]	40.41[b]	448.20[a]
QV	48.14[b]	641.86[ab]	63.04[b]	840.53[b]	140.1[a]	1871.1[a]	31.96[bc]	425.60[ab]
TV	50.11[ab]	835.16[a]	57.93[b]	965.50[a]	78.1[b]	797.3[b]	24.66[c]	411.7[b]
Mean	46.80	579.03	64.19	773.09	127.70[A]	1175.10[A]	37.86[A]	436.95[A]
				Extreme®568				
V	55.15[a]	459.58[bc]	82.03[a]	683.58[c]	148.8[a]	1242.0[ab]	32.80[a]	249.50[ab]
CV	29.12[c]	320.32[c]	64.27[b]	706.97[c]	120.51[ab]	1324.4[a]	25.48[b]	282.10[a]
QV	44.07[b]	587.60[b]	60.31[bc]	804.13[b]	94.7[b]	1244.2[ab]	13.85[bc]	182.00[b]
TV	48.14[ab]	802.33[a]	55.08[c]	918.00[a]	53.6[c]	551.4[b]	10.70[c]	179.30[b]
Mean	44.12	542.45	65.42	778.17	104.40[AB]	1090.50[AB]	20.70[B]	223.22[C]

[i] Cumulative labor (2017 to 2020).

[ii] Cumulative labor (2019 to 2022).

[iii] Different lowercase letters indicate differences between training systems according to cultivars, and uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

Day et al. (2005) stated that increasing branches and growing points reduce labor efficiency. Consistent with Day et al. (2005), winter pruning labor of the Tri-V system, which had fewer branches, was lower. The increase in trees per hectare has led to an increase in winter pruning labor time per hectare in the Tri-V system. In the Quad-V system, where the number of trees per hectare is close to the Tri-V system, less time was spent on winter pruning per hectare than in the Tri-V system, whereas more time was spent compared with the Vase and Catalan Vase systems (Table 3). Likewise, Taylor (2003) stated that the Quad-V system has the greatest cost per acre in terms of pruning labor compared with the Perpendicular-V and Vase systems.

The results showed that thinning labor was significantly affected by training systems and cultivars (Table 3). Regarding cultivars, the highest thinning labor was obtained from Extreme® 436 (127.70 min/tree) and the lowest was required for Extreme® 314 (84.5 min/tree) trees. For all cultivars, the Vase system required the most time, followed by the Catalan Vase system, while the Tri V system required the least time. The least time was also obtained by training Extreme® 314 (87.50 min/tree) and Extreme® 568 (94.70 min/tree) trees according to the Quad-V system. The Tri-V and Quad-V systems had a straightforward, easy-to-operate skeletal structure facilitating thinning labor. Similarly, Day et al. (2005) stated that in the V systems, every tree has exactly the same number of scaffolds, and the variation between trees is reduced, increasing labor efficiency. Caruso et al. (2015) reported that labor needed for fruit thinning was similar in Catalan Vase and Y systems. The thinning labor difference between the Catalan Vase system and the Tri-V was evident in the present study. Although the number of trees per hectare increases in the Tri-V system, the time spent for thinning is less than in other systems.

Harvesting labor was affected by the training systems and cultivars (Table 3). Regardless of training system, the highest harvesting labor was obtained from Extreme® 436 (37.86 min/tree). For all cultivars, the most time was required by the Vase system, and the least time was required by the Tri-V system. The Tri-V and Quad-V systems had a straightforward, easy-to-operate skeletal structure facilitating labor. Central opening activity in the second year created a very open and low tree for the Catalan Vase, and in turn, it required a lower minute per tree than the Vase system. Consistent with this, Caruso et al. (2015) stated that a greater percentage of labor was used for harvesting in the Catalan Vase. Although there were fewer trees per hectare, more time was spent per tree in the Vase system in all years compared with other systems, which increased the time spent per hectare for the system. The highest cumulative harvest labor per hectare was obtained from the Vase system for all cultivars, the least from the Tri-V system for Extreme® 436 (411.70 h/ha) and Extreme® 568 (179.30 h/ha) and from the Catalan Vase (266.40 h/ha) for Extreme® 314.

Table 4. Average labor (2019 to 2022) needed for leading cultural practices (h/ha) and harvest efficiency (2019 to 2022) (kg/h) of peach cultivars trained to different training systems.

TS	Avg labor (h/ha)	Harvest efficiency (kg/h)
	Extreme® 314	
V	505.73[i,c]	93.14[b]
CV	585.89[b]	112.11[ab]
QV	665.82[a]	104.31[b]
TV	704.55[a]	154.04[a]
Mean	620.49[C]	115.90
	Extreme®436	
V	651.95[c]	100.91[b]
CV	783.57[b]	116.82[b]
QV	927.51[a]	140.67[ab]
TV	833.56[b]	161.75[a]
Mean	799.14[A]	130.03
	Extreme® 568	
V	728.05	101.69[c]
CV	705.08	116.72[bc]
QV	675.47	151.08[ab]
TV	704.58	177.71[a]
Mean	703.29[B]	136.80

[i] Different lowercase letters indicate differences between training systems according to cultivars, and uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

Average labor associated with cultural practices and tree management was 17% greater in the Quad-V (756.27 h/ha) than in the Vase (628.58 h/ha) system, regardless of cultivar (Table 4). One point to consider with the Vase system compared with the others is the additional "forking" that occurs, resulting in more complex upper canopies. This added complexity can significantly increase labor time. Caruso et al. (2015) stated that the average labor needed for leading cultural practices in the Catalan Vase system was 729 h/ha, and less time was spent per hectare compared with the Y system. Also, Iglesias and Echeverria (2022) reported that Catalan Vase's labor efficiency was 650 h/ha. These results are consistent with the study findings.

In an hour, the most fruit was harvested from trees trained to the Tri-V (164.50 kg) system, followed by the Quad-V (132.02 kg) system (Table 4). As a result of yield levels and the amount of harvest labor required, the Tri-V and Quad-V systems were 41% and 27% more efficient than the Vase system in terms of kilograms of fruit produced per hour of harvest labor.

Iglesias and Echeverria (2022) stated that adult trees of the midseason cultivar Luciana had a harvest rate of 120 kg/h per person for the Catalan Vase. In the present study, the harvest rate for the Catalan Vase was 116.22 kg/h, similar to Iglesias and Echeverria (2002), and the system was 17% more efficient than the Vase system. However, determining the efficient training system depends on long-term studies that include rootstock, climatic conditions, and economic factors, in addition to the cultivar (Badiu et al. 2015; Lordan et al. 2019; Reig et al. 2020).

Yield, cumulative yield, and yield efficiency. The results showed that yield was significantly affected by training systems and cultivars (Table 5). The earlier bearing was observed for all cultivars trained to Catalan Vase; this characteristic is essential in orchards to hasten economic returns. Neri et al. (2015) reported that the Catalan Vase system is preferred in Mediterranean countries because of its early bearing. Iglesias et al. (2023) stated that the fewer pruning cuts made in the first years, the faster the tree will come into production. Consistent with Neri et al. (2015) and Iglesias et al. (2023), Catalan Vase was the system that required less pruning in the first year, and early yield was obtained from all cultivars. In other years, the highest yield for all cultivars was obtained from the Vase system. The yield gap between the Vase and Quad-V systems tended to decrease after the fourth year, and in 2022, Extreme® 314 and Extreme® 436 cultivars gave higher yields when trained to the Vase and Quad-V systems. The elimination of the yield difference between Vase and Quad-V starting from the fourth year is related to the Quad-V system filling the row. Regarding cultivars, the highest yield was obtained from Extreme® 436 for all training systems in all years. The yield of Extreme® 314 was negatively impacted by the low temperatures during flowering in 2020, as it bloomed ≈1 week earlier than other cultivars, but in 2022, the yield increased dramatically. The low yield of Extreme® 568 in 2022 was attributed to the favorable temperatures for brown rot development and inadequate disease management.

The highest cumulative yield per tree was obtained from Extreme® 314 (50.2 kg), Extreme® 436 (73.3 kg) and Extreme® 568 (45.6 kg) trees trained to the Vase system. Also, cumulative yield was high in the Extreme® 436 cultivar trained to the Catalan Vase (64.5 kg) and Quad-V (62.7 kg) systems. The lowest cumulative yield was obtained from the Tri-V (26.6 kg) system for all cultivars (Fig. 1). Dejong et al. (2008) reported that a Vase system could facilitate proper illumination of most areas in the canopy; however, watersprouts and vigorous branches growing in the center of this 3D canopy can negatively impact fruit yields and quality. Also, Gullo et al. (2014) reported that open Vase systems intercept less light and lead to lower crop loads unless summer pruning. The present study did not encounter low yield per tree due to intensive summer pruning in the Vase system. Similarly, Taylor (2003) reported that the yield per tree of the Redglobe (midseason) cultivar at third and fourth leaf trees were 15.46 kg to 25.96 kg for the Vase system and 13.97 kg to 24.40 kg for the Quad-V system. In the present study, when the Extreme® 436 (midseason) was compared with Taylor's (2003) results, it was found to be similar to Taylor's (2003), and the yield per tree was found to be higher in the Vase system.

Training systems significantly affected yield per hectare. In 2018, although the highest yield

Table 5. Yield (kg/tree) and yield (t/ha) of peach cultivars trained to different training systems. There was no crop in 2021 because of frost.

TS	Yield (kg/tree)				Yield (t/ha)				CCL (fruit number/cm^2)
	2018	2019	2020	2022	2018	2019	2020	2022	2019 to 2022
					Extreme® 314				
V	0.13^{b,i}	2.5	11.9	34.5^{a}	0.06^{b}	1.2^{a}	6.4^{a}	17.2^{b}	2.05
CV	0.45^{a}	0.8	9.8	22.3^{b}	0.29^{a}	0.5^{a}	7.2^{a}	14.7^{b}	1.43
QV	0.02^{b}	1.2	9.8	32.7^{a}	0.02^{b}	0.9^{a}	8.6^{a}	26.1^{a}	1.84
TV	0.02^{b}	1.5	9.5	22.0^{b}	0.02^{b}	1.5^{a}	10.1^{a}	22.0^{ab}	1.80
Mean	0.10^{B}	1.5	10.3^{C}	27.9^{B}	0.10^{B}	1.09	8.1^{B}	20.0^{A}	1.78^{B}
					Extreme® 436				
V	0.43^{b}	5.4^{a}	24.5^{ab}	42.9^{a}	0.22^{b}	2.7^{ab}	12.2^{b}	21.4^{b}	2.60^{ab}
CV	0.86^{a}	1.1^{b}	27.9^{a}	34.5^{ab}	0.57^{a}	0.7^{b}	18.4^{a}	22.8^{b}	2.16^{b}
QV	0.16^{b}	1.6^{b}	24.0^{ab}	36.9^{ab}	0.13^{b}	1.3^{ab}	19.2^{a}	29.5^{a}	3.12^{a}
TV	0.25^{b}	3.4^{ab}	16.0^{b}	25.6^{b}	0.22^{b}	3.4^{a}	16.9^{ab}	25.6^{ab}	2.24^{b}
Mean	0.40^{A}	2.9	23.3^{A}	35.0^{A}	0.29^{A}	2.04	16.7^{A}	24.8^{A}	2.52^{A}
					Extreme® 568				
V	0.25	4.6^{a}	27.2^{a}	17.0	0.12	2.3	11.8	8.5^{b}	1.58
CV	0.32	1.3^{b}	19.2^{ab}	20.1	0.21	0.9	12.7	13.2^{ab}	1.44
QV	0.27	1.6^{b}	12.6^{b}	18.4	0.21	1.3	10.0	14.7^{a}	1.29
TV	0.17	2.1^{b}	10.7^{b}	16.6	0.17	2.1	10.7	16.6^{a}	1.44
Mean	0.2^{AB}	2.4	17.6^{B}	18.0^{C}	0.18^{AB}	1.67	11.3^{B}	13.2^{B}	1.44^{C}

[i] Different lowercase letters indicate differences between training systems according to cultivars, and uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

per hectare was obtained from Extreme® 314 (0.29 t/ha) and Extreme® 436 (0.57 t/ha) trained according to Catalan Vase, in 2022, it was obtained from Quad-V (23.43 t/ha) and Tri-V (21.40 t/ha) systems regardless of cultivars (Table 5). Although Iglesias and Echeverria (2022) received a yield of 34 t/ha from the 7-year-old 'Noracila' (early season) cultivar trained according to the Catalan Vase system, in the study, 22.3 t/ha were obtained from the 5-year-old Extreme® 314 (early season) cultivar trained according to the Catalan Vase system. The highest yield per tree was obtained from the Vase, and the highest yield per hectare was obtained from the Quad-V and Tri-V (Table 5). The yield gap between the Vase and Tri-V systems decreased after the second year. Caruso et al. (2015) reported that the average yield per hectare from years 4 to 6 in the Catalan Vase system was 25.6 t. In the present study, in the Catalan Vase, the average yield was found to be 14.84 t/ha, regardless of the cultivars. Yield may vary depending on many combinations such as location, cultivar, rootstock, and cultural processes.

The highest cumulative yield per hectare was obtained from Extreme® 314 and Extreme® 436 trees trained according to the Quad-V system, followed by the Tri-V system. However, no difference was found between the training systems in the Extreme® 568 cultivar (Fig. 1). Tri-V had the highest tree density, and its cumulative yield was similar to Quad-V regardless of cultivar. Hoying et al. (2007) reported that the Quad-V and Tri-V systems provided a cumulative efficiency increase of 21% and 47%, respectively, compared with the Vase system. In the present study, similar to Hoying et al. (2007), the Quad-V system provided a 20% cumulative efficiency increase compared with the Vase system, but no increase over 20% was achieved in the Tri-V system regardless of cultivars. Regarding cultivars, the Extreme® 436 resulted in high yield efficiency and crop load for all training systems. The Vase and Quad-V systems had the highest yield efficiency and crop load for Extreme® 436. This may indicate a good match between scion productivity and tree architecture, which produced sufficient fruit-filled canopy. No differences were found in yield efficiency and crop load between the training system in the Extreme® 568 cultivar.

This is probably because Extreme® 568 normally produces large fruit and trees were thinned to less than the critical crop load that would have teased out a potential training system effect. However, it is difficult to ascertain whether a Vase canopy is more productive than the other systems. Despite efforts to thin all systems equally, the crop load was consistently slightly higher on the Vase system in both Extreme® 314 and Extreme® 436. This was partly because of the difficulty of seeing and reaching the fruitlets on the inside and upper part of the Vase after the trees had leafed out. Taylor (2003) stated that yield efficiency for the open-center and Quad-V systems demonstrated in the first year of production that the open-center trees did not produce fruit as efficiently as the Quad-V systems. The results of the present study did not show similarities to those statements; Quad-V had the highest yield efficiency.

Fruit characteristics. Fruit weight was significantly affected by training systems and cultivars. The late-season cultivar Extreme® 568 had the biggest fruits followed by Extreme® 436 in all training systems. This genetic difference is primarily linked to the precocity of fruit maturation. Regarding the training system, larger fruits were obtained from the Extreme® 436 and Extreme® 568 trees trained to the Vase system, whereas there was no difference in Extreme® 314 trees based on training systems (Table 6). Fruit size was less influenced in early-season peach cultivars than in late maturing ones (Grossman and DeJong 1995). Dejong et al. (2008) reported that when Vase systems are managed properly, they can produce large quantities of high-quality fruit. However, Gullo et al. (2014) reported that in the Vase system, the lower/inner parts of the tree are usually shaded as it captures a higher amount of light at the top/outer parts of the tree and that the upper fruits may be of good quality, while the lower fruits may be of poor quality. In the study, the Vase system has not yet filled the space between rows, preventing shadow formation and ensuring the desired level of light distribution. When assessing the relationship between fruit weight and crop load, the Extreme® 436 cultivar trained to the Quad-V system was found to had lower fruit weight and higher crop load. However, this inverse relationship between crop load and fruit weight was not observed for all cultivars across all training systems. Light and fruit position within the tree canopy altered peach fruit quality (Lewallen and Marini 2003). Fruit weight decreased from the top to the bottom in the Vase, whereas in the V systems, fruit weight remained stable across the canopy (Day et al. 2005; DeJong et al. 2008). When the Extreme® 568 cultivar was trained to the Quad-V system, it produced the second largest fruits after the Vase, and it produced the smallest fruits when trained using the Tri-V and Catalan Vase systems. The fruit size was smaller than expected at a given crop load for Tri-V, which could be because of the style of pruning of the Tri-V, which requires the removal of all large limbs to contain the trees in the small allotted space. This somehow reduces fruit size at a given crop load. Similarly, Hoying et al. (2007) stated that smaller fruit size is inherent to high-density planting systems and is not improved with more aggressive thinning. Also, Robinson et al. (2012) reported that fruit size was generally greatest with the Open center and Quad-V systems, intermediate with the Tri-V system. The smallest fruits were obtained from the Catalan Vase system, which could be a result of the higher number of branches per tree.

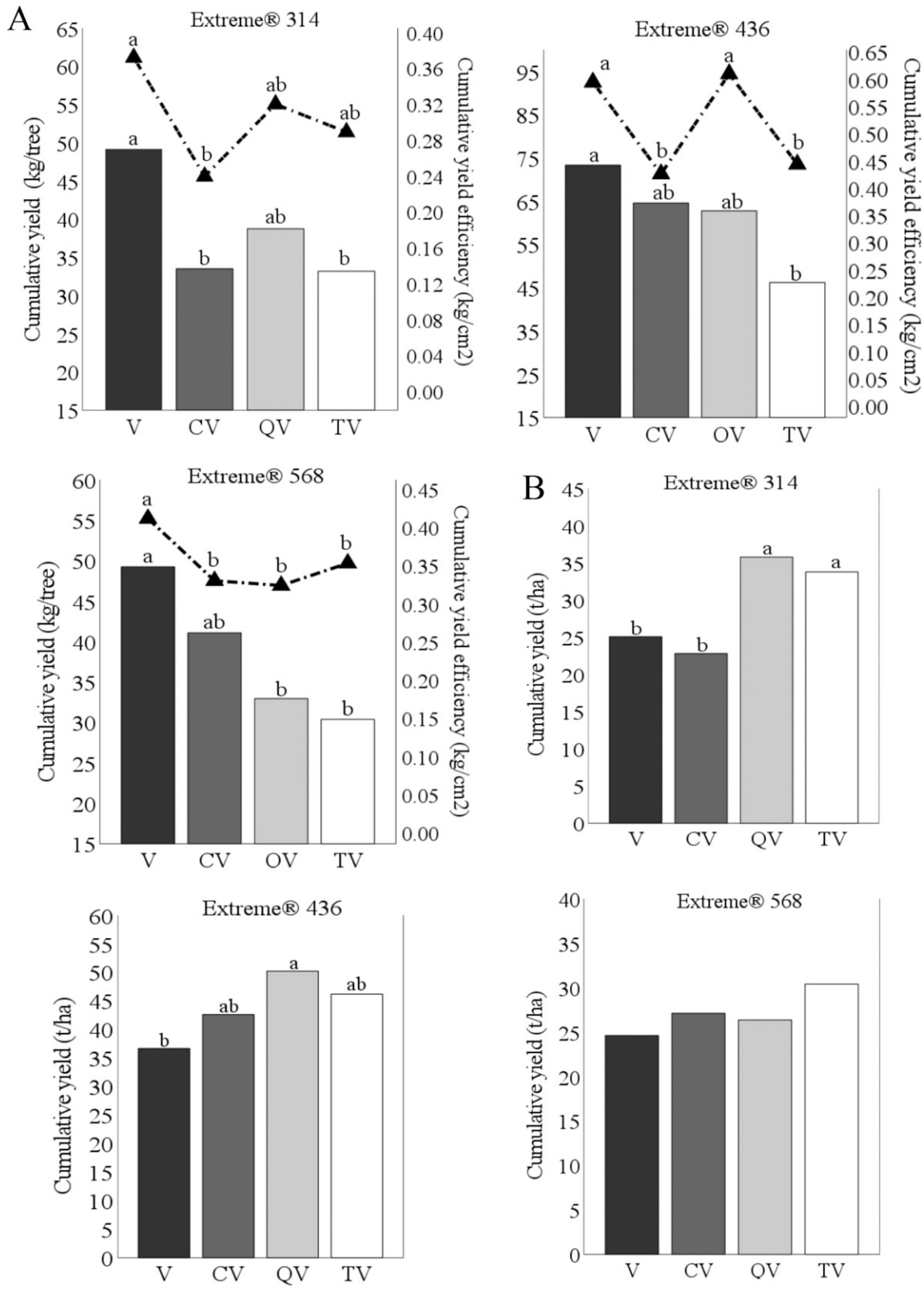

Fig. 1. Cumulative yield (kg/tree) and yield (t/ha) of peach cultivars were trained to different training systems. Different letters indicate a significant difference according to the Duncan test, $P \leq 0.05$. V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

In the study, the system was composed of six to seven main branches. Consistent with this, Mazzoni et al. (2022) reported that in the Catalan Vase system, there was a difference in fruit size between six and four main branches depending on the cultivars. Flesh firmness was affected by training systems (Table 6). The highest firmness was obtained from Tri-V system for Extreme® 436 and Extreme 568 cultivars, and the lowest was obtained from the Catalan Vase system. According to breeder data, all three cultivars must be harvested at ≈44.12 N firmness (personal communication with Viveros Provedo's representative on 14 May 2023).

As a fruit development characteristic, firmness decreases during maturity progress. From this point, when a system has higher firmness values on the same day, it indirectly means harvesting should start later. The Catalan Vase training system may promote earlier ripening, whereas the Tri-V system could

Table 6. Fruit characteristics of peach cultivars trained according to different training systems (2019 to 2022).

TS	Fruit wt (g)	Fruit diam (mm)	Fruit firmness (N)	TA (g/100 mL)	SSC (°Brix)	SSC/TA	L	C	Hue (°)
				Extreme® 314					
V	179.43	69.34	47.46	0.38	12.26	34.45	31.86	26.06	25.45^{b}
CV	169.62	67.99	49.71	0.40	12.53	31.71	35.11	26.83	28.54^{b}
QV	173.56	69.86	43.93	0.36	12.36	34.60	34.28	24.87	28.78^{ab}
TV	163.34	67.44	42.07	0.36	12.11	33.94	34.25	27.28	29.22^{a}
Mean	171.49^{C,i}	68.66^{C}	47.03	0.37^{A}	12.31^{B}	33.67^{C}	33.87^{C}	26.26^{B}	28.00^{C}
				Extreme® 436					
V	231.85^{a}	75.65^{a}	46.87^{b}	0.33	14.96	47.03^{a}	34.38	34.91	29.42^{b}
CV	202.26^{b}	71.46^{b}	43.44^{b}	0.38	14.26	38.49^{b}	37.08	36.91	32.58^{ab}
QV	197.68^{b}	71.80^{b}	46.87^{b}	0.37	15.25	45.26^{ab}	36.86	34.71	31.03^{ab}
TV	204.33^{b}	73.24^{ab}	56.48^{a}	0.36	14.87	40.81^{ab}	38.01	37.26	34.37^{a}
Mean	209.03^{B}	73.04^{B}	45.72	0.36^{A}	14.83^{A}	42.90^{B}	36.58^{B}	35.94^{A}	31.85^{B}
				Extreme® 568					
V	253.76^{a}	77.95^{a}	47.56^{a}	0.27^{bc}	13.36^{b}	49.46^{b}	40.54	34.80	36.28^{b}
CV	225.86^{c}	75.27^{b}	40.69^{b}	0.33^{ab}	15.05^{a}	49.23^{b}	39.01	36.74	37.81^{ab}
QV	246.37^{ab}	77.97^{a}	49.52^{a}	0.24^{c}	14.91^{a}	66.10^{a}	39.71	33.71	39.43^{a}
TV	241.31^{b}	76.28^{ab}	50.79^{a}	0.39^{a}	15.62^{a}	42.86^{b}	40.90	36.61	39.35^{a}
Mean	241.83^{A}	76.87^{A}	47.14	0.31^{B}	14.73^{A}	51.91^{A}	40.04^{A}	35.46^{A}	38.22^{A}

[i] Different lowercase letters indicate differences between training systems according to cultivars, while uppercase letters indicate cultivar differences according to the Duncan test ($P \leq 0.05$). TS = training system, TA = titratable acidity, SSC = soluble solids content, L = lightness, V = Vase, CV = Catalan Vase, QV = Quad-V, TV = Tri-V.

potentially delay it. Marini (1985) reported that summer pruning in peaches stimulates shoot growth and increases firmness. In the Tri-V system, because the formation of lateral branches from the main branches is not allowed, severe summer pruning might have affected ripening and, as Marini (1985) stated, could have increased the firmness of the fruits. Similarly, Uberti et al. (2019) reported that V systems promote later but more homogeneous fruit ripening. In the Catalan Vase system, increasing the number of leaders per tree allows spacing of the leaders closer together for more efficient light interception and fruitwood formation with a reduced presence of excessively vigorous (and shade-inducing) shoots. This could potentially lead to earlier ripening of the fruit.

Training systems and cultivars affected the titratable acidity (TA). Differences among training systems were observed only for the Extreme® 568 cultivar. The higher TA was obtained from fruits trained to the Tri-V (0.39 g/100 mL) and Catalan Vase (0.33 g/100 mL) systems (Table 6). In the present study, the lowest TA was measured from Vase and Quad-V showed substantial similarity to Lal et al. (2017) findings. SSC was affected by the training system and cultivars. The highest SSC was obtained from Tri-V, Quad-V, and Catalan Vase for Extreme® 568 (Table 6). Open Vase, Catalan Vase, or V-shaped systems that share this similar shape can maintain a higher level of light interception at solar noon, given their open and receptive shape. However, planting density plays an important role in the emergence of differences in light interception. More densely planted V systems maximize light interception while maintaining even distribution throughout the canopy (Grossman and DeJong 1998; Sansavini and Corelli-Grappadelli 1997; Silviera Pasa et al. 2017). Therefore, the higher SSC in the V systems compared with the Vase system in the study could be related to the distribution of light. The influence of training system on SSC is not always clear. Some recent studies reported the influence of the training system on fruit SSC (Silviera Pasa et al. 2017; Taylor 2003), and others did not (Lal et al. 2017).

The effect of the cultivar within the training system on the lightness (L) values was statistically significant (Table 6). All training systems obtained the highest L values from the Extreme® 568 and the lowest from the Extreme® 314 cultivar. The lowest C and hue values and darker red color were obtained from the Extreme® 314 cultivar, and more yellowish tones were obtained from the Extreme® 568 cultivar in all training systems. Hue values significantly differed between training systems, and the lighter-colored fruits (highest hue values) were obtained from Tri-V (34.31°) and the darker ones from Vase (30.38°) (Table 6). Similarly, Robinson et al. (2006) found that the best color was obtained from the Open center system compared with Quad-V, Perpendicular V, and Slender Spindle systems. In the Vase system, the open canopy architecture tends to promote darker fruit color unless there is shading within the canopy (DeJong et al. 2008). The study suggests that darker fruit color in the Vase system may be related to trees not yet fully filling the row spacing and undergoing sufficient summer pruning, thereby reducing shading within the canopy. However, once the Vase system fills out the row and reaches full productivity, it can compromise quality and often fails to provide sufficient light penetration to the lower parts of the trees, leading to shading and potential declines in fruit color and quality (DeJong et al. 2008; Lal et al. 2017). Also, the Catalan vase system, characterized by its wide branch angles and open structure, has demonstrated results similar to Vase. However, the effect of training systems on fruit color is not consistently evident. Although some recent studies have documented the effect of training systems on fruit color (DeJong et al. 2008; Robinson et al. 2006; Sharma et al. 2018), Taylor (2003) reported that fruit ground color did not affect the training system and was affected by the position of the fruit on the shoot and the height in the crown.

Conclusion

The present study compares different peach tree training systems for their impact on growth characteristics, yield, and labor efficiency of newly released cultivars as alternatives to the Vase system. Results indicate that these systems enhance yield and fruit quality while reducing labor costs. The Quad-V and Tri-V systems maximize yield per hectare and reduce pruning, thinning, and harvesting costs; however, requiring higher initial investment because of higher tree density. The Quad-V system stands out for its efficient winter pruning compared with the Tri-V system despite similar tree density. The Vase and Catalan Vase systems have lower establishment costs because of lower tree density but require more complex pruning, especially the Vase system. The Catalan Vase system shows advantages in labor efficiency and early high yields compared with the Vase system. Preliminary findings suggest that Catalan Vase and Quad-V systems were superior to standard Vase systems, particularly in higher productivity and lower worker costs for all cultivars without affecting fruit quality in terms of fruit size, SSC, and color. However, especially when the Extreme® 436 cultivar trained according to the Catalan Vase and Quad-V systems, its trees developed quite well and started filling the rows allocated to them, which increased the yield per unit area. Further evaluations are needed to assess long-term productivity and labor efficiency accurately. The selection of an appropriate training system should consider local conditions, available rootstock genotypes, labor availability, economic feasibility, and growers' expertise.

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