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Earliness, yield, and fruit quality characteristics in low chill peach-nectarines: a comparison of protected and open area cultivation

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Abstract: This study was carried out to determine the effects of protected cultivation on the earliness, yield, and fruit quality characteristics of some low chill peach-nectarine cultivars grown in the eastern Mediterranean region of Turkey. Phenological observations, yield parameters, and fruit quality characteristics were investigated. The chilling durations as CH (chilling hours), CU (chilling unit), and heat accumulations were determined. The 'Astoria' cultivar reached the highest cumulative yield of 29.11 kg/tree and 38.72 t/ha, and fruit size was 131.89 g and 61.74 mm in protected cultivation. The CH and CU values under protected cultivation were 28% and 40% lower than in open area cultivation, respectively. The heat accumulation was 30% higher for GDH30 in the protected cultivation. The results of this study revealed that low chill peach-nectarine cultivars grown in protected cultivation showed variable earliness, yield, and fruit quality depending on chilling duration and heat accumulation.

Key words: Early harvest, peach-nectarine, performance, protected cultivation

1. Introduction

Peach-nectarines are one of the leading fruit species in the world, after apples, in terms of annual production. Several new cultivars are improved due to the high ability of peach-nectarines to adapt to different ecologies, early cultivars with attractive fruit, and regular yields (Fideghelli et al., 1998; Kuden et al., 2010).

Turkey is the fifth peach-nectarine producer in the world after China, Italy, Greece, and Spain.[1] The primary production areas in Turkey are located in the Mediterranean region, Mersin and Antalya; in the Marmara region, Bursa and Çanakkale; and in the Aegean region, İzmir and Denizli, respectively. Production of peach-nectarine cultivars with early ripening, yield, and the lowchill requirement takes place in the Mediterranean region of Turkey and has significantly increased in the last decades as a consequence of an improvement in orchard systems. In this region, early peach production under both protected and open areas, leads to high economic value in April and May. The trend toward protected cultivation systems has also increased. Currently, the open vase system is commonly used as the orchard system for peach cultivation in Turkey. However, diverse high-density systems are used for commercial peach production.

Fruit consumers prefer cultivars having high quality in the fresh fruit market. The most crucial point is that the fruits that arrive early to the market are preferred because they do not have alternatives and, as a result, are sold at high prices. To dominate the world markets by providing the earliest yields, the cultivation of stone fruits seems very economical under plastic cover (Erez et al., 2000).

The early-ripening cultivars of peach-nectarines are characterized by yellow flesh, cling stones, regular round shape, a red-colored peel cover, resistance to handling and shipping, and medium-high soluble solid content at ripening (Crisosto and Costa, 2008; Ghrab et al., 2016).

The Mediterranean coastline of Turkey is quite a favorable location for early fruit cultivation because of the advantages of its favorable ecology. The cultivars of some stone fruit species such as peach, apricot, and plum in this region, ripen about 10–15 days earlier than those from both other areas of Turkey as well as those from Spain and Italy, which are the critical fruit growing countries of Europe (Imrak et al., 2009; Caliskan et al., 2012). Erez et al. (1998) indicated that there is an excellent opportunity

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in the world peach-nectarine market during the end of March and April and that protected cultivation can have a prominent place. However, few studies have been carried out so far on improving protected fruit cultivation. Falqui et al. (1994) showed that the fruit ripening date of peaches grown under plastic cover is 24–28 days earlier and 17–21 days earlier for nectarines compared with those produced in an open area. Miller et al. (2008) showed that early ripening is a function of early flowering and fruit growth stage in open cultivation. Besides, Layne et al. (2013) reported that stone fruits with low chilling requirements and high fruit quality should be favored for protected cultivation. However, chilling duration and heat accumulation have not been compared between protected cultivation and open area. Moreover, comprehensive researches are needed to improve the performance of early peach-nectarine varieties in the greenhouse.

This study aimed to compare the effects of protected cultivation on earliness, yield, and fruit quality of some low chill peach-nectarine cultivars in the eastern Mediterranean region of Turkey. These critical data will be useful to improve protected fruit cultivation.

2. Material and methods

2.1. Plant material and cultural practices

This study was carried out between 2018 and 2019 in the research area of the Department of Horticulture, Faculty of Agriculture, Hatay Mustafa Kemal University, latitude 36°13′N, longitude 36°09′W and 117 m above sea level, with a typical Mediterranean climate. The soil texture of the experimental area was sandy-clay (39.5% sand, 25.3% clay, 6.10% silt), and a pH of 7.8.

In the study, 'Astoria' and 'Maya' peaches and 'Garbaja' nectarine cultivars (PSB Producción Vegetal, Spain) were used under protected cultivation and in an open area. The cultivars were chosen for their low chilling and heat requirements. The chilling duration expressed as chilling hours (CH) was less than 200 CH for Astoria, less than 300 CH for Garbaja, and was between 300–400 CH for Maya peaches.

The plastic cover was 10.5 m wide, 22 m long, and has a total area of 231 m^2. The side height was 2.00 m and the height of the roof was 4 m with a spring roof. The cultivars were budded on GN15 (Garnem) rootstock and the saplings were planted on May 30 in 2017, at a distance 2 × 3 m.

In protected and open cultivation, "open vase with four main branches" was applied in the concrete pole-wire support system. The main principle of the pruning system was to create 20–25 fruit branches on each main branch. The fruit branches were cut regularly every year, 2–3 on buds after harvest. Thus, fruit branches of the following year were formed during the summer period. In winter pruning, shoots growing upright on the main branches were removed from the bottom and dilution cuts were made on the fruit branches (Hoying et al., 2007). The summer pruning of the trees was done in late March and early April for the protected area and mid-April for the open area, according to Bayazit et al. (2012).

The fertilization system was used at 10–15 day intervals during January and February, seven day intervals in March, April, and May, 14 day intervals in June, July, and August, and 21 day intervals in September, October, and November depending on plant phenological stages and climatic conditions. A fertilizer program was applied, according to Johnson (2008).

When the fruit diameter reached 1.5–2 cm in the cultivars (before the core hardening), fruit thinning was made so that one fruit would remain on every 15 cm on the shoot (Caruso et al., 2015). Standard management was applied against diseases and pests such as leaf curl, leaf aphid, and *Empoasca spp*.

To compare the performance of peach-nectarine cultivars under protected cultivation and in an open area in this study, phenological observations, yield, fruit quality analysis, and fruit set percentages were determined for a total of 5 plants in each cultivar.

In the protected cultivation, all aerations were open throughout the winter, but were closed on January 15–20 based on the climatic conditions and bud burst dates. On the days when the temperature of the air was above 25 °C in the protected area, side aerations were opened between 10.00 AM and 4.00 PM.

2.2. Heat requirements

The temperature values in both cultivation areas were recorded hourly with a data logger (Testo 174H). The quantification of chill requirements was calculated by two different methods: (i) the CH model described by Kuden and Kaska (1992), as the number of hours below 7.2 °C and above 0 °C and (ii) the chill unit (CU) model (Richardson et al., 1974), which considers positive and negative chill unit contributions depending on air temperature during the dormancy period as follows: < 1.4 °C, 0 CU; 1.5–2.4 °C, 0.5 CU; 2.5–9.1 °C, 1.0 CU; 9.2–12.4 °C, 0.5 CU; 12.5–15.9 °C, 0 CU; 16.0–18.0 °C, –0.5 CU; > 18.0 °C, –1.0 CU.

Heat requirements were calculated as the accumulation of growing degree hours (GDH) based on hourly air temperatures above 4.5 °C (Sawamura et al., 2017). Trees have no additional growth advantage at temperatures above 25 °C; therefore, the temperatures above 25 °C were accepted as equal to 25 °C. The GDH1 (GDH30) was calculated for 30 days after full flowering. The GDH2 was investigated from the full flowering to the date when fruits were ripened. The days from full bloom to harvest (FBD; days) were also determined.

2.3. Phenological observations

Phenological traits including first flowering (5% of open flowers), full flowering (70% of open flowers, end of flowering (falling 95% of flower petals), harvest date, and harvest duration (days) were observed. Besides the number of days from full bloom to harvest, bud numbers per shoot, flowering percentage, initial fruit set, and final fruit set percentages were determined (Westwood, 1995). For these observations, a total of four branches selected randomly per tree from different directions were used. The flower buds of each tagged branch were counted and the flowering percentage was calculated by calculating the proportion of open flowers to flower buds. At the end of flowering, the percentage of initial fruit sets was evaluated by dividing the number of fruits by the number of flowers. The final fruit set was calculated by taking the proportion of the number of fruits in the ripening stage to the number of total flowers. Multiple pistils were also investigated before fruit thinning, as described by Johnson and Phene (2008).

2.4. Yield parameters

The yield was determined as yield per tree, yield per hectare, and yield per unit trunk cross-sectional area. Besides, the cumulative yield per tree and cumulative yield per hectare was calculated (Westwood, 1995).

2.5. Fruit quality characteristics

Fruits were harvested at the full ripening stage, total soluble solids (TSS) above 10% (Kader, 1999). For each cultivar, 30 fruits were randomly sampled for the fruit quality analyses. Fruit weight (g) and seed weight (g) was calculated with a scale sensitive to 0.01 g (Precisa XB 2200C, UK). A digital calliper (0–150 mm; Mitutoyo, Kawasaki, Japan) was used to determine fruit diameter (mm) and fruit length (mm). The fruit shape index was evaluated by dividing the fruit height to fruit diameter. The fruit firmness was investigated for each replicate, measuring the force (in kg) required by an 8 mm probe to penetrate the peeled surface in two different regions of the fruit mesocarp, using a digital penetrometer (TR Turoni Srl, Forli, Italy). The TSS content was determined with a digital refractometer (Atago, 0%–53% Brix, Japan) and pH was measured using a pH meter (Orion 3 Star pH meter, Thermo Fisher Scientific, Waltham, MA, USA). Titratable acidity (expressed as citric acid %) was investigated by titrating with 0.1 N NaOH to pH 8.10.

The colors of fruit skin and flesh were measured with a colorimeter (Chroma Meter CR-300, Konica Minolta Co., Tokyo, Japan). The measurements were performed as L*, a*, b*, *C*, and *h*°. In the system, L shows color brightness, low for dark colors, and high for bright colors; a* is negative for green and positive for red, and b* is negative for blue and positive for yellow. Chroma (*C*) is the color's intensity and hue value also shows the angle value of the color. The color measurements were investigated at two opposite positions per fruit (Colantuono et al., 2012).

2.6. Statistical analysis

Data were analyzed using SAS software and procedures (SAS, 2005). Analysis of variance (ANOVA) tables were constructed with Fisher's least significant difference (LSD) method at $P < 0.05$. Percentage values were transformed to arcsine, before analysis of variance.

3. Results and discussion

3.1. Heat requirements

According to the mean temperature data collected during January and December (Figure 1), the average temperatures under protected cultivation were 2 °C higher in January, 4–7 °C higher in February, 2–4 °C higher in March, 3–5 °C higher in April, and 2–4 °C higher in May than in the open area temperatures in the eastern Mediterranean region of Turkey. This increase in average temperature was one of the most significant reasons for early flowering and ripening as protected cultivation provided more accumulation of growth degree temperatures.

Chilling values of protected and open areas were shown in Figure 2. The highest chill accumulation in both cultivation areas occurred in December and January; however, there were significant differences between their chilling duration. In 2018, 295 CH and 203 CU chilling values accumulated under protected cultivation while 392 CH and 301 CU chilling values occurred in the open area. The chilling values were 308 CH and 173 CU under protected cultivation, whereas it was 485 CH and 346 CU in the open area in 2019. The chilling duration under protected cultivation was lower than 97 CH and 177 CH and lower than 98 CU and 173 CU in 2018 and 2019, respectively, compared to the open area. These results were the first data on the chill period, which were the main problem in protected cultivation. Therefore, Miller et al. (2008) suggested that the peach-nectarine cultivars that will be grown under protection should be exposed to less than 400 CH of chilling time to avoid an insufficient chilling problem. However, our data showed that excellent performance could be obtained with cultivars that have a chilling time below 200 h (such as 'Astoria') in the protected cultivation. Otherwise, bud drops, irregular flowering and foliation, empty areas on the branches, low fruit set and yield, and poor fruit quality can occur (Erez, 2000; Yong et al., 2016). Therefore, more detailed studies are required on the effects of dormancy-breaking agents (Dozier et al., 1990; Ionescu et al., 2017) and evaporative cooling (Sheard and Savage, 2001) on the chilling duration under protected cultivation.

The number of days from full flower to harvest was the lowest in the 'Astoria' cultivar (67 and 81 days, respectively) grown in protected cultivation, in 2018

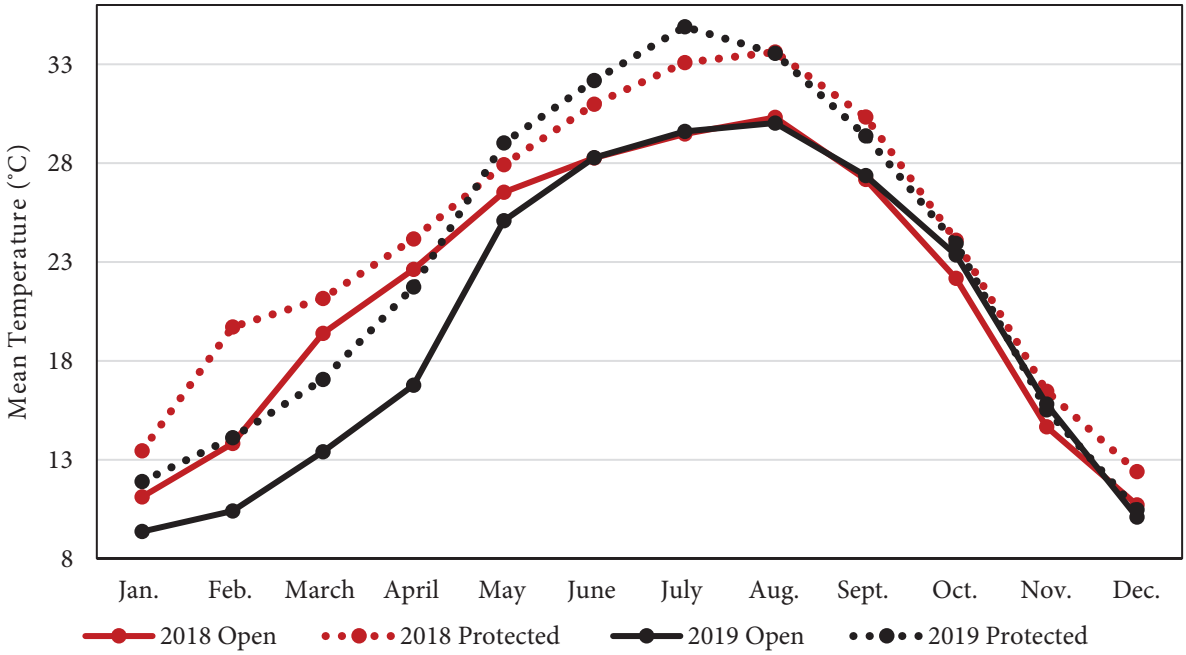

Figure 1. Mean temperature (°C) values of protected and open areas in 2018 and 2019.

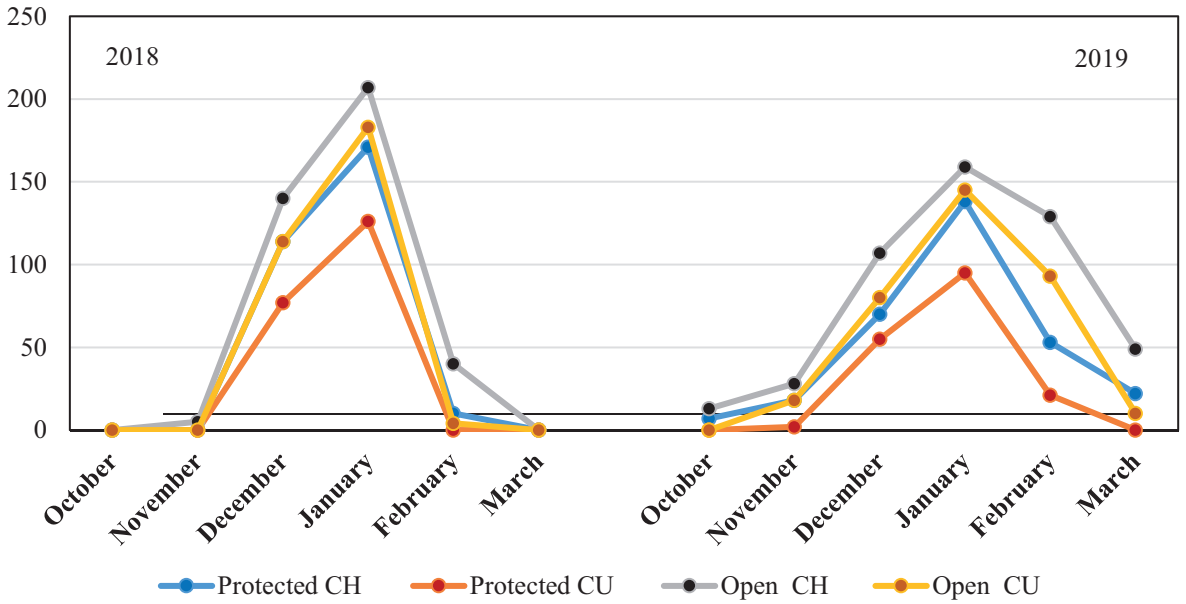

Figure 2. Chilling durations (CH: chilling hours; CU: chill unit) of protected and open areas in 2018 and 2019.

and 2019 (Table 1). In 2018, GDH1 ranged from 7672 ('Garbaja' and 'Maya') and 7742 ('Astoria') in protected cultivation while it varied between 7318 ('Astoria') and 7471 ('Maya') in the open area. Similarly, GDH1 values were higher in the protected area. These results were similar to those obtained by Lopez et al. (2007), who displayed that high GDH accumulation during the first 30 days after bloom can create early fruit ripening. The GDH2 value was the highest in the 'Garbaja' cultivar (30,179 and 22,289, respectively) in the protected cultivation, in 2018 and 2019. Besides, GDH2 values in the open area ranged between 19,159 and 21,665 in 2018, whereas these ranged between 14,127 and 17,800 in 2019. Generally, the high GDH1 and low GDH2 values of the cultivars under protected cultivation were evaluated as significant characters of earliness and fruit size. The data

was similar to those reported by Marra et al. (2002) and Reighard and Rauh (2015).

3.2. Phenological observations

The flowering observations showed that the differences in earliness among cultivars varied from 7 ('Astoria') to 12 ('Garbaja') days in protected cultivation (Figure 3). While the flowering period continued for 18 days under protected cultivation and this period continued for 20 days in the open area. The 'Garbaja' cultivar was earlier than other cultivars with its full flowering date on February 9 in protected cultivation. In the open area, early full blossoming was also observed in the 'Astoria' cultivar (February 20). This result may be because the average temperatures under protected cultivation were 3–4 °C higher in January, 4–6 °C higher in February, and 2–4 °C higher in March than in the open area (Figure 2).

The protected cultivation significantly affected the harvest time of the cultivars (Figure 4). The protected cultivation showed an earliness ranging from 16 to 20 days compared to the open area. While the 'Astoria' cultivar (April 24 and May 14, respectively) ripened the earliest, the harvest date was the latest for the 'Garbaja' cultivar (May 10 and May 26) in both protected cultivation and the open area, respectively. The harvest duration of the cultivars varied from 7 to 8 days in protected cultivation and 4 to 7 days in the open area. In the fruit development period, the average temperatures under protected cultivation were 2–4 °C higher in March, 3–5 °C higher in April, and 2–4 °C higher in May than in the open area (Figure 1). The harvest time was earlier because the cultivars grown in the protected area accumulated a higher level of the required heat and the number of days from full blossoming to harvest was short (Table 1). These results were similar to those reported by Ben Mimoun and DeJong (1999) and Marra et al. (2002). The harvest time also depended on cultivars with low chilling (Sawamura et al., 2017) and location (Marra et al., 2002). In previous studies, the harvest data for peach-nectarines were in the range of May 1–7 in Italy (Falqui et al., 1994) and May 5–16 in Turkey (Kuden et al., 2007).

The cultivation system had a significant effect on bud numbers per shoot, flowering, final fruit set, and multiple pistil percentages (Table 2). The bud numbers per shoot ranged from 18.66 ('Garbaja') to 26.08 ('Astoria') under protection, whereas they varied between 22.25 ('Maya') and 39.47 ('Garbaja') in the open area. The highest bud numbers per shoot were found in the open area (32.10) compared with the protected cultivation (21.53).

The flowering percentage was the highest in the open area (95.95%). However, the differences among cultivars in final fruit percentages were higher in the protected cultivation (59.95%) than in the open area (27.51%). Initial fruit set percentages were not significantly affected by cultivars and cultivation systems. Similarly, Falqui et al. (1994) displayed that the final fruit set of peach-nectarines was the highest in the protected cultivation due to the more favorable climatic conditions.

Multiple pistil formation, which is influenced by the high summer temperatures, water stress during bud differentiation, and the genetic structure of the cultivar

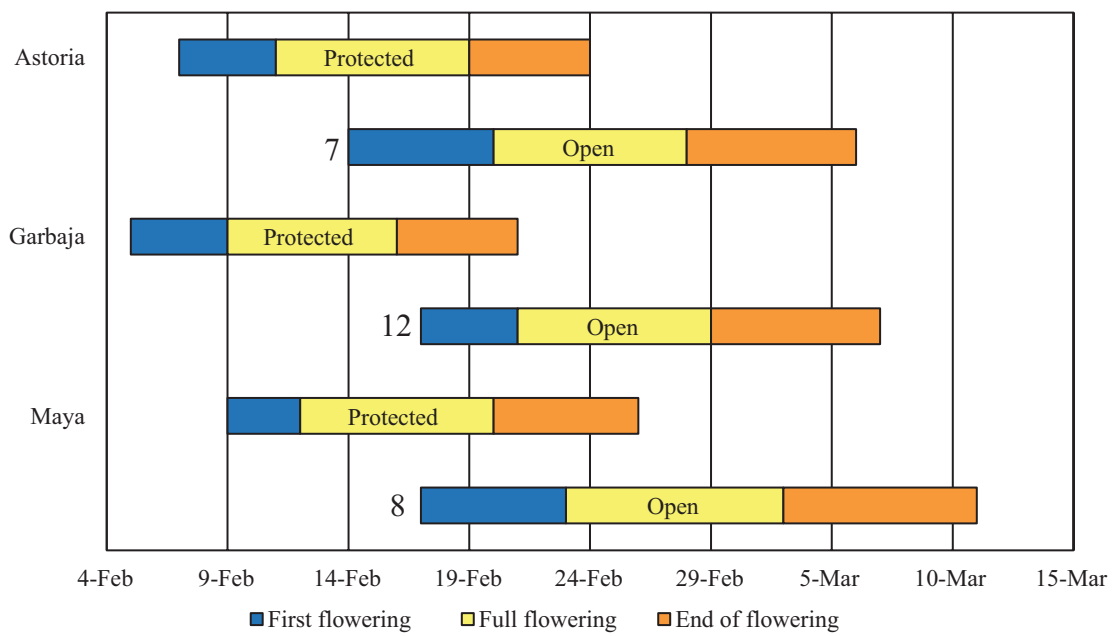

Figure 3. Phenological observation of peach-nectarine cultivars (average results from 2018 and 2019).

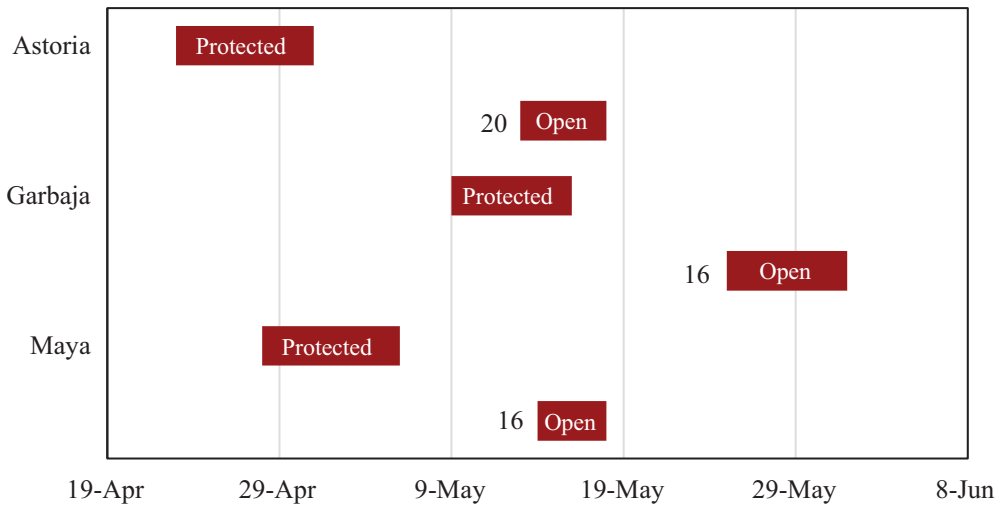

Figure 4. Harvest duration of peach-nectarine cultivars (average results from 2018 and 2019).

Table 1. Number of days from full blossoming to harvest (FBD) and heat requirements (GDH1 and GDH2) of peach-nectarines.

Variable	Cultivars	FBD		GDH			
		2018	2019	2018		2019	
				GDH1	GDH2	GDH1	GDH2
Protected	Astoria	67	81	7742	24703	6459	17667
	Garbaja	77	104	7672	30179	6008	22289
	Maya	77	76	7672	24111	6809	16831
Open area	Astoria	81	88	7318	19159	2935	14303
	Garbaja	92	99	7321	21665	2910	17800
	Maya	78	85	7471	21665	3060	14127

is undesirable in peach-nectarines because it is reduces fruit quality (Handly and Johnson, 2000; Imrak, 2016). In this study, 'Maya' (29.96%) had the highest multiple pistil percentage, followed by 'Astoria' (12.75%) in the protected cultivation. In the open area, the highest multiple pistil percentages were found in 'Astoria' and 'Maya' cultivars (3.83% and 2.64%, respectively). Multiple pistil percentages were higher in the protected cultivation (14.70%) than in the open area (2.33%). These results could be due to the average temperatures being above 30 °C under protected cultivation in the June, July, and August months (Figure 2). Indeed, Imrak (2016) explained that temperatures over 30 °C in June and July increased the formation of multiple pistils in peach-nectarines.

3.3. Yield parameters

Yield parameters of peach-nectarines grown in protected cultivation and the open area are presented in Table 3. The data displays that annual yield values were higher in the open area than the protected cultivation for both yields per tree and hectare. The yield values among cultivars were also statistically significant according to the year and cultivation systems. In the first yield, in 2018, the highest yield per tree was obtained from the 'Astoria' cultivar in protected cultivation (7.75 kg/tree) and the open area (5.21 kg/tree). The 'Astoria' cultivar had the highest yield per tree (21.36 kg/tree) under protected cultivation in 2019, while 'Garbaja' (26.58 kg/tree) and 'Astoria' (25.60 kg/tree) cultivars had the highest yield per tree in the open area. The yield per tree was higher in the open area (22.25 kg/tree) than in protected cultivation (15.24 kg/tree). Falqui et al. (1994) reported that the yield per tree in peach-nectarines grown under protected cultivation was 5.5 kg/tree in the 'Maravilha' cultivar and 4.5 kg/tree in the 'San Pedro' cultivar. Kuden et al. (2007) showed that yields ranged from 8.20 kg/tree to 15.60 kg/tree under protected

Table 2. Bud number per shoot, flowering, fruit set, and multiple pistil percentages of peach-nectarines.

Variable	Bud number per shoot	Flowering (%)	Initial fruit set (%)	Final fruit set (%)	Multiple pistils (%)
Protected					
Astoria	26.08 a	90.24	79.92	65.28	12.75 b
Garbaja	18.66 b	91.66	81.52	54.27	1.39 c
Maya	21.75 b	77.90	71.00	60.26	29.96 a
LSD (5%)	3.57	NS	NS	NS	8.35
Open					
Astoria	31.38 b	99.28	95.23 a	25.28	3.83 a
Garbaja	39.47 a	96.22	75.52 b	30.16	0.52 b
Maya	22.25 c	92.36	58.58 c	27.10	2.64 a
LSD (5%)		NS	7.82	NS	4.59
Cultivation system					
Protected	21.53 b	86.60 b	77.48	59.95 a	14.70 a
Open	32.10 a	95.95 a	75.44	27.51 b	2.33 b
LSD (5%)	7.94	5.89	NS	4.12	4.49

Different letters within columns indicate significant differences by Fisher's LSD (least significant difference) test at $P < 0.05$.
NS: non significant.

Table 3. Yield characteristics of peach-nectarines grown in protected and open area.

Variable	Yield per tree (kg/tree)		Yield per trunk cross-sectional area (kg/cm^2)		Yield per hectare (t/ha)		Cumulative yield per tree (kg/tree)	Cumulative yield per hectare (t/ha)
	2018	2019	2018	2019	2018	2019		
Protected								
Astoria	7.75 a	21.36 a	1.93 a	0.90 a	10.31 a	35.46 a	29.11 a	38.72 a
Garbaja	0.58 b	9.70 b	0.11 b	0.37 b	0.77 b	16.11 b	10.28 b	13.67 b
Maya	1.15 b	14.68 ab	0.13 b	0.36 b	1.53 b	24.30 ab	15.83 b	21.06 b
LSD (5%)	3.71	10.95	0.31	0.26	4.93	18.18	8.08	10.75
Open area								
Astoria	5.21 a	25.60 ab	0.44 a	0.72 a	6.92 a	42.50 ab	30.81 a	40.97 a
Garbaja	0.87 b	26.58 a	0.12 b	0.66 a	1.15 b	44.14 a	27.46 a	36.52 a
Maya	0.99 b	14.57 b	0.09 b	0.32 b	1.32 b	24.20 b	15.71 b	20.71 b
LSD (5%)	1.81	11.36	0.15	0.21	2.41	18.87	11.73	15.60
Cultivation system								
Protected	*3.16*	15.24 b	*0.72 a*	0.54	*4.21*	25.31 b	18.41 b	24.49 b
Open area	*2.35*	22.25 a	*0.22 b*	0.57	*3.13*	36.94 a	24.61 a	32.73 a
LSD (5%)	NS	6.33	0.13	NS	NS	10.50	5.18	6.88

Different letters within columns indicate significant differences by Fisher's LSD (least significant difference) test at $P < 0.05$.
NS: non significant.

cultivation and 8.50 kg/tree and 13.40 kg/tree in the open area for peach-nectarines cultivated in Adana/Turkey. Dolek and Kalyoncu (2014) found that the yield per tree was 17.33 kg in 'Sunfire' nectarines grown in protection. Generally, the data obtained for yield per tree in the second yield age was higher than those reported by Falqui

et al. (1994), Kuden et al. (2007), and Dolek and Kalyoncu (2014). These differences might be due to technical and cultural practices, cultivar, planting, and pruning systems (Meitei et al., 2013; Caruso et al., 2015).

The highest yield per trunk cross-sectional area was found in 'Astoria' and 'Garbaja' cultivars in both cultivation systems and growing seasons. Similarly, the 'Astoria' cultivar under protected cultivation had the highest yield per hectare with 10.31 t/ha and 35.46 t/ha, in 2018 and 2019, respectively. In the open area, the 'Astoria' cultivar had the highest yield per hectare (6.92 t/ha) in 2018, whereas 'Garbaja' and 'Astoria' had the highest yield per hectare (44.14 t/ha and 42.50 t/ha, respectively) in 2019. However, the 'Garbaja' cultivar grown under protected cultivation and 'Maya' cultivar grown in the open area had the lowest yield per hectare values. These results were in agreement with previous studies that showed that the yield of peach-nectarines in the third year, under protected cultivation, can reach 30 tons per hectare (Falqui et al., 1994) and range between 27 t/ha ('Flordaprince') and 35 t/ha ('San Pedro') (Bellini et al., 2000a). Also, Bellini et al. (2000b) reported that the open vase training system (33.5 t/ha) had a higher yield per hectare compared to the Y training system (25 t/ha) grown in protected cultivation.

The cumulative yield per tree and cumulative yield per hectare were higher in the open area (24.61 kg/tree and 32.73 t/ha, respectively) compared to in protected cultivation (18.41 kg/tree and 24.49 t/ha, respectively). In protected cultivation, the 'Astoria' cultivar had the highest cumulative yield per tree (29.11 kg/tree) and cumulative yield per hectare (38.72 t/ha) while the cumulative yield parameters were highest in 'Astoria' (30.81 t/tree and 40.97 t/ha, respectively) and 'Garbaja' (27.46 t/kg and 36.52 t/ha, respectively) cultivars in the open area. The results showed that yield and fruit quality characters of 'Maya' cultivar were low due to insufficient chilling both in the open area and under protected conditions in the eastern Mediterranean region of Turkey. A similar result was obtained from the 'Garbaja' cultivar under protected cultivation. The previous studies on peach-nectarines also reported that irregular flowering, low yield, and poor fruit quality are obtained from cultivars that do not fulfill their chill requirements (Erez, 2000; Yong et al., 2016).

3.4. Fruit quality characteristics

The protected cultivation significantly affected fruit weight, fruit diameter, fruit length, and flesh/seed ratio characteristics (Table 4). However, the fruit height, firmness, seed weight, TSS, pH, and acidity values were not statistically affected by cultivation systems.

The mean fruit weight, fruit size, and flesh/seed ratio values were higher in the open area than protected cultivation. The result was due to the low fruit weight of the 'Maya' cultivar grown in protected cultivation. However, the 'Astoria' cultivar had a higher fruit weight, fruit diameter, fruit length, and fruit height values both in protected cultivation (131.89 g, 61.74 mm, 63.66 mm, 63.81 mm, respectively) and the open area (130.87 g, 63.74 mm, 64.12 mm, 60.27 mm, respectively) than other cultivars. The smallest fruit size was found in the 'Maya' cultivar under protected cultivation and the 'Garbaja' cultivar in the open area. The results were in agreement with those of Kamota (1988), who reported that fruit weight in peach-nectarines grown in protected cultivation was higher than in an open area. Similarly, Falqui et al. (1994) showed that the fruit weight under protected cultivation is 102 g for 'Maravilha' cultivar and 119 g for 'San Pedro' cultivar in Sicily, whereas the fruit weight values of these cultivars are 97 g and 105 g, respectively in open areas. Indeed, when the GDH30 value is higher than 6000 day-Celsius (Lopez and DeJong, 2008) and the temperatures during cell division are close to the optimum (Souza et al., 2019), the fruit size can be positively affected under protected cultivation. Similarly, our results showed that GHD30 values were higher than 6000 day-Celsius in protected cultivation (Table 1).

A round fruit shape is one of the desired quality characteristics in peaches-nectarines. The high temperatures in the fruit development period (Campoy et al., 2011) and the cultivar having insufficient chilling time, causes the fruit shape to be longer (Yong et al., 2016). Actually, in this study, the shape index values of cultivars under protected cultivation (1.05) were higher than in the open area (0.99).

The fruit firmness was the highest in the 'Garbaja' cultivar in both protected cultivation and the open area (5.71 kg-force and 5.00 kg-force, respectively). The highest seed weight was detected in 'Garbaja' and 'Astoria' cultivars in both cultivation systems. In the open area, 'Maya' and 'Astoria' cultivars had the highest flesh/seed ratio (16.57 and 14.53, respectively).

Minimum harvest criteria are accepted as 10% TSS for yellow-fleshed peach-nectarines in Europe and the USA (Crisosto and Costa, 2008). 'Garbaja' and 'Astoria' cultivars had the highest TSS (10.68% and 10.48%, respectively) under protected cultivation. The highest TTS was found in 'Garbaja' (11.83%) in the open area. The TSS was not statistically affected by cultivation systems. Besides, 'Garbaja' had the highest acidity values in both cultivation systems.

Consumer acceptance of peaches has been related to soluble solid concentration, acidity, or soluble solid concentration/acidity ratio; however, the main attribute factor is fruit color (Crisosto and Costa, 2008). The protected cultivation significantly affected the fruit skin and flesh color characteristics (Table 5). The fruit skin lightness (L) value of the cultivars was the highest under protected cultivation. In contrast, red skin color with high

Table 4. Fruit quality attributes of peach-nectarines grown under protected and open area (average results from 2018 and 2019).

Variable	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit height (mm)	Fruit shape index	Firmness (kg-force)	Seed weight (g)	Flesh/seed ratio (%)	TSS (%)	pH	Acidity (%)
Protected											
Astoria	131.89 a	61.74 a	63.66 a	63.81 a	1.03	3.54 b	12.32 a	10.25	10.48 a	3.71	1.07 b
Garbaja	120.05 b	57.81 b	59.98 b	60.84 b	1.05	5.71 a	10.11 a	10.38	10.68 a	3.27	1.37 a
Maya	69.88 c	49.05 c	50.54 c	54.05 c	1.10	4.59 ab	7.16 b	8.97	9.68 b	3.44	0.89 c
LSD (5%)	10.33	2.10	2.23	1.80	NS	1.20	2.51	NS	0.72	NS	0.15
Open area											
Astoria	130.87 a	63.74 a	64.12 a	60.27 a	0.95	4.05 b	8.43 b	14.53 a	10.03 b	3.37	1.07 b
Garbaja	103.58 c	55.87 c	58.10 c	55.32 b	0.99	5.00 a	10.08 a	9.10 b	11.83 a	3.32	1.58 a
Maya	121.17 b	60.39 b	61.65 b	61.56 a	1.02	3.73 b	7.42 c	16.57 a	10.06 b	3.39	0.95 c
LSD (5%)	8.03	1.57	1.48	2.36	NS	0.47	0.52	1.66	1.06	NS	0.11
Cultivation systems											
Protected	107.27 b	56.20 b	58.06 b	59.57	1.05 a	4.62	9.86	9.87 b	10.28	3.48	1.11
Open	118.54 a	60.00 a	61.29 a	59.05	0.99 b	4.26	8.64	13.40 a	10.64	3.36	1.20
LSD (5%)	5.38	2.94	2.95	NS	0.05	NS	NS	1.62	NS	NS	NS

Different letters within columns indicate significant differences by Fisher's LSD (least significant difference) test at $P < 0.05$.
NS: non significant.

Table 5. Fruit skin and flesh color characteristics of peach-nectarines grown under protected and open areas (average results from 2018 and 2019).

Variable	Fruit skin color					Fruit flesh color				
	L	a*	b*	*C*	*h*°	L	a*	b*	*C*	*h*°
Protected										
Astoria	56.81 a	23.48 b	31.75 a	40.81 b	54.66	77.08 a	–1.08 a	55.09 b	55.49 b	90.60 b
Garbaja	42.82 b	34.09 a	24.05 b	42.49 a	54.16	73.38 b	–1.35 a	59.43 a	59.78 a	90.90 b
Maya	57.90 a	21.69 b	32.77 a	40.73 b	57.87	79.27 a	–4.98 b	52.55 b	52.91 b	95.29 a
LSD (5%)	2.48	2.41	2.98	NS.	NS	3.42	3.54	3.04	2.71	4.14
Open area										
Astoria	45.07	28.79 b	20.73	35.83 b	35.08	74.27 a	2.38 b	55.95 b	56.36 b	87.17 b
Garbaja	43.59	29.79 b	23.66	40.27 a	37.37	73.74 a	–2.97 c	64.99 a	65.09 a	92.62 a
Maya	45.49	33.68 a	24.07	41.98 a	34.60	69.69 b	7.32 a	52.87 c	54.28 c	81.50 c
LSD (5%)	NS	2.62	NS	2.37	NS	2.1	2.94	1.5	0.93	3.74
Cultivation systems										
Protected	52.52 a	26.42 b	29.52 a	41.34 a	48.90 a	76.58 a	–2.47 b	55.69 b	56.06 b	92.26 a
Open	44.72 b	30.75 a	22.82 b	39.36 b	35.68 b	72.57 b	2.24 a	57.94 a	58.58 a	87.09 b
LSD (5%)	3.52	3.07	3.67	1.47	7.33	1.68	2.05	1.53	1.29	2.47

Different letters within columns indicate significant differences by Fisher's LSD (least significant difference) test at $P < 0.05$.
NS: non significant.

positive a* values was found in the cultivars grown in the open area (except for 'Garbaja'). Also, the cultivars grown in the open area had a darker fruit skin color (low *C* and *h*° values). These results were in agreement with those of Giovanelli et al. (2014), who displayed that low L values of fruit skin color can be explained by having low *h*° values. In

this case, fruits with low *C* and *h*˚ value have an increased number of anthocyanins with more red color (Jia et al., 2005). However, the b* value indicating yellowish in the fruit skin was the highest in cultivars grown under the protected cultivation.

The fruit flesh color a* (2.24), b* (57.94), and *C* (58.58) values were the highest in protected cultivation. A yellow color (high b* value) of fruit flesh in peaches is often preferred by consumers, probably because of their higher level in orange carotenoids (Vizzotto et al., 2006). The data showed that there was no severe loss of fruit skin and flesh colors in peach-nectarines grown in protected cultivation. Kelley et al. (2015) indicated that peach consumers prefer red color over the yellow peel. Therefore, the reflective mulch (Layne et al., 2001) can be used to increase preharvest fruit exposure to sunlight and enhance the red skin color, and tree canopy management can be arranged in such a way that it provides sufficient light under protected cultivation.

4. Conclusion

Protected cultivation of stone fruits such as peach-nectarine, apricot, and plum has developed remarkably in the Mediterranean region of Turkey in recent years. To our knowledge, this was the first detailed study comparing the protected cultivation of low chill peach-nectarine cultivars. The harvest time of peach-nectarines grown in protected cultivation provided an earliness of 16–20 days compared to the open area. The earliness of the protected cultivation was due to the cultivars with low chilling and higher heat accumulation. The 'Astoria' cultivar that had less than 200 CH showed an excellent performance in protected cultivation in terms of earliness, yield, and superior fruit quality characteristics, in the eastern Mediterranean region of Turkey. Also, 'Astoria' and 'Garbaja' cultivated in an open area were promising cultivars for earliness for peach-nectarine growing in the region. This data can be used in improving the low chill peach-nectarines in protected cultivation.

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