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Fruit Yield and Quality Performance of Low Chilling Nectarine Cultivars under Mediterranean Climate

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ABSTRACT

This study was carried out to investigate fruit yield and quality characteristics among new nectarine cultivars grown in the eastern Mediterranean region of Turkey. 'Gardeta', 'Gartario', and 'Garofa' nectarine cultivars were cultivated on 'GN15' rootstock. The flowering stage, fruit set percentage, yield, and fruit quality properties of these cultivars were investigated between 2018 and 2021. During the study, chill requirements ranged between 391 and 600 chilling hours and between 207 and 361 chill units in the area, and huge values were obtained for the average initial fruit set above 60% and the final fruit set above 45%. 'Gardeta' had the highest cumulative yield per tree (80.15 kg tree^{-1}) and cumulative yield per hectare (133.04 tons ha^{-1}). The fruit size, Total Soluble Solids (TSS) content, and fruit coloration were homogeneously distributed in all three cultivars. In addition, the Flowering (F) and Initial Fruit Set (IFS) characters were negatively correlated with Fruit Weight (FW), Fruit Length (FLE), and Fruit Diameter (FD). As a result, the 'Gardeta' was found remarkable with late flowering, the highest yield, and superior fruit quality characteristics such as size, red skin color, and high TSS/total acidity values in the eastern Mediterranean region of Turkey. In addition, the date of Full Flowering (FF) and Fruit Firmness (FF) were negatively correlated with fruit Skin color L* (SL), *C* (SC), and *h*° (SH) variables. The results demonstrated that the new nectarine cultivars used here showed changes in yield parameters and fruit quality attributes depending on the genotypic and environmental effects.

Keywords: Adaptability, Fruit color, Fruit set, Fruit size, *Prunus persica*.

INTRODUCTION

Nectarines (*Prunus persica* var. *nucipersica*) are widely cultivated in temperate and warm regions, partly due to the availability of several cultivars that have high quality, are productive, and adapt to different ecological conditions (Byrne *et al*., 2012). The peach-nectarines is the third most important temperate tree fruit species behind apples and pears. Peach-nectarines are harvested worldwide on 1,491,817 ha with a production of 24,569,744 tons in 2020 (FAOSTAT, 2022). The main producer countries are China, which accounts for about 61% of the world production, followed by Spain (5.3%), Italy (4.1%), Turkey (3.6%), and Greece (3.6%).

In Turkey, peach production areas have improved in the past two decades as a result of the widespread of new cultivars, planting, and training systems. Generally, the peach-nectarine season in Turkey covers 6 months, starting in April, from protected cultivation in the Mediterranean region, and it continues until the end of September in the Marmara Region. Further, the per capita consumption of peaches has increased to 7.6 kg per year in 2021 compared to 1.5 kg per year in 2000 (TUIK, 2022). The Mediterranean region of Turkey has suitable areas for early peach-nectarines with low chilling requirements (Çalışkan *et al*., 2021a). The particular climate of the region allows for the production of extra-early and early ripening peaches in the coastal areas as well as

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medium ripening peaches on inland and hillsides.

Peach-nectarines can have cultivars suitable for consumer preferences with differences in size, color, shape, and taste (Belisle *et al.*, 2018). New peach-nectarine cultivars are released each year from different breeding programs and they have different organoleptic characteristics. However, new peach-nectarine cultivars need to adapt to the ecological conditions of the region where they are introduced. This is critically important to better identify the advantages of the cultivars with high yield and fruit quality characteristics and suitability for consumer preferences (Cantín *et al.*, 2009a).

Many studies have been conducted over nearly 70 years to understand the factors that affect tree performance and fruit quality. For this purpose, many studies are carried out on the performance of different ecological conditions (Font i Forcada *et al.*, 2020) and training systems (Caruso *et al.*, 2015; Mazzoni *et al.*, 2022) on the new peach-nectarine cultivars.

Kaşka *et al.* (1981) reported that the Mediterranean region of Turkey is early compared to other southern European countries due to its latitude being at 36 and 37 degrees and that each unit decrease in latitude provides 4-5 days of earliness. Besides Kaşka (2001) indicated that the performance of an adaptation of new cultivars should be examined and notable cultivars should be cultivated due to the continuous updating of peach-nectarine cultivars with low chilling accumulation, ripening at different harvest periods, and suitable for consumer preferences. Chilling requirement knowledge plays a primary role in selecting suitable cultivars for the growing area (Aslamarz *et al.*, 2009). On the other hand, climate change affects chilling and heat accumulation values, which are vital for fruit set and yield (Campoy *et al.*, 2019; Bielenberg, and Gasic, 2022). Thus, the chilling durations, late spring frosts, and summer temperatures of the region should also be evaluated for the sustainable yield and fruit quality in peach-nectarine cultivation (Ghrab *et al.*, 2016).

The objective of this study was to investigate the performance of low-chilling early nectarine cultivars grown in the eastern Mediterranean region of Turkey.

MATERIALS AND METHODS

Plant Material and Cultural Practices

This study was carried out between 2018 and 2021 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 altitude 117 m), Hatay, Turkey. The soil texture of the studied area was sandy clay (39.5% sand, 25.3% clay, 6.10% silt), with a pH of 7.8. According to the climate data of the study area, the minimum temperatures were rarely below 0°C in February (Figure 1).

The mean temperatures and sunshine duration during the flowering and fruit development stages, March to June, were higher in 2021 and 2018 than in 2019 and 2020. Also, no precipitation was recorded in May of 2019 and 2021.

‘Gardeta’, ‘Gartario’, and ‘Garofa’ nectarine cultivars (PSB Producción Vegetal, Spain) were used in the study. The cultivars were preferred for mid-early cultivation with their low chilling and heat requirements. The chilling durations are indicated as Chilling Hours (CH) was less than 400 CH for the cultivars. The cultivars budded on GN15 (Garnem) rootstock and the saplings were planted in 2017, at a distance of 2.0×3.0 m. A tri-V pruning system with wire-supported was applied to the trees (Robinson *et al.*, 2012). The summer pruning of the trees was applied in mid-April (Çalışkan *et al.*, 2021a).

The fertilization system was used at 10-15 days intervals during January and February,

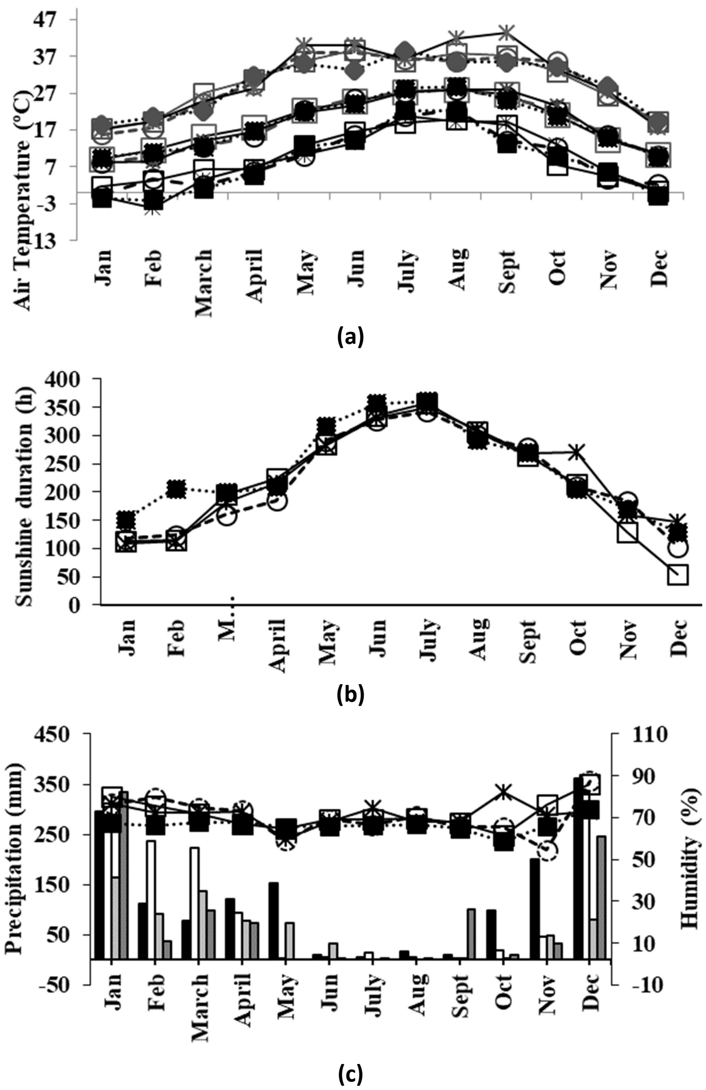

Figure 1. Meteorological data for Hatay, in the eastern Mediterranean region of Turkey. (A) Minimum, maximum, and average air temperatures in 2018 (□), 2019 (○), 2020 (ж), and 2021 (■); (B) sunshine duration in 2018 (□), 2019 (○), 2020 (ж), and 2021 (■); (C) precipitation level in 2018 (black columns), 2019 (white columns), 2020 (light grey columns), and 2021 (grey columns) and mean humidity in 2018 (□), 2019 (○), 2020 (ж), and 2021 (■).

seven days intervals in March, April, and May, 14-day intervals in June, July, and August, and 21 days intervals in September, October, and November depending on plant phenological stages and climatic conditions. A fertilizer program was applied, as described by Johnson (2008). In the thinning application, up to a month after full flowering, one fruit was left at every 15 cm (Caruso *et al.*, 2015). Standard management was applied against diseases such as leaf curl, powdery mildew, and pests such as aphids and *Empoasca* spp. To compare the performance of nectarines in this study, phenological observations, yield, fruit quality analysis, and fruit set percentages were determined for a total of 5 plants in each cultivar.

Heat Data

The air temperatures were recorded hourly using a data logger (Testo, Lenzkirch, Germany). The chill requirements were determined by two different methods as a chill hour (CH) model (Weinberger, 1950) and the Chill Unit (CU) model (Richardson *et al.*, 1974). The numbers of hours below 7.2°C and above 0°C were calculated for CH. For the CU, the positive and negative chill unit contributions were considered 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. In addition, the sum of Growing Degree Hours (GDH) was determined based on hourly air temperatures above 4.5°C as defined by Sawamura *et al.* (2017). Temperatures above 25°C have no additional growth advantage for trees; therefore, temperatures above 25°C are considered equal to 25°C. These temperatures were calculated for 30 days after full flowering (GDH1) and for the days from full flowering to harvest (GDH2). In addition, the days from full flowering to harvest (FBD; days) were also counted.

Phenological Stages

Phenological stages include first flowering time (5% of open flowers), Full Flowering time (FF; 70% of open flowers), end of flowering time (falling 95% of flower petals), the number of days from full flowering to the harvest (FBD) and Harvest Date (HD) were observed. The Flowering percentage (F), Initial Fruit Set (IFS), and Final Fruit Set (FFS) percentages were evaluated as described by Westwood (1995):

$$\mathbf{F} = {}^{(\text{number of open flowers})}\big/_{(\text{number of flower buds})} \times 10$$

$$\mathbf{IFS} = {}^{(\text{number of initial fruits})}\big/_{(\text{number of flower buds})} \times$$

$$\mathbf{FFS} = {}^{(\text{number of harvested fruits})}\big/_{(\text{number of flower buds})} \times 100$$

For these observations, a total of four randomly selected branches of each tree from different directions were used.

Yield Parameters

The yield components such as Yield per Tree (YT) and Yield per Hectare (YH) were evaluated. In addition, the cumulative yield per tree and cumulative yield per hectare was determined as described by Westwood (1995).

Fruit Quality Characteristics

Fruits at the commercial ripening time were harvested, with TSS above 10% (Kader, 1999). For fruit quality analysis, a total of 30 fruits were used in each cultivar, with three replications and 10 fruits in every replication. Fruit Weight (FW; g) was calculated with a scale sensitive to 0.01 g (Precisa XB 2200C, UK). A digital caliper (0-150 mm; Mitutoyo, Kawasaki, Japan) was used for the Fruit Diameter (FD; mm) and Fruit Length (FL; mm). The Fruit Firmness (FFr) was evaluated as 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 Total Soluble Solids (TSS) content was investigated with a digital refractometer (Atago, 0%–53% Brix, Japan) and pH was determined using a pH meter (Orion 3 Star pH meter, Thermo Fisher Scientific, Waltham, MA, USA). Total acidity (expressed as citric acid %) was evaluated by titrating with 0.1N NaOH to pH 8.10. TSS/Acidity (T/A) was also calculated. The colors of fruit skin and flesh were measured with a colorimeter (Chroma Meter CR-300, Konica Minolta Co., Tokyo, Japan). The color investigations were achieved as *L**, *C*, and *h*° because it was red in three cultivars. In the system, L shows color brightness, low for dark colors, and high for bright colors;

Chroma (*C*) is the color's intensity and the hue value also shows the angle value of the color (Çalışkan *et al.*, 2021a).

Statistical Analysis

Data were analyzed using variance analysis in a completely randomized design. Analysis Of Variance (ANOVA) tables were constructed with Fisher's Least Significant Difference (LSD) method at $P< 0.05$ using SAS software and procedures (SAS, 2005). Percentage values were transformed to arcsine, before analysis of variance. Pearson correlation coefficients were used to determine the relationships among the examined characteristics using the R corrplot package (Wei and Simko, 2021).

RESULTS AND DISCUSSION

Heat Parameters

The chilling requirements values calculated by considering a 50% bud burst in the nectarines are presented in Figure 2. These results showed that the chilling requirement between leaf fall and bud burst of the cultivars varied depending on the winter temperatures and there was no problem in meeting the chilling accumulation requirement of the cultivars. The highest chill accumulation occurred in 2020, followed by 2021 and 2019 years. 'Gardeta' cultivar had the highest CH and CU chilling accumulation in 2019 (421 CH and 319 CU, respectively), 2020 (600 CH and 361 CU, respectively), and 2021 (541 CH and 214 CU). Chilling accumulations were similar in 'Gartario' and 'Garofa'.

The lowest GDH1 values were calculated in 'Gartario' (5.522, 2.981, 4.181, and 7.266, respectively) and 'Garofa' nectarines (5.836, 3.062, 4.338, and 7.266, respectively) for four seasons. Similarly, the lowest GDH2 values were found in 'Gartario' (20.976, 19.079, 20.393, and 32.823, respectively) and 'Garofa' (20.939, 19.011, 19.736, and 32.823, respectively) in all seasons. (Figure 3). These results were consistent with those obtained by Lopez *et al.* (2007), who indicated that low GDH1 values are considered a sign of early fruit ripening.

Phenological Stages

The flowering observations showed that flowering phenology was affected by cultivar and environmental differences (Table 1). 'Garofa' and 'Gartario' completed flower phenological periods earlier than the 'Gardeta'. According to the four-year average data, full flowering in the 'Gartario'

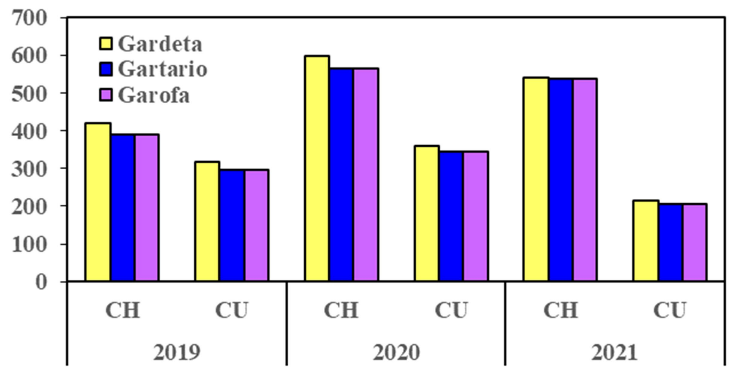

Figure 2. The Chill Hour (CH) and Chill Unit (CU) values of 'Gardeta', 'Gartario', and 'Garofa' nectarines grown in the eastern Mediterranean region of Turkey.

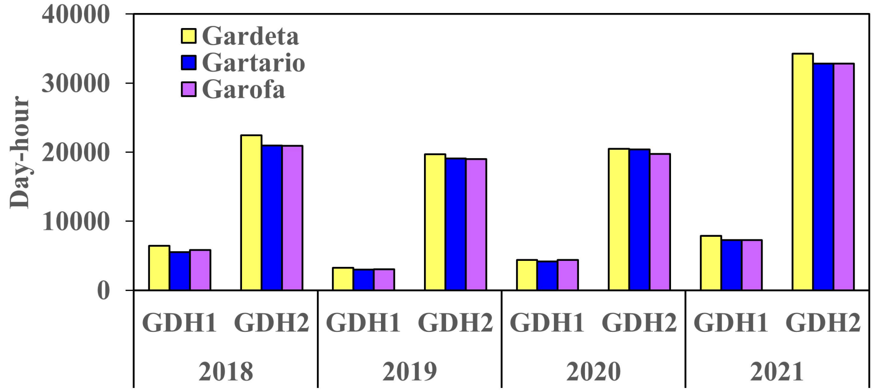

Figure 3. Accumulation values of Growing Degree Hours for 30 days after full flowering (GDH1) and from the full flowering to the date when fruits were ripened (GDH2) of 'Gardeta', 'Gartario', and 'Garofa' nectarines grown in the eastern Mediterranean region of Turkey.

cultivar occurred on 27 Feb., followed by the 'Garofa' cultivar on 01 Mar.

The full flowering time of the 'Gardeta' cultivar was the latest (04 Mar.). The average harvest date was determined as the earliest in the 'Garofa' cultivar (05 Jun.), followed by the 'Gartario' cultivar (07 Jun.). 'Gardeta' cultivar was the latest harvest date (11 Jun.). The flowering period of the 'Gardeta' was 6 days in 2018, 14 days in 2019 and 2020, and 13 days in 2021. This period was 8 days in 2018, 14 days in 2019, 7 days in 2020, and 16 days in 2021 in 'Gartario', whereas this period was 14 days in 2018, 12 days in 2019, 9 days in 2020, and 16 days in 2021 in 'Garofa'. The average flowering period of the cultivars was 11 days in 'Garofa', 12 days in 'Gardeta', and 14 days in 'Gartario'. These differences between the first flowering and the end of flowering can be due to bud breaks after the cold accumulation is sufficient in low-chilling cultivars, and then the flowering period begins with an increase in temperature (Bielenberg and Gasiz, 2022). In this study, high chill accumulation and subsequent temperature increases in the 2020 season may be the cause of early flowering and harvesting in the season.

The number of days from full flowering to the harvest (FBD) of the cultivars differed according to the seasons. The FBD values of the nectarines ranged between 84 ('Garofa') and 86 ('Gartario') days in 2018, between 104 ('Garofa') and 109 ('Gardeta') days in 2019, between 94 ('Gartario') and 97 ('Garofa') days in 2020. In addition, the FBD value was 102 days in 2021 for all cultivars. In the first yield year, 2018, the FBD values of nectarines were lower than in the following years. This result may be due to the low yield per tree in the first year and the completion of ripening of these fruits in a short time. Besides, the average FBD value was 97 in 'Gartario' and 'Garofa' and 98 in 'Gardeta'. These results showed that although the average FBD values of nectarine cultivars were close to each other, the differences in chilling requirement and the GDH values affected harvest dates. These results were similar to those of Lopez and DeJong (2007), who indicated that the GDH accumulation during the first 30 days after bloom (GDH1) caused a decrease in the FBD values of peaches.

In 2018, the flowering periods of the cultivars, as well as the harvest times, were earlier compared to 2019, 2020, and 2021 years (Table 1). This may be the result of higher minimum temperatures and average temperatures, especially in March, April, and May of 2018 (Figure 1). The sunshine duration, especially in April of this year, maybe also affected the early harvest. Similar to these results, the increase in average temperatures and sunshine induced earliness in the previous studies on peach (Wert *et al.*, 2009) and apricot (Caliskan *et al.*, 2012). Besides, flowering and harvest time in the peach cultivars can be changed every year depending on the chilling accumulation (Çalışkan *et al.*, 2021a) and growth temperatures (Cantín *et al.*, 2009a).

Flowering and Fruit Set Percentages

In this study, the flowering percentage ranged between 86.17% (‘Gartario’) and 90.00% (‘Garofa’) in 2019, between 79.16% (‘Gartario’) and 85.87% (‘Gardeta’) in 2020, and between 80.58% (‘Gartario’) and 83.31% (‘Gardeta’) in 2021 (Table 2). The mean flowering percentage was the highest for ‘Gardeta’ (86.13%) and ‘Garofa’ (85.17%), whereas it was the lowest for ‘Gartario’ (81.97%). Erez *et al.* (1990) indicated that the amount of bud break in peach-nectarines was affected by chilling accumulation during the dormant period and

Table 1. Phenological stages of ‘Gardeta’, ‘Gartario’, and ‘Garofa’ nectarines grown in the eastern Mediterranean region of Turkey. [a]

Cultivar	Stage	2018	2019	2020	2021	Average
Gardeta	First Flowering Time	02 Mar.	01 Mar.	04 Mar.	02 Mar.	02 Mar.
	Full Flowering Time	05 Mar.	03 Mar.	09 Mar.	04 Mar.	04 Mar.
	End of Flowering Time	08 Mar.	15 Mar.	18 Mar.	15 Mar.	14 Mar.
	Harvest Time	28 May	19 Jun.	08 Jun.	12 Jun.	11 Jun.
	FBD	85	109	96	102	98
Gartario	First Flowering Time	21 Feb.	24 Feb.	28 Feb.	21 Feb.	23 Feb.
	Full Flowering Time	27 Feb.	27 Feb.	03 Mar.	25 Feb.	27 Feb.
	End of Flowering Time	01 Mar.	10 Mar.	08 Mar.	09 Mar.	09 Mar.
	Harvest Time	23 May	11 Jun.	05 Jun.	06 Jun.	07 Jun.
	FBD	86	105	94	102	97
Garofa	First Flowering Time	20 Feb.	26 Feb.	01 Mar.	21 Feb.	25 Feb.
	Full Flowering Time	01 Mar.	28 Feb.	08 Mar.	25 Feb.	01 Mar.
	End of Flowering Time	05 Mar.	10 Mar.	10 Mar.	09 Mar.	08 Mar.
	Harvest Time	23 May	11 Jun.	05 Jun.	06 Jun.	05 Jun.
	FBD	84	104	97	102	97

[a] FBD: Number of Days from Full Blossoming to harvest.

Table 2. Flowering and fruit set percentages of ‘Gardeta’, ‘Gartario’, and ‘Garofa’ nectarines grown in the eastern Mediterranean region of Turkey. [a]

Stage	Cultivar	2019	2020	2021	Average
Flowering rate (%)	Gardeta	89.20 a	85.87 a	83.31	86.13 a
	Gartario	86.17 b	79.16 b	80.58	81.97 b
	Garofa	90.00 a	82.59 ab	82.31	85.17 a
	LSD (5%)	**4.55**	**4.09**	**ns**	**2.42**
Initial fruit set (%)	Gardeta	77.16	59.77	67.90	68.28 a
	Gartario	72.04	49.47	61.27	60.92 b
	Garofa	78.03	49.46	66.54	66.18 a
	LSD (5%)	**ns**	**ns**	**ns**	**3.20**
Final fruit set (%)	Gardeta	43.90	47.45 a	61.18 ab	50.84
	Gartario	37.29	46.29 a	57.76 b	47.11
	Garofa	34.93	38.33 b	64.22 a	45.82
	LSD (5%)	**ns**	**5.88**	**3.45**	**ns**

[a] (a-b) The different letters within each column indicate significant differences according to the LSD test at $P< 0.05$. ns: Not significant.

then heat accumulation in spring. Besides, Fyhrie *et al.* (2018) reported that carbohydrate levels and environmental conditions were important in the regulation of flowering capacity in the spring of peach-nectarines.

Initial fruit set percentages of the nectarines were not significantly affected by cultivars (Table 2). According to the four-year average data, the highest initial fruit set percentage was found for ‘Gardeta’ and ‘Garofa’ (68.28 and 66.18%, respectively), whereas it was the lowest for ‘Gartario’ (60.92%). The final fruit set percentage varied between 34.93% (‘Garofa’) and 43.90% (‘Gardeta’) in 2019. ‘Gardeta’ and ‘Gartario’ had the highest final fruit percentages (47.15 and 46.29%, respectively) in 2020. In 2021, the highest final fruit set percentage was found for ‘Garofa’ (64.22%) and ‘Gardeta’ (61.18%). The mean final fruit set percentage ranged from 45.82% (‘Garofa’) and 50.74% (‘Gardeta’). Considering the differences between initial and final fruit set values as in ‘Garofa’, we can say that direct competition between fruits reduces the final fruit set. In addition, Fyhrie *et al.* (2018) stated that a critical factor determining fruit set is increased carbohydrate competition with increasing fruit number.

Flowering and final fruit set ratios of peaches can change depending on the climatic conditions such as high and low temperatures and precipitation during the flowering period in season (Mazzoni *et al.*, 2022). In the study area, late spring frosts were not observed at a level that would decrease the flowering and fruit set values of nectarine cultivars between 2018 and 2021 (Figure 1). The lowest temperature in the location was measured as -7.3°C in February 11 in 2020. Since the flower buds of the nectarine cultivars were at rest during this period, low-temperature damage did not occur to them. Our results were in agreement with those reported by Milatović *et al.*, (2010), who indicated that the initial fruit set ratio in peaches ranged from 54 to 87% and the final fruit set ratios range from 23 to 68% in Serbia ecology. These results were also similar to those of Fyhrie *et al.* (2018), who showed that final fruit set ratios were above 30% in early-ripening peach cultivars.

Yield Characteristics

The yield values of nectarines are presented in Figure 4. The results showed that annual yield values were variable depending on the plant age. In the first yield age, in 2018, the highest yield per tree was obtained from the ‘Gardeta’ cultivar (8.49 kg $tree^{-1}$). ‘Gardeta’ and ‘Gartario’ had the highest yield per tree (26.59 and 25.69 kg $tree^{-1}$, respectively) in 2019 (at the 3rd age), whereas the ‘Garofa’ had the highest yield per tree in 2020 (23.83 kg $tree^{-1}$) and 2021 (26.89 kg $tree^{-1}$). These results revealed that low-chilling nectarines grown in the eastern Mediterranean region of Turkey were an economic yield at the 3rd age. Similarly, Çalışkan *et al.* (2021a) reported that new peach-nectarine cultivars such as ‘Astoria’, ‘Maya’, and ‘Garbaja’ had a higher yield per tree (25.60, 26.58, and 14.57 kg $tree^{-1}$, respectively) at the 3rd age. We can say that the yield per tree values of ‘Gardeta’, ‘Gartario’, and ‘Garofa’ were positively affected by the accumulation of sufficient chilling (< 400 CH) during all growing seasons.

‘Gardeta’ had the highest yield per hectare (14.09 t ha^{-1}) in the 2nd year, whereas ‘Gardeta’ and ‘Gartario’ had the highest yield per hectare (44.14 t ha^{-1} and 42.64 t ha^{-1}, respectively) in 3rd year (Figure 4). The lowest yield per hectare was in the ‘Garofa’ (2.65 and 39.00 t ha^{-1}, respectively) in the 2nd and 3rd years. In contrast, the ‘Garofa’ cultivar had the highest yield per hectare in the 4th and 5th years (39.56 and 44.63 t ha^{-1}, respectively). Furthermore, the ‘Gardeta’ exhibited the highest cumulative yield per tree (80.15 kg $tree^{-1}$) and cumulative yield per hectare (133.04 t ha^{-1}) from 2nd year to 5th, whereas the ‘Gartario’ cultivar had the lowest cumulative yield values (71.44 kg

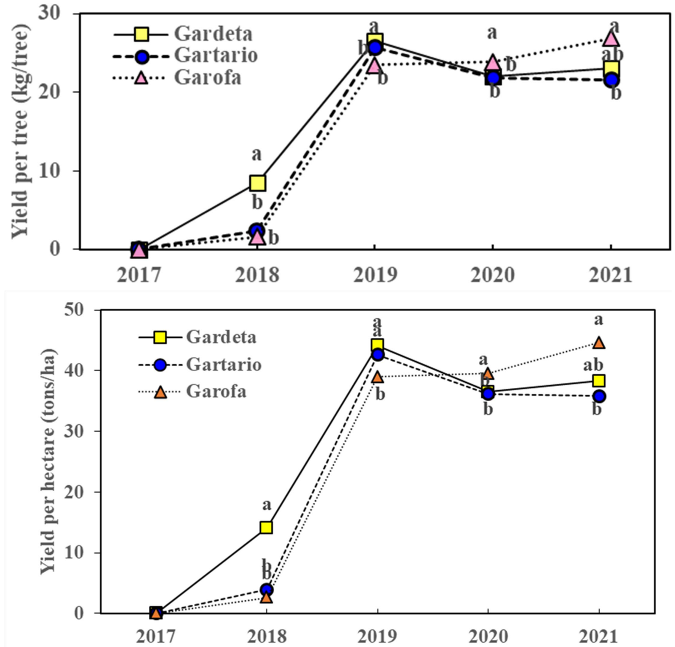

Figure 4. Yield per tree (upper) and yield per hectare (bottom) trends after planting of 'Gardeta', 'Gartario', and 'Garofa' nectarines grown in the eastern Mediterranean region of Turkey. The letters indicate significant differences between cultivars within the same year for the LSD test at P< 0.05.

tree^{-1} and 118.59 t ha^{-1}) (data not shown). Yield trends display that 'Gardeta' and 'Garofa' cultivars were significantly producing more than the 'Gartoria' cultivar at the full production orchard stage. These findings were consistent with the findings of Hoying *et al.* (2007), who indicated that the yield values of peach-nectarines in the 3rd age can reach above these results showed that the yield per hectare increased to over 40 tons when the new nectarine varieties were planted densely with a 3-V pruning system. However, Neri *et al.* (2010) showed that the yield per hectare was 32.7 t ha^{-1} in the tri-V pruning system (740 plants ha^{-1}). Besides, high temperatures in the summer period (Ghrab *et al.*, 2016), low chilling duration in the winter (Çalışkan *et al.*, 2021b) and late spring frosts in the cultivated location (Font i Forcada *et al.*, 2020) can reduce the yield of early cultivars. Our results showed that the early peach-nectarines with low chilling were rarely damaged by the late spring frosts in the eastern Mediterranean region of Turkey.

Fruit Quality Properties

The fruit quality characteristics of 'Gardeta', 'Gartario', and 'Garofa' nectarines are presented in Table 3. The cultivar 'Gartario' produced the greatest fruits, with an average above 135 g, while 'Garofa' produced intermediate fruits, with an average of 128 g, and 'Gardeta' produced the smaller fruits (average 122.19 g). 'Garofa' had the highest fruit weight (135.79 g) in the 2019 season, whereas 'Gartario' had the highest fruit weight in the 2020 (172.24 g) and 2021 (153.55 g) seasons. Similarly, the fruit diameter and length values of the cultivars changed over the years. In 2018, the fruit size (weight, diameter, and length) values were the lowest in all cultivars, which can be due to the first yield age. The mean fruit size of the nectarine cultivars used in this study was higher than in previous studies using low-chill peach cultivars (Wert *et al.*, 2009).

Table 3. Fruit quality characteristics of the fruit in 'Gardeta', 'Gartario', and 'Garofa' nectarines grown in the eastern Mediterranean region of Turkey.

Cultivar	Fruit weight (g)				Mean
	2018	2019	2020	2021	
Gardeta	77.15 c	125.23 b	145.14 b	141.24 b	122.19 b
Gartario	106.48 a	125.42 b	172.24 a	153.55 a	139.42 a
Garofa	96.29 b	135.79 a	153.71 ab	128.49 c	128.57 ab
LSD (5%)	**4.81**	**4.25**	**23.74**	**10.14**	**15.43**
	Fruit length (mm)				
Gardeta	53.46 c	61.75 a	61.11 b	63.10 b	59.86 b
Gartario	57.88 a	60.17 b	66.39 a	65.98 a	62.60 a
Garofa	56.00 b	62.33 a	65.75 a	61.38 b	61.37 ab
LSD (5%)	**1.12**	**0.89**	**1.44**	**2.06**	**2.19**
	Fruit diameter (mm)				
	2018	2019	2020	2021	
Gardeta	48.92 b	61.02 b	64.63 b	62.67 b	59.31
Gartario	55.68 a	59.53 c	69.12 a	64.43 a	62.19
Garofa	54.29 a	61.89 a	66.84 ab	60.45 c	60.87
LSD (5%)	**1.93**	**0.84**	**3.26**	**1.45**	**ns**
	Fruit firmness (kg-force)				
Gardeta	6.30	3.96	5.29	4.49 a	5.01
Gartario	5.45	3.58	4.75	3.27 b	4.27
Garofa	5.54	3.51	5.23	3.34 b	4.41
LSD (5%)	**ns**	**ns**	**ns**	**0.77**	**ns**
	TSS (%)				
Gardeta	12.47 a	14.73 a	15.83 a	17.53 a	15.14 a
Gartario	11.23 b	12.05 b	12.33 b	16.93 ab	13.14 b
Garofa	11.35 b	11.90 b	12.33 b	16.10 b	12.92 b
LSD (5%)	**0.49**	**0.65**	**1.44**	**0.96**	**1.77**
	Acidity (%)				
Gardeta	0.45 b	0.59	0.50	0.64	0.53
Gartario	0.52 a	0.59	0.54	0.63	0.57
Garofa	0.54 a	0.60	0.52	0.57	0.57
LSD (5%)	**0.06**	**ns**	**ns**	**ns**	**ns**
	pH				
Gardeta	3.88	3.50 a	3.83	3.72	3.73
Gartario	3.88	3.42 b	3.81	3.70	3.71
Garofa	3.96	3.44 ab	3.77	3.65	3.71
LSD (5%)	**ns**	**0.08**	**ns**	**ns**	**ns**
	TSS/Acidity				
Gardeta	28.12 a	24.80 a	31.49 a	30.63 a	28.76 a
Gartario	21.75 b	20.54 b	23.25 b	27.02 ab	23.14 b
Garofa	21.14 b	19.92 b	23.78 b	25.46 b	21.57 b
LSD (5%)	**2.43**	**1.73**	**3.30**	**4.83**	**2.57**

[a] (a-c) The different letters within each column indicate significant differences according to the LSD test at P< 0.05. ns: Not significant.

Similar to our results, Abdel-Sattar *et al.* (2021) reported that fruit weight values changed between 110 g and 146 g in early peach cultivars. These results were consistent with previous studies and indicated that the fruit load per tree was very effective in regulating the fruit's final size;

however, this relation was cultivar-specific (Sutton *et al.*, 2020).

Early-spring temperatures for 30 days after bloom (GDH1) have a negative effect on early peach fruit growth and potential fruit size at harvest, and the threshold value was approximately 5.700 GDH (Lopez *et al.*, 2007). Our results showed that the GDH1 values were below the specified threshold value, except for 2018, and the fruit size of the cultivars was not adversely affected by the spring temperatures. For appropriate marketing in European countries, peach fruit weight should be greater than approximately 100 g for low-chill peach cultivars (Badenes *et al.*, 1998). Our data showed that the fruit size of the cultivars was also fulfilled with this threshold value.

All nectarine cultivars had similar fruit firmness values in the 2018, 2019, and 2020 seasons (Table 3), whereas for 2021, 'Gardeta' had higher firmness (4.49 kg-force) than the 'Garofa' (3.34 kg-force) and 'Gartario' (3.27 kg-force) cultivars. The low fruit firmness values of all nectarine cultivars in 2018, and these results may be due to the large size of the fruits. These results were consistent with the results explained by Neri and Brigati (1994), who stated that for adequate fruit quality in peaches, firmness should not be more than 5 kg-force and TSS content should not be less than 12%. According to four-year average results, fruit firmness changed within commercial standards for the best handling and storage time.

Crisosto and Costa (2008) stated that the optimum harvest standard is at least 10% TSS for early peach-nectarines in Europe and the USA. In all three cultivars used in this study, the TSS values were mostly measured above 12%. 'Gardeta' had the highest TSS in all four seasons (12.47, 14.76, 15.83, and 17.53%, respectively), with an average of 15.14% (Table 4). The mean TSS values (from 12.92 to 15.14%) of the cultivars in this study were in agreement with those of Cantín *et al.* (2009b) (from 7.6 to 17.5%) and Belisle *et al.* (2018) (from 8.3% to 15.65%).

The pH values of the cultivars (except for the 2019 season) were similar in all seasons. Besides, the acidity values were close to each other in all seasons, except for the 2018 season. The average pH and acidity values of cultivars varied between 3.71 and 3.73 and between 0.53 and 0.57%, respectively (Table 3). This result may be due to the harvesting of nectarine cultivars on a similar ripening stage. However, Belisle *et al.*

Table 4. Fruit skin and flesh color characteristics of fruit in 'Gardeta', 'Gartario', and 'Garofa' nectarines grown in the eastern Mediterranean region of Turkey. [a]

Cultivar	Skin L*				Mean	Flesh L*				Mean
	2018	2019	2020	2021		2018	2019	2020	2021	
Gardeta	78.63 a	39.09	35.50	40.24	48.37 a	-	60.94 b	74.80 a	66.31 a	67.35 ab
Gartario	40.24 b	38.01	35.93	40.49	38.14 b	-	72.20 a	73.34 b	53.99 b	66.51 b
Garofa	38.87 b	38.92	35.99	40.45	38.45 b	-	71.59 a	73.41 b	71.91 a	72.33 a
LSD (5%)	**13.75**	**ns**	**ns**	**ns**	**18.43**	**-**	**12.86**	**0.73**	**11.30**	**6.80**
	Skin *C*					Flesh *C*				
Gardeta	35.05	33.62 b	29.60 b	33.07 b	32.09 b	-	47.84 b	56.14	52.13 a	52.04
Gartario	35.38	39.10 a	32.90 a	34.48 b	35.49 a	-	59.52 a	55.59	42.89 b	52.67
Garofa	34.07	39.36 a	33.25 a	37.35 a	36.65 a	-	58.75 a	54.78	55.95 a	56.49
LSD (5%)	**ns**	**1.58**	**2.79**	**1.79**	**2.68**	**-**	**5.73**	**ns**	**8.82**	**ns**
	Skin *h*°					Flesh *h*°				
Gardeta	22.32 b	26.97	21.35	29.52	25.95	-	91.10	94.01	98.03 a	94.38 a
Gartario	29.60 a	26.49	22.57	31.00	26.69	-	88.60	93.53	90.90 b	91.01 b
Garofa	29.08 a	27.79	22.85	30.07	26.90	-	88.97	93.43	91.43 b	91.28 b
LSD (5%)	**3.41**	**ns**	**ns**	**ns**	**ns**	**-**	**ns**	**ns**	**1.64**	**2.48**

[a] (a-b) The different letters within each column indicate significant differences according to the LSD test at $P < 0.05$. ns: Not significant.

(2018) reported that the acid content of the peaches can be changed by the fruit ripening stage.

Colaric *et al.* (2005) found a strong correlation between the TSS/acidity ratio and the fruit flavor of peach-nectarines and the cultivar with a higher TSS/acidity was sweeter. In this study, the highest TSS/acidity ratio was found in 'Gardeta' cultivars in all seasons (28.12, 24.80, 31.49, and 30.63, respectively). The mean TSS/acidity values ranged from 21.57 ('Garofa') to 28.76 ('Gardeta'). The results were in agreement with those of Farina *et al.* (2019), who indicated that TSS/acidity values changed between 14.8 and 37.6 in peach-nectarine cultivars grown in Sicily/Italy ecology. Our results also were similar to those of Wert *et al*. (2009), who reported that the decrease in the acid content with the ripening of the fruit may cause an increase in the TSS/acid ratio.

Although sugar and acid content contribute to the taste of peaches, the main factor affecting consumer preference is fruit color (Crisosto and Costa, 2008). According to four-year data, fruit skin color $L*$ and $h°$ values of nectarine cultivars were not statistically significant according to season (except for the first year). However, the mean fruit skin Lightness (L*) value was highest in 'Gardata' (48.37), whereas it was lowest in 'Gartario' (38.14) and 'Garofa' (38.45) cultivars (Table 4). 'Gardeta' cultivar had the lowest fruit skin color C value (lower values indicate color intensity) in 2019, 2020, and 2021 years (33.62, 29.60, and 33.07, respectively). The color data showed that the cultivars used in this study had red skin color, but especially the 'Gardeta' cultivar had a darker red skin color. The C and $h°$ values of the cultivars were lower than Belisle *et al.* (2018) and Abdel-Sattar *et al.* (2021). Previous studies reported that fruit skin color may differ depending on the sunlight and temperature during the fruit-growing period and the temperature is the main factor in the color formation and anthocyanin accumulation season (Wert *et al.*, 2009; Belisle *et al.*, 2018). Furthermore, the fruit skin color in peach-nectarines is different depending on the cultivar, ripening time, and fruit load (Mazzoni *et al.*, 2022). Also, these results may be due to the tri-V pruning system providing high light penetration into the tree canopy, increasing color formation in the fruit. Our results were similar to those obtained by Hoying *et al.* (2007), who reported that fruit color was more intense in the V pruning system.

The fruit flesh color $L*$, C, and $h°$ values of nectarine cultivars mainly differed according to the growing season. According to average data, 'Garofa' had the brightest fruit flesh color (72.33), while 'Gartario' had the lowest $L*$ value (66.51). The average C values ranged from 52.04 ('Gardeta') to 56.49 ('Garofa'). For hue, mean values ranged from 91.01 for 'Gartario' to 94.38 for 'Gardeta'. The results showed that the inner color of the nectarines was brightest when the skin color was darker. Our results were similar to those reported by Belisle *et al.* (2018).

Correlations among the Studied Variables

The correlation matrix of the studied variables in this study are presented in Figure 5. The negative correlation between the date of Full Flowering (FF) and fruit Skin color L (SL), C (SC), and Hue (SH) values, was moderately weak. These results were consistent with those obtained by Belisle *et al.* (2018), who indicated that insufficient fruit skin colorcan occur due to a more intense tree shade in the season. In addition, we can say that there is a decrease in fruit skin color values in early cultivars due to the precipitation of more than 50 mm in April and May (Figure 1) and cloudy days.

The FBD was negatively correlated with FW, FD, and FFr variables. However, Rawandoozi *et al.* (2021) reported that fruit development in days in peach had positive weak correlations with FW and FD. This

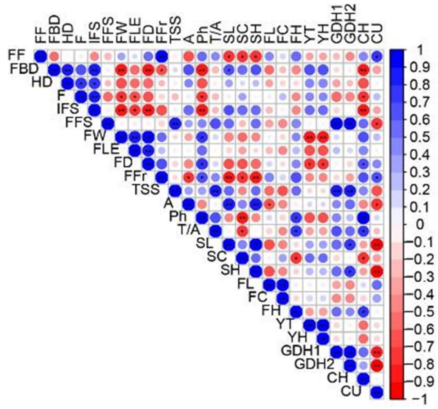

Figure 5. Pearson correlation coefficient (r) matrix among the 26 investigated variables of nectarine cultivars. Blue and red colors indicate positive and negative correlation coefficients between variables, respectively. The size of the circles shows the value of correlations.

difference may be due to the effect of fruit thinning, heat accumulation, and fertilization programs on fruit size. Besides, increasing CH accumulation decreased the FBD value. The Harvest Date (HD) was positively correlated with Flowering (F) and Initial Fruit Set percentages (IFS). However, the F and IFS variables were negatively correlated with FW, FLE, and FD (except for F). Similarly, some researchers reported a negative relationship between fruit set and fruit size in peach (Sutton *et al.*, 2020; Mazzoni *et al.*, 2022). IFS was also negatively correlated with high CH.

A positive correlation was found between FFS and GDH1 and GDH2 variables. Since temperatures between 4.5 and 25°C were calculated as growth degree hours, these temperatures may be a positive effect on the final fruit set. Fruit physical characteristics (FLE, FW, and FD) were significantly correlated with each other. These relationships had also been defined earlier by Matias *et al.* (2014). FW and FD showed a negative correlation to Yield per Tree (YT) and yield per hectare (YH), which indicates that nectarines with a high yield per tree reduce fruit size (Sutton *et al.*, 2020). Our results showed that IFS and FFS were not correlated with yield per tree and yield per hectare; however, Milatović *et al.* (2010) found a significant correlation between the final fruit set and yield.

Fruit Firmness (FFr) was negatively associated with SL, SC, and SH variables, as previously reported by Byrne *et al.* (1991). The TSS was significantly correlated with T/A, GDH1, and GDH2. Similarly, Belisle *et al.* (2018) reported that TSS was moderately positively correlated with T/A. In addition, Rawandoozi *et al.* (2021) indicated that fruit development in days was significantly correlated to TSS. Also, the increase of total soluble solids, decrease in acidity, softening of fruit flesh, and formation of red color may change with the progress of the fruit ripening in the peaches (Guizani *et al.*, 2019). The acidity content of the fruit was positively correlated with fruit Skin color brightness (SL) and Hue angle (SH) value, while it was negatively correlated with FFr.

The Skin color brightness (SL) was positively correlated with the Skin color Chroma (SC), whereas it was negatively correlated with the Flesh color Chroma (FC) and CH. Our data showed that high CH values in nectarines were found to be associated with low *C* (FC) values, indicating dark fruit skin color.

CONCLUSIONS

This study showed considerable differences in fruit yield and quality characteristics of some nectarine cultivars grown in the eastern Mediterranean region of Turkey. There were no problems of chill accumulation in nectarine cultivars during the study seasons where the chilling duration was between 391 and 600 CH and between 207 and 361 CU. According to the averages, the flowering stages of the nectarine cultivars were between 23 Feb. and 14 Mar., while the fruit of the cultivars was harvested between 5 and 11 Jun. The data revealed that the ‘Gardeta’ cultivar had the highest cumulative yield per tree (80.15 kg tree^{-1})

and yield per hectare (133.04 tons/ha). Moreover, 'Gardeta' was remarkable with high fruit quality characteristics such as size, dark skin color, and high TSS/acidity values in the eastern Mediterranean region of Turkey. These results will contribute to the widespread cultivation of new nectarine cultivars that can adapt better to the change in climatic conditions.

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عملکرد میوه و کیفیت کولتیوارهای شلیل کم سرمایی درآب‌وهوای مدیترانه ای

او. چالیشکان، د. کیلیچ، و ص. بایزیت

چکیده

این پژوهش برای بررسی عملکرد و ویژگی‌های کیفی میوه در ارقام جدید شلیل کشت‌شده در منطقه مدیترانه شرقی ترکیه انجام شد. ارقام شلیل «گاردتا»، «گارتاریو» و «گاروفا» روی پایه «GN15» کشت شدند.مرحله گلدهی، درصد تشکیل میوه، عملکرد و خواص کیفی میوه این ارقام بین سالهای ۲۰۱۸ تا ۲۰۲۱ بررسی شد. در طی پژوهش، نیاز سرمایی بین ۳۹۱ تا ۶۰۰ ساعت سرما و بین ۲۰۷ تا ۳۶۱ واحد سرما در منطقه بود و برای میانگین اولیه تشکیل میوه (initial fruit set) بالای ۶۰٪ و میوه نهایی بالای ۴۵٪ مقادیر بزرگی به دست آمد. «گاردتا» بیشترین عملکرد تجمعی در هر درخت (۸۰/۱۵ کیلوگرم در درخت) و عملکرد تجمعی در هکتار (۱۳۳/۰۴ تن در هکتار) را

داشت. اندازه میوه، کل مواد جامد محلول (TSS) و رنگ میوه به طور همگن در هر سه کولتیوار توزیع شده بود. افزون بر این، ویژگی‌های گلدهی (F) و مجموعه میوه اولیه (IFS) همبستگی منفی با وزن میوه (FW)، طول میوه (FLE) و قطر میوه (FD) داشت. در نتیجه، «گاردتا» با گل‌دهی دیر، بالاترین عملکرد، و ویژگی‌های کیفی برتر میوه مانند اندازه، رنگ پوست قرمز و مقادیر بالای " کل اسیدیته /کل مواد جامد محلول" در منطقه مدیترانه شرقی ترکیه قابل توجه بود. افزون بر این، تاریخ گلدهی کامل (FF) و سفتی میوه (FF) با متغیرهای رنگ پوست میوه L* (SL)، C (SC) و h° (SH) همبستگی منفی داشت. بر پایه نتایج ، ارقام جدید شلیل مورد استفاده در اینجا، بسته به اثرات ژنوتیپی و محیطی، تغییراتی را در پارامترهای عملکرد و ویژگی‌های کیفی میوه نشان دادند.