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Growth, Yield and Quality Performance of Pear (*Pyrus communis* L.) cv. 'Santa Maria' under High Density Planting

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HIGHLIGHTS

- Performances of 'Santa Maria' pear cultivar on different quince rootstocks were evaluated under high density planting systems.
- Yield efficiency of 'Santa Maria' pear cultivar under high density planting on QA rootstocks determined better than other quince rootstocks were used in the experiment.

Abstract: The present study was carried out to determine the effect of quince rootstocks (BA29, QA and MC) on plant growth, fruit quality and yield of 'Santa Maria' pear cultivar in 2020 and 2021. In this study, significant differences were determined by all growth, yield and quality parameters except for trunk diameter (TD), trunk cross-sectional area (TCSA), canopy volume, fruit stalk thickness, acidity, total soluble solids (TSS) in terms of research years and rootstocks from analysis of variance. Tree height, annual shoot length, leaf area, fruit weight, fruit width, and fruit length was lower in the MC rootstock than in the others. In the case of research years, out of annual shoot growth in 2020, all other parameters were higher in 2021. Fruit stalk length, fruit stalk thickness and fruit firmness were higher on MC rootstock than BA29 and QA. There was an insignificant difference between rootstocks in terms of TSS. The highest L* was in QA and MC; chroma was in QA and hue angle was in BA29 rootstock. The number of fruit was the highest (139.01 pieces/tree) in BA29 in 2021 and the lowest in MC (11.97 pieces/tree) in 2020. The highest yield per tree (30.62 kg), yield per hectare (58484.2 kg), yield per trunk cross-sectional area (2.24 kg/cm^2) and yield per canopy volume (71.21 kg/m^3) were measured in QA in 2021. In conclusion, the yield efficiency of 'Santa Maria' pear cultivar under high density planting on QA was better than other combinations in 2021. Since the plants on which the research is carried out are still young, it may be recommended to continue the research for many years to determine the most suitable rootstock.

Keywords: Pear; *Pyrus communis* L.; Quality; Rootstocks; 'Santa Maria'; Yield Properties.

INTRODUCTION

Pear is the second most important temperate fruit after apple in terms of production quantity and area, and it has a great degree of adaptation to a different climatic situation. It can grow in a wide range of temperatures, from -26 °C when dormant to 45 °C during the growing season. Pears grown in temperate climates require 500 - 1500 chilling hours, while pears grown in subtropical climates require 200 - 300 chilling hours [5]. World pear production was about 23.1 million tons in 2020. Sixteen million tons (69.2%) of the production was carried out by China, followed by Italy, America, Argentina, and Türkiye is the 5th position with 545.569 tons pear production [19]. The production of 'Santa Maria', which is widely used in pear cultivation, is increasing year by year in Türkiye [49, 63]. The positive properties of grafting pears on quince rootstocks are controlling the growth of trees, precocity, and increase in yield and fruit quality. However, quince clonal rootstocks have a low tolerance to chlorosis, fire blight (caused by the *Erwinia amylovora* bacterium), and calcareous soils, and are not being firmly attached to the soil as pear rootstocks [20]. Nowadays, improved pear orchards are based on a high density planting system (HDP) around 2000 - 5000 trees in a hectare. The establishment costs of HDP pear orchards are high, for this reason in all the pre and post establishment processes must be very tactful for getting better yield and quality. Carelessness in the pre and post establishment processes of HDP orchards, can be an inducement to the fewer production and quality due to unawareness regarding best rootstocks and scion cultivars as well as their combinations, illustrating more vegetative growth, less flower formation, unfertile flowers formation and low fruit set. The reasons of high costs in the establishment of HDP system orchards are the proper choice of desired cultivar, providing appropriate dwarfing rootstocks, improved orchard management techniques and using costly irrigation systems in such orchards [25, 52]. High density planting completely encloses the soil beneath the tree canopy, preventing it from receiving sunlight. It minimizes the loss of soil organic carbon caused by photo-decomposition. The decrease in organic carbon content with increasing plant spacing can be due to more soil surfaces exposed to sun rays when plants are spaced further apart. High density planting provides the maximum sunlight utilization per unit area, which can be related to increased leaf covering than traditional planting patterns. Plants produced in high density planting systems can better utilize solar radiation and improve their photosynthetic efficiency [31]. Plants grown close together grew higher than plants planted farther apart due to a lack of appropriate sunlight. Plants with close spacing exhibited columnar growth due to insufficient light interception, whereas plants with broader spacing had lateral and balanced development due to adequate light interception space [45]. According to studies, despite the higher organic carbon concentration in high density plantings, almost all nutrient concentrations in numerous areas of trees in high density plantings were poor. As a consequence, constant pruning and training of the trees could have taken significant amounts of nutrients from different plant parts. Furthermore, a significant amount of fertilizers may be required to generate nearly three times greater fruit yield per unit area than plants cultivated in a traditional plantation system. Under high density planting, the enhanced favorable microclimate such as low temperature, high humidity, and less sunlight, could have actively encouraged insect pest multiplication [56]. In high density planting orchards, regular pruning stimulates new growth that attracts leaf borer, and the level of an infestation stays proportional to the area and intensity of pruning. On an area basis, the high density established orchards produced considerably more fruit than the conventional system due to the enhanced utilization of solar radiation, higher nutrients, water, and photosynthetic efficiency, which raise the yield [32]. In many European countries such as Spain, Italy, France, Austria, Belgium, and others, quince dwarfing rootstocks have led to the establishment of high density planting fruit orchards. Nevertheless, the economic sustainability of these systems is still questionable and seems not assured for a prolonged time. Many of the quince rootstocks have made it possible to reduce the size of pear trees noticeably. Besides all these, some limitations are still in the way. Severe difficulties such as sudden pear decay are surfacing, primarily in high density 'Abate Fetel' orchards grafted on dwarfing quince clonal rootstocks. All of these concerns affect the fruit trees long-term viability under high density planting [4, 37]. Planting density is an old and relative concept that varies depending on production. Fruit tree plantings with a high density were created to boost productivity and improve fruit quality. In terms of density and number of trees per hectare, pear orchards are now divided into five categories: low density planting (LDP= 1000 to 1500 trees/ha), medium density planting (MDP= 1500 to 3000 trees/ha), high density planting (HDP= 3000 to 4000 trees/ha), very high density planting (VHDP= 4000 to 8000 trees/ha), and ultra high density planting (UHDP= 8000 and more trees/ha) almost since the early 2000s. The high density planting pear orchards are meant to last for not very long years. The orchard design of today tends to reduce the economic life of the orchard within 20 years. So, trees must crop early by the second or third year. Other potential issues included in HDP are the intense management required, disease and insect outbreaks, and meteorological occurrences such as hail or frost, which can affect the orchard's economic viability too [37, 38, 60, 67]. For this reason, we established a modern HDP pear orchard to consider the response of 'Santa Maria' pear cultivar grafted on BA29, QA and MC quince in case of growth, productivity and fruit quality during two consecutive years 2020 and 2021.

MATERIALS AND METHODS

Materials

In the research, 'Santa Maria' cultivar was grafted on 1-year-old BA29, QA and MC quince clonal rootstocks in 2018. The study was carried out in the Bafra Agriculture Research Station of Ondokuz Mayıs University (41^o 33' 50'' N; 35^o 52' 21'' E; altitude 20 m) 2020-2021. Bafra district generally has a hot and humid climate in summers and a cool climate in winters, with the most precipitation in late autumn and early winter. According to the climate data of Bafra district (Samsun) during 2020-2021, the highest temperature was 35.1 ^oC in July at 2020, the lowest temperature was -4.5 ^oC in February at 2020 (Figure 1) and the average annual temperature is 14.1 ^oC [42].

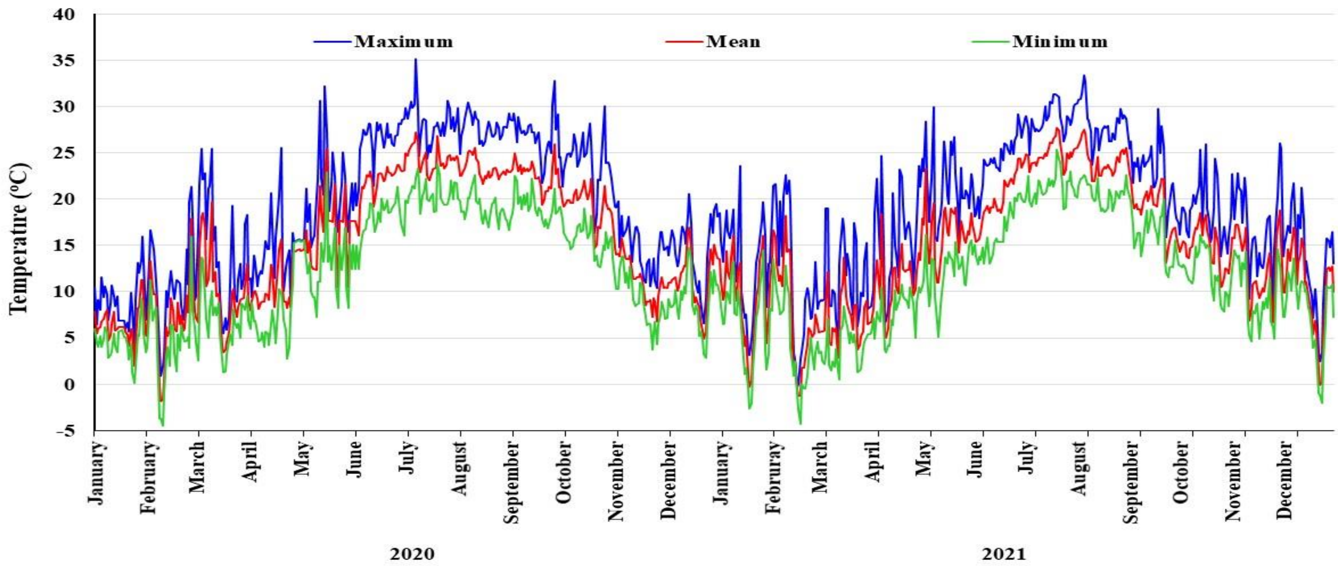

Figure 1. Daily temperature (^oC) values in the experiment area during the research period

Methods

The grafted trees were planted at a distance of 3.5 x 1.5 m distances in a high density planting system (1910 tree/ha) and pruned according to the modified leader system. A supporting system of metal poles supported the saplings and tied up the branches; for this case, three rows of wire were tied to the poles at 0.5, 1.0 and 1.5 m from the ground (Figure 2). The trees were pruned regularly every year, and irrigation was carried out usually twice a week in June - October, depending on the water requirement of the trees with pressure compensating drippers at 1.20 m intervals, with two pipes per each row on both sides of the trees. Weed control was performed regularly with a rotovator, many times each year. Growth, yield and quality parameters were done according to similar researches were done in such areas [2, 29, 40, 47, 62].

Vegetative growth characteristics

In the research, vegetative growth characteristics such as trunk diameter (mm), tree height (cm), annual shoot length (cm), trunk cross-section area (cm^2), tree canopy volume (m^3) and leaf area (cm^2) were considered.

Figure 2. Experimental site, Bafra/Samsun

Pomological characteristics

Fruit weight (g) was measured in randomized harvested 30 fruits in each replication with 0.01 g sensitive digital balance (CAMRY L-500). Fruit width (mm), fruit length (mm), fruit stalk length (mm), and fruit stalk thickness (mm) were determined with 0.01 mm digital compass (Mitutoyo CD-20CPX). Fruit firmness (kg/cm^2) was measured with hand penetrometer (EXTECH FHT 200- with 5/16 head) according to [15].

Chemical and color characteristics

Total soluble solids (%) were determined with a digital refractometer (ATAGO, PAL-1) and titratable acidity (%) was evaluated by using 0.1N NaOH in the titration method from the extracted fruit juice previously was prepared [1, 58]. The skin color of the fruit was determined by reading the skin color of the fruit from 2 different points on the equatorial part with the help of a colorimeter (Minolta, model CR-300, Tokyo, Japan) in terms of L*, a*, b*, Chroma and hue angle (h^o) [14].

Yield and productivity characteristics

Yield per tree (kg), yield per hectare (kg), yield per trunk cross-section area (kg/cm^2), yield per canopy volume (kg/m^3) and the number of fruits (pieces/tree) were determined.

Statistical analysis

The experiment was designed in a Randomized Complete Block Design method (RCBD or RBD), with three replications and ten trees in each replication. The obtained data were analyzed with IBM SPSS 21.0 program (SPSS Inc. Chicago, ABD) and mean comparison was done with Duncan Multiple Comparison Test (DMRT) at 5 levels of significance ($p<0.05$).

RESULTS AND DISCUSSION

Vegetative growth characteristics

The effects of rootstocks, research years and rootstock x year interactions on vegetative growth characteristics of ‘Santa Maria’ pear cultivar that was grafted on different quince rootstocks are given in Table 1. As seen in Table 1, except for trunk diameter, trunk cross-sectional area and canopy volume in terms of rootstocks and trunk diameter in terms of rootstock x year interactions, examined all vegetative growth characteristics were statistically significant.

In terms of years, it had been determined that the trunk diameter in 2021 (38.67 mm) was higher than in 2020 (28.30 mm). In the case of rootstocks, trunk diameter ranged from 32.69 mm to 35.01 mm. It had been determined that the stem diameter varied between 27.54 - 41.99 mm in terms of year x rootstock interaction. Tree height was higher in 2021 (225.05 cm) than in 2020 (171.70 cm). In terms of rootstock averages, tree height varied between 180.33 - 210.20 cm. Tree heights were lower in the MC rootstock than in the others.

The interaction effect of year x rootstock on tree height varies between 169.00 - 243.45 cm. The highest tree height was determined in 2021 on BA29 (243.45 cm) and QA (240.05 cm). The annual shoot length in 2020 (53.29 cm) was higher than in 2021 (29.37 cm). From rootstock averages, the annual shoot length varied between 31.02 and 49.41 cm. The highest annual shoot growth was in BA29 and QA, the lowest was found in MC rootstock. The year x rootstock interaction effect on annual shoot growth ranged between 20.93 to 69.89 cm. The highest annual shoot growth (69.89 cm) was measured in 2020 on QA rootstock and the lowest in 2021 on MC rootstock (20.93 cm). In the case of rootstocks, TCSA was observed to range between 9.32 – 10.30 cm^2. The trunk cross-sectional area in 2021 (12.43 cm^2) was higher than in 2020 (7.36 cm^2) in terms of years. On trunk cross-sectional area, the effect of year x rootstock interaction ranged from 6.91 to 13.69 cm^2. The highest trunk cross-sectional area was found in QA (13.69 cm^2) and MC (13.09 cm^2) rootstocks in 2021. Tree canopy volume (TCV) in 2021 (0.33 m^3) was higher than in 2020 (0.17 m^3) in years. In the case of rootstocks, TCV was between 0.24 - 0.27 m^3. The highest tree canopy volume in 2021 (0.43 m^3) was observed on QA and the lowest tree canopy volume (0.11 m^3) rootstocks were measured on QA rootstocks in 2020, followed by BA29 (0.17 m^3) rootstocks in 2020 with regards to year x rootstock. In 2021 (12.94 cm^2), the leaf area was higher than in 2020 in terms of years (10.75 cm^2). Rootstock averages illustrated that leaf area varied between 4.79 - 15.53 cm^2. The highest leaf area was 15.53 cm^2 in BA29, the lowest was found as 4.79 cm^2 in MC rootstock. On leaf area, the effect of year x rootstock interaction ranged from 4.72 to 18.19 cm^2. The highest leaf area (18.19 cm^2) was detected in 2021 on BA29 and the lowest leaf area on MC rootstock in 2020 (4.72 cm^2) and 2021 (4.86 cm^2) (Table 1).

Trunk diameter and trunk cross-sectional area of the ‘Comice’ pear cultivar were higher in BA29 than MC rootstock [59]. It has been reported that rootstocks significantly affect tree height [34]. The highest (265.94 cm) plant height was determined on BA29 rootstock, and the lowest (185.22 cm) on MC rootstock [49]. Rootstocks affect the growth characteristics of cultivars at different levels [12, 18, 21, 26, 34, 59]. Shoot growth limitation of pear on quince was due to unfavorable conditions like dry and excessively hot weather. Even irrigation was done properly but such conditions increased graft incompatibility between pear and quince [37, 61]. The shoot length of one year old was observed to be varied in the case of different rootstocks [55]. The rootstocks with partial incompatibility with the pear cultivars tended to early cropping and limited shoot growth, especially in the fruiting years [12]. The less shoot growth in the high fruiting year was due to less amount of carbohydrate for shoots as it was used for fruit formation [52]. Observed that, there were differences in the one-year-old shoot growth between pear cultivars ‘Packham’s Triumph’ (34.3 cm) and ‘Hosui’ (80.4 cm) [13]. Reported 1-year-old shoot length as following ‘Santa Maria’/QA (35.56 to 49 cm), ‘Santa Maria’/OHF333 (15.69 to 37.90 cm) [17]. In our research, shoot length was significantly different in both year and rootstocks due to the transformation from vegetative to the fruiting stage. Furthermore, an inverse relationship was determined between trunk cross-sectional area and annual shoot length. It was determined that the yield efficiency of the trunk cross-sectional area was low in rootstocks with higher shoot lengths. Rom and Carlson [57] stated that the annual shoot length is directly related to the trunk diameter and trunk cross-sectional area of the tree; they reported that the longer the shoot growth continues, the lower the yield per trunk cross-sectional area of the tree. It was observed that there was not statistically different between pear cultivars ‘Clina’ (37.4 cm^2), ‘Clara’ (34.9 cm^2), ‘Ingrid’ (31.0 cm^2) and ‘Kristina’ (36.1 cm^2), but found statistical differences in TCSA between other cultivars in another study as the following ‘Anna’ (25.2 cm^2), ‘Fritjof’ (29.1 cm^2) and ‘Ingeborg’ (37.3 cm^2) [43]. Statistically, differences in TCSA were also reported in seven-year-old pear trees of different cultivars by [44] from 10.8 to 19.2 cm^2, while no significant effect in the case of different rootstocks from 13.8 to 15.9 cm^2 was recorded. TCSA was greatest when ‘Santa Maria’ was grafted on seedling rootstock, followed by BA 29, and lowest when MA and MC quince rootstocks had been used [22]. Another study of Engin [17] reported TCSA as follows ‘Santa Maria’/QA (15.29 to 50.0 cm^2), ‘Santa Maria’/OHF333 (13.83 to 39.01 cm^2). Similarly, no significant results of TCSA reported by [55] when grafted ‘Williams’ onto Champion, Melliforme and *P. calleryana* rootstocks. Our results are similar to the above-mentioned previous studies. In the case of TCSA values variation age of trees are the causes. Canopy management was important for light penetration and regular flower and fruit production; otherwise, naturally there is an adverse effect between fruit set and canopy volume as mentioned by [7, 8, 16]. Some managemental canopy strategies need to improve productivity in cultivars with low yield. However, generally most pear cultivars need thinning for crop load [6]. Engin [17] mentioned that canopy volume was as the following ‘Santa Maria’/QA (0.26 to 1.02 m^3), ‘Santa Maria’/OHF 333 (0.23 to 0.53 m^3). Leaf area (LA) is a withstand factor of tree canopy volume efficiency and fruit quality [67]. As well as, to understand respiration, evaporation, photosynthesis, light reception, water and nutrient usage, flowering, fruit set and yield efficiency, leaf area is a crucial consideration as mentioned by [48] and found that the leaf area of ‘Santa Maria’ while grafted on BA29 was 23.82 cm^2. In another study [47] researcher stated that the effect of rootstocks on the leaf area of the ‘Deveci’ pear is important and reported that the leaf area of the plants grafted on BA29 was higher than the other rootstocks. Engin [17] mentioned that leaf area was observed as the following ‘Santa Maria’/QA (15.72 to 23.78 cm^2), ‘Santa Maria’/OHF333 (17.07 to 21.61 cm^2).

Table 1. Vegetative growth characteristics of ‘Santa Maria’ pear cultivar under high density planting

Years	Rootstocks	Trunk Diameter (mm)	Tree Height (cm)	Annual Shoot Growth (cm)	Trunk Cross-Sectional Area (cm^2)	Tree Canopy Volume (m^3)	Leaf Area (cm^2)
2020	BA29	29.35 a*	176.94 b	48.86 b	8.12 c	0.17 bc	12.86 c
	QA	28.02 a	169.16 b	69.89 a	6.91 c	0.11 c	14.67 b
	MC	27.54 a	169.00 b	41.11 b	7.04 c	0.24 abc	4.72 d
2021	BA29	36.21 a	243.45 a	38.27 bc	10.51 b	0.31 ab	18.19 a
	QA	41.99 a	240.05 a	28.92 cd	16.69 a	0.43 a	15.77 b
	MC	37.83 a	191.66 b	20.93 d	13.09 a	0.25 abc	4.86 d
Main Effects							
Rootstocks	BA29	32.78 a	210.20 a	43.57 a	9.32 a	0.24 a	15.53 a
	QA	35.01 a	204.61 a	49.41 a	10.30 a	0.27 a	15.22 a
	MC	32.69 a	180.33 b	31.02 b	10.07 a	0.25 a	4.79 b
Years	2020	28.30 b	171.70 b	53.29 a	7.36 b	0.17 b	10.75 b
	2021	38.67 a	225.05 a	29.37 b	12.43 a	0.33 a	12.94 a
Significance							
Rootstocks		0.430	0.001	0.001	0.393	0.871	0.001
Years		0.001	0.001	0.001	0.001	0.007	0.001
Years x Rootstocks		0.231	0.023	0.004	0.023	0.048	0.001

*: Averages shown with different letters in the same column, the difference between them is statistically significant.

Pomological characteristics

The effects of rootstocks, research years and rootstock x year interactions on pomological characteristics of ‘Santa Maria’ pear cultivar that was grafted on different quince rootstocks are given in Table 2. As seen in Table 2, except for fruit stalk thickness in terms of research years and fruit weight, fruit length, fruit width, and fruit stalk length in terms of rootstock x year interactions, examined all pomological characteristics were found to be statistically significant.

Rootstock averages illustrated that fruit weight varied between 130.52 to 177.56 g. The highest fruit weight was 177.56 g in QA, the lowest was found as 130.52 g in MC rootstock. The fruit weight in 2020 (179.63 g) was higher than in 2021 (142.84 g). In the interactions, the fruit weight ranged from 104.08 to 193.71 g. In terms of year x rootstock interactions, in 2020, QA was shown to be higher (193.71 g) than the other combinations. In terms of rootstock, results illustrated that fruit width was recorded between 56.07 - 62.59 mm. the highest fruit width was 62.59 mm in QA, and the lowest was found as 56.07 mm in MC rootstock. In the case of years, the fruit width in 2020 (62.77 mm) was found to be more (56.55 mm) than the fruit width in 2020. In terms of year x rootstock interaction, the fruit width varies between 51.34 to 65.54 mm. The year x rootstock interaction of QA in 2020 was determined to be higher (65.54 mm) than other interactions (Table 2).

Table 2. Pomological characteristics of 'Santa Maria' pear cultivar under high density planting

Years	Rootstocks	Fruit Weight (g)	Fruit Width (mm)	Fruit Length (mm)	Fruit Stalk Length (mm)	Fruit Stalk Thickness (mm)	Fruit Firmness (kg/cm²)
2020	BA29	188.22 a	61.98 a	91.09 a	26.48 a	4.41 b	8.64 b
	QA	193.71 a	65.54 a	88.19 a	21.80 a	4.02 b	8.45 b
	MC	156.96 a	60.78 a	84.22 a	28.56 a	4.14 b	8.64 b
2021	BA29	163.06 a	58.66 a	88.43 a	16.48 a	3.77 b	7.30 c
	QA	161.40 a	59.64 a	86.80 a	18.09 a	3.67 b	6.34 c
	MC	104.08 a	51.34 a	76.98 a	22.79 a	6.58 a	10.05 a
Main Effects							
Rootstocks	BA29	175.65 a	60.33 a	89.76 a	21.48 ab	4.10 b	7.97 b
	QA	177.56 a	62.59 a	87.50 a	19.95 b	3.85 b	7.40 b
	MC	130.52 b	56.07 b	80.60 b	25.68 a	5.36 a	9.35 a
Years	2020	179.63 a	62.77 a	87.83 a	25.61 a	4.19 a	8.58 a
	2021	142.84 b	56.55 b	84.07 b	19.12 b	4.67 a	7.89 b
Significance							
Rootstocks		0.001	0.012	0.001	0.047	0.036	0.001
Years		0.001	0.001	0.045	0.005	0.296	0.025
Years x Rootstocks		0.442	0.283	0.417	0.422	0.028	0.001

*: Averages shown with different letters in the same column, the difference between them is statistically significant.

Rootstock results were shown that fruit length was observed at 80.60 to 89.76 mm, the maximum fruit length was 89.76 mm in BA29, the minimum was found as 80.60 mm in MC. In terms of years, the fruit length in 2020 (87.83 mm) was higher than the fruit length in 2021 (84.07 mm). In terms of year x rootstock interactions, the fruit length differed between 76.98 to 91.09 mm. The year x rootstock interaction in 2020 was ascertained to be higher (91.09 mm) than other interactions on BA29 rootstock. The fruit stalk length was observed at 19.95 to 25.68 mm; the maximum fruit stalk length was 25.68 mm in MC, the minimum was found as 19.95 mm in QA rootstock in terms of rootstocks. The fruit stalk length in 2020 (25.61 mm) was higher than in 2021 (19.12 mm). In terms of year x rootstock interactions, MC in 2020 was higher (28.56 mm) than the other combinations. In terms of rootstock, fruit stalk thickness was between 3.85 - 5.36 mm. The highest fruit stalk thickness was 5.36 mm in MC, the lowest was found as 3.85 mm in QA. In terms of years, it had been determined that the fruit stalk thickness in 2021 (4.67 mm) was higher than in 2020 (4.19 mm). It had been determined that the fruit stalk thickness varied between 3.67 to 6.58 mm in terms of year x rootstock interaction. MC was found to be higher (6.58 mm) than other interactions. In terms of rootstock results, fruit firmness was recorded between 7.40 - 9.35 kg/cm². The highest fruit firmness was 9.35 kg/cm² in MC, the lowest was found as 7.40 kg/cm² in QA rootstock. In terms of years, the fruit firmness in 2020 (8.58 kg/cm²) was higher than in 2021 (7.89 kg/cm²). In terms of year x rootstock combinations, the fruit firmness ranged from 6.34 to 10.05 kg/cm². The highest (10.05 kg/cm²) fruit firmness was observed in MC in 2021 and the lowest fruit firmness (6.34 kg/cm²) was found in QA followed by BA29 (7.30 kg/cm²) in 2021 (Table 2).

Fruit size in pears is an important marketing criterion [26, 62]. Appropriate rootstock selection for pear is essential in increasing the average fruit size for each cultivar and variety [3, 26, 54, 62, 66]. Reported the fruit weight of pear varies between 80 - 400 g, and they reported that the average fruit weight of the 'Santa Maria' cultivar was 250 g [51]. Ozturk and coauthors [46] reported that fruit weight was 190.36 g, fruit width was 64.25 mm, and fruit length was 107.27 mm in 'Santa Maria' pear cultivar. The fruit weight of 'Santa Maria' cultivar grafted on BA29 quince clone rootstock varied 147.5 - 169.4 g [14], and recorded 140.0 - 156.2 g by [29]. Reported that fruit weight was 183.00 - 290.00 g and fruit width was 61.18 - 81.86 mm in some pear cultivars grown in western Kosovo, and they reported that fruit weight was 195.18 g, fruit width was 65.21 mm, and flesh firmness was 4.96 kg/cm² in 'Santa Maria' cultivar [33]. The fruit weight of 'Santa Maria' pear cultivar grafted on different rootstocks in semi-arid conditions was 265.49 - 290.37 g [22], also mentioned that rootstocks significantly affect fruit firmness of 'Santa Maria' pear cultivar grafted on different rootstocks, as the flesh firmness was highest in BA29 and MA rootstocks and the lowest in pear seedlings. The semi-arid and calcareous soil conditions [23] stated that fruit weight was 304.1 g and flesh firmness was 22.3

lbs/cm^2. Pasa and coauthors [54] reported that fruit weight was 163.94 - 186.11 g and flesh firmness was 62.11 - 66.46 N in ‘Santa Maria’ pear cultivar. Kucuker and Aglar [30] mentioned that fruit weight differs according to the research years and cultivars as well as were recorded fruit weight between 211 - 231 g in ‘Santa Maria’. Jovanovic and coauthors [25] reported that fruit weight was 188.4 g, fruit length was 8.8 cm, and fruit width was 6.5 cm in ‘Santa Maria’ pear cultivar. Flesh firmness, the most crucial factor in pear fruits' maturity [26, 27], is reported to vary according to rootstocks, growing years, and management practices in pear orchards [11, 24, 28, 64]. Results from this study are generally in agreement with previous studies.

Chemical and color characteristics

In the study, rootstocks and research years generally significantly affect the chemical and color characteristics of ‘Santa Maria’ pear cultivar (Table 3). Total soluble solids (TSS) in rootstocks were significant but not significant in the case of years and rootstocks x year interactions. In terms of rootstock, TSS was recorded between 8.83 - 10.56%. The highest TSS was 10.56 in BA29; the lowest was 8.83 in MC rootstock. In terms of years, TSS in 2020 (10.16%) was higher than in 2021 (9.78%). In the interactions, TSS ranged from 8.40 to 10.64% and BA29 in 2020 was shown a higher value (10.64%) than the other combinations. Research results of ‘Santa Maria’ on quince rootstocks had a significant difference in acidity in terms of years and year x rootstocks, while no significant effect in the case of rootstocks. In the case of rootstocks, acidity varied between 0.50 - 0.63%. The acidity in 2020 (0.64%) was higher than in 2021 (0.48%). Acidity in the interactions, ranged from 0.42 to 0.82%. The highest acidity observed in BA29 (0.82%) and lowest were determined in QA (0.42%) both in 2020. In the study, fruit skin color characteristics of h^o value were not significant in terms of year x rootstocks, but other values were all significantly important. Regarding with rootstocks, the highest L* was in QA and MC; chroma was in QA and h^o was in BA29 rootstocks. While the lowest was observed as the following L* BA29; chroma was in BA29, and h^o was in QA rootstock. In terms of years, the higher L* 2021 (71.85), chroma 2021 (35.15), and h^o in 2020 was observed (124.08). In terms of year x rootstock combination, the highest L* in MC in 2021 (87.84), chroma in MC in 2021 (45.50), and h^o was (126.35) on BA29 rootstocks in 2020. In contrast, the lowest L* in MC in 2020 (51.90), chroma in MC in 2020 (21.15), and h^o in MC in 2021 (115.75) were detected (Table 3).

Total soluble solids (TSS) are important measures in determining the ripeness of pear fruits and are observed to be increased as maturity increased, but the acidity value decreased with the increase in ripening [27]. In ‘Santa Maria’ pear cultivar, it was determined that TSS content was highest in pear seedlings, lowest in BA29 quince clonal rootstock, while titratable acid was highest in BA29 and lowest in the pear seedlings [22]. Askari-Khorosgani and coauthors [3] reported that the effect of rootstocks and years were important on TSS and acidity of ‘Shamiveh’ pear cultivar grafted on different quince and pear rootstocks. Rootstocks and production years significantly affect the acidity, which varied between 0.39 - 0.47% in rootstock and 0.39 - 0.42% in production years [50]. Color is one of the essential quality characteristics measured with the L* value, which expresses the brightness according to the color plane, which is between 0 (white) and 100 (black). Chroma (C*) indicates the saturation level of the color, and a value of zero indicates a completely neutral color, while the higher the C* values, the higher the color saturation. For hue angle (hue°) values, 0° shows red, 90° yellow, 180° green and 270° blue [41]. Color differences were reported to be related to the tree's canopy structure and leaf area as a result of vegetative development [50]. It was determined that the canopy volume of the cultivar on the MC rootstock was lower than the other rootstocks [49], so this situation caused slow growth of the tree and the canopy part received more sunlight. That caused the formation of the red blush of pear bark color [51]. It was reported that the most important color parameters indicating the fruit maturity level in pear were L* and b* features which increased with the improvement of maturity. Moreover, the increase in b* value, which expresses the yellow color, indicated higher sugar content of pear fruit as well [27]. In the high density planting system of ‘Santa Maria’, growth and fruit quality characteristics were changed on different quince rootstocks. Many studies were shown that rootstocks had important effects on growth and fruit qualities [3, 9, 10, 11, 14, 24, 28, 29, 36, 53, 59, 64]. While, Wertheim [65] stated that fruit quality parameters of pears were less affected by rootstocks.

Table 3. Chemical and color characteristics of 'Santa Maria' pear cultivar under high density planting

Years	Rootstocks	Total Soluble Solids (%)	Acidity (%)	Fruit Skin Color		
				L*	Chroma	Hue Angle
2020	BA29	10.64 a*	0.82 a	58.14 c	31.62 d	126.35 a
	QA	10.60 a	0.42 c	70.72 b	41.46 b	121.62 a
	MC	9.25 a	0.68 ab	51.90 c	21.15 e	124.26 a
2021	BA29	10.48 a	0.43 bc	53.08 c	24.43 e	118.24 a
	QA	10.45 a	0.58 abc	74.64 b	35.51 c	116.37 a
	MC	8.40 a	0.44 bc	87.84 a	45.50 a	115.75 a
Main Effects						
Rootstocks	BA29	10.56 a	0.63 a	55.61 b	28.03 c	122.30 a
	QA	10.53 a	0.50 a	72.68 a	38.49 a	119.00 b
	MC	8.83 b	0.56 a	69.87 a	33.33 b	120.01 ab
Years	2020	10.16 a	0.64 a	60.25 b	31.41 b	124.08 a
	2021	9.78 a	0.48 b	71.85 a	35.15 a	116.79 b
Significance						
Rootstocks		0.001	0.311	0.001	0.001	0.041
Years		0.265	0.028	0.001	0.001	0.001
Years x Rootstocks		0.613	0.011	0.001	0.001	0.424

*: Averages shown with different letters in the same column, the difference between them is statistically significant.

Yield and productivity characteristics

The yield and yield efficiency of 'Santa Maria' pear cultivars are presented in Table 4. As seen in Table 4, rootstocks, research years and year x rootstock interaction significantly affected the yield characteristics of 'Santa Maria' pear cultivar. The number of fruits observed between 14.49 - 79.03 pieces/tree in terms of rootstock averages. While the rootstock with the highest number of fruits was BA29 with 79.03 pieces/tree, the lowest was found at 14.49 pieces/tree in the MC rootstock. The number of fruits in terms of years was higher in 2021 (78.82) than in 2020 (13.41). The interaction effect of year x rootstock on the number of fruits was found to vary between 9.21-139.01 pieces/tree. The highest number of fruits was determined in 2021 on BA29 rootstock (139.01 pieces/tree). Rootstocks findings showed that yield per tree (YPT) ranged between 1.93 to 16.20 kg/tree. While the rootstock with the highest YPT was QA with 16.20 kg/tree, the lowest was found at 1.93 kg/tree in the MC. The YPT in 2021 (17.63 kg/tree) was higher than in 2020 (2.40 kg/tree) in terms of years. On YPT, the effect of year x rootstock interaction ranged from 1.77 to 30.62 kg/tree. The highest YPT (30.62 kg/tree) was observed in 2021 on QA rootstock. In the case of rootstocks averages, yield per hectare (YPH) ranged between 3667.2 to 30932.5 kg. The rootstock with the highest YPH was QA with 30932.5 kg; the lowest was found at 3667.2 kg in the MC. In terms of years, the YPH in 2021 (33666.9 kg) was greater than in 2020 (4584.0 kg). The effect of interactions on YPH ranged from 3571.7 kg to 58484.2 kg. The greatest YPH in 2021 (58484.2 kg) was observed on QA rootstock. In terms of rootstocks, yield per trunk cross-sectional area (YPTCSA) varies between 0.21 – 1.25 kg/cm^2. The rootstock with the highest YPTCSA was QA with 1.25 kg/cm^2, and the lowest was found at 0.21 kg/cm^2 in the MC rootstock. The YPTCSA in 2021 (1.44 kg/cm^2) was higher than in 2020 (0.32 kg/cm^2) in terms of years. On YPTCSA, the effect of year x rootstock interaction ranged from 0.15 – 2.24 kg/cm^2. The highest YPTCSA (2.24 kg/cm^2) was detected in 2021 on QA, and lowest YPTCSA (0.15 kg/cm^2) in 2021 on MC. Rootstock results showed that yield per canopy volume (YPCV) ranged between 7.84 to 43.65 kg/m^3. While the rootstock with the highest YPCV was in the QA with 43.65 kg/m^3, the lowest was found at 7.84 kg/m^3 in the MC. The YPCV was higher in 2021 (48.18 kg/m^3) than in 2020 (14.94 kg/m^3) in terms of years. The interaction effect of year x rootstock on YPCV was found to vary between 7.79 to 71.21 kg/m^3. The highest YPCV was determined in QA (71.21 kg/m^3) in 2021.

The effect of rootstocks and cultivars on yield per plant, numbers of fruits per plant and trunk cross-sectional area were reported significant in high density planting orchards of pear [36]. There were differences between rootstocks in yield per plant and yield per trunk cross-sectional area in 'Abate Fetel' pear in high density planting [39]. In 'Santa Maria' pear cultivar, it was reported that the highest cumulative yield efficiency was in Quince C, and the highest cumulative yield was in BA29 and Quince C rootstocks [22, 23]. Cabrera and coauthors [9] cited that rootstocks significantly affect yield (ton/ha), yield per plant, and trunk cross-sectional area in pear cultivation. Pasa and coauthors [53] determined that planting frequency affected the number of fruits per plant, yield and yield efficiency in ‘Santa Maria’ pear cultivar. The highest yield efficiency (kg/cm^2) in the ‘Carrick’ pear cultivar grafted on different quince rootstocks was in Portugal and MC rootstocks [54]. Pasa and coauthors [55] stated that the highest yield per tree (kg/tree), number of fruits per plant and yield efficiency (kg/cm^2) in ‘Williams’ pear cultivar was in Champion rootstock. Kucuker and Aglar [30] noted that the yield per plant varied from 3.80 kg/tree to 7.60 kg/tree, and yield efficiency varied from 2.22 kg/cm^2 to 2.97 kg/cm^2 in ‘Santa Maria’ pear cultivar on the Quince A rootstock. The number and quality of flowers produced, the efficacy of pollination and fruit set, the severity of natural or artificial fruitlet abscission, and the degree and rate of cellular proliferation and expansion in the persisting fruits, besides the mentioned factors also genetic (scion cultivar and rootstock), environmental elements (climate and soil) as well as a variety of management factors (training, pruning, plant growth regulators, manuring), all influence pear yields [5, 23, 25, 30, 52, 55]. It can be said that the results obtained from this study are in accordance with previous studies on similar subjects in pear.

Table 4. Yield and yield efficiency of ‘Santa Maria’ pear cultivar under high density planting

Years	Rootstocks	Number of Fruits (pieces/tree)	Yield (kg/tree)	Yield (kg/ha)	Yield per Trunk Cross Sectional Area (kg/cm^2)	Yield per Canopy Volume (kg/m^3)
2020	BA29	19.05 c*	3.56 c	6799.6 c	0.44 c	20.94 c
	QA	9.21 c	1.77 c	3380.7 c	0.26 cd	16.09 c
	MC	11.97 c	1.87 c	3571.7 c	0.27 cd	7.79 c
2021	BA29	139.01 a	20.29 b	38753.9 b	1.93 b	65.45 b
	QA	80.46 b	30.62 a	58484.2 a	2.24 a	71.21 a
	MC	17.00 c	1.97 c	3762.7 c	0.15 d	7.88 c
Main Effects						
Rootstocks	BA29	79.03 a	11.93 b	22776.7 b	1.18 b	43.20 a
	QA	44.84 b	16.20 a	30932.5 a	1.25 a	43.65 a
	MC	14.49 c	1.93 c	3667.2 c	0.21 c	7.84 b
Years	2020	13.41 b	2.40 b	4584.0 b	0.32 b	14.94 b
	2021	78.82 a	17.63 a	33666.9 a	1.44 a	48.18 a
Significance						
Rootstocks		0.001	0.001	0.001	0.001	0.001
Years		0.001	0.001	0.001	0.001	0.001
Years x Rootstocks		0.001	0.001	0.001	0.001	0.001

*: Averages shown with different letters in the same column, the difference between them is statistically significant.

CONCLUSION

The impact of the year, rootstocks, and the year x rootstock interaction on the ‘Santa Maria' vegetative growth, profitability, and fruit quality showed variations. Under high density planting, QA rootstock became dominant in terms of numerous attributes of the ‘Santa Maria’ pear cultivar. Based on the results, we believe that the planting distance inside rows for ‘Santa Maria’/QA combinations for young trees was optimal. Furthermore, it is recommended that the research be continued for a more extended period of time to reach more precise results to determine the most suitable rootstock, since the trees were young on which the research was carried out.

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