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Leaf chlorophyll contents in some European pear cultivars grafted on different rootstocks and its relation with growth and yield

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Abstract

Aim of study: To investigate the effect of different combinations of pear rootstocks and cultivars on the contents of leaf photosynthetic pigments and their relation with some growth and yield characteristics.

Area of study: Ondokuz Mayis University, Samsun, Türkiye, in two years, 2021 and 2022.

Material and methods: The pear cultivars 'Santa Maria', 'Williams', and 'Deveci' were grafted on eight rootstocks: two quince clonal rootstocks (BA29 and QA), five pear clonal rootstocks (FOX9, FOX11, OH×F333, OH×F87, FAROLD40) and *Pyrus communis L.* seedlings. Growth and yield attributes were calculated and chlorophyll and carotenoid contents were determined by the spectrophotometric method, using 99.8% methanol solvent for chlorophyll (chl) extraction.

Main results: Chl a/b in the case of rootstocks, chl a and total carotenoids in the cultivars were found statistically significant; the ratio chl a/b ranged 1.71-2.30 in the case of rootstocks; in the case of cultivars chl a ranged from 17.77 (cv. 'Santa Maria') to 19.88 (cv. 'Deveci') µg mL^{-1}, and carotenoids ranged 0.21-0.95 µg mL^{-1}. Under the main impact of cultivars, rootstocks and their combinations, a significant difference was seen in the growth and yield attributes.

Research highlights: A negative correlation coefficient was observed between photosynthetic pigments and morphological characteristics; however, the correlation coefficient was positive for canopy volume and annual shoot growth. Canopy management, especially with the use of rootstocks and cultivars that result in weaker growth, is helpful for improving chlorophyll content and yield performances.

Additional key words: *Cydonia oblonga*; *Pyrus communis*; clonal rootstocks; carotenoids; plant physiology; photosynthetic pigments.

Abbreviations used: BA29 (quince BA29); CV (canopy volume); chl (chlorophyll); DMF (di-methyl-formamide); DMSO (dimethyl sulfoxide solvent); PS (polystyrene); PMMA (polymethylacrylates); PCA (principal component analysis); QA (quince A); TSMS (Turkish State Meteorological Service)

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Introduction

Pear (*Pyrus communis* L.) is the second most prominent temperate fruit in many countries worldwide, and it has a great degree of adaptation to a wide range of climatic situations (Kurt et al., 2022). In 2020, 23.1 million tons of pears were produced globally. Sixteen million tons (69.2%) were produced in China, followed by Italy, America, Argentina, and Türkiye in the fifth position producing 545.569 tons of pears (FAOSTAT, 2022). Rootstocks are important in the fruit production sector since they help producers reach remarkable yield and resistant against biotic and abiotic factors. Many experts now recognize that rootstocks are just as valuable as cultivars. Rootstocks can affect growth, fruiting initiation, yield productivity, fruit quality, biological, physiological and economical qualities as inducers or inhibitors (Sabajeviene et al., 2006). Currently, pear cultivars are grafted on quince (*Cydonia oblonga*) and pear clone rootstocks (Hancock & Lobos, 2008), which are recommended because they provide precocity, increase fruit quality, facilitation of cultural processes, and reduction of the tree size (Francescatto et al., 2014). Pear clones and seedling rootstocks show stronger growth than quince clone rootstocks (Hancock & Lobos, 2008).

It is well known that plant productivity is influenced by the relationship between leaf area light absorption, light use efficiency, and light dispersion within the canopy for CO_2 assimilation, which ultimately determines the amount of fruit yield (Aikman, 1989; Bosa et al., 2016; Proietti et al., 2023). The major leaf pigments, chlorophyll and carotenoids, offer essential insights into the physiological state of plants. Chlorophylls are essentially necessary pigments for converting light energy into chemical energy which can be stored. The amount of photosynthetic pigments in a leaf determines how much solar radiation it can absorb; as a result, chlorophyll concentration can directly affect photosynthetic potential and primary production. For assessing the physiological state of plants during development, senescence, acclimatization and adaptation to various environments and stresses, variations in leaf carotenoids content and their proportion to chlorophyll are frequently used (Sabajeviene et al., 2006; Simkin et al., 2022). Changes in chlorophyll content occur due to nutrient deficiency, especially nitrogen (N) as it is leached from soil quickly. Low concentrations of chlorophyll contents in the leaves, directly curtail photosynthetic potential of the trees (Ghasemi et al., 2011). The leaf chlorophyll content is a good indicator of mutations, photosynthesis activity, biotic and abiotic stress conditions (Naumann et al., 2008), and nutritional composition of plants (Wu et al., 2008). To assess the nutritional status of pear trees, particularly N content in the leaves, the measurement of total chlorophyll is very helpful because there is a strong positive correlation between total chlorophyll and N content of pear leaves. Pear trees require precise nutrient schedules during vegetative growth as well as fruiting periods (Ghasemi et al., 2011).

The aim of this work was to study the effect of rootstocks on the contents of leaf photosynthetic pigments and its relation with some growth and yield characteristics of different pear cultivars. To our knowledge, this is the first work presenting various rootstock effects in combination with some cultivars on the chlorophyll and carotenoid content of pear leaves.

Material and methods

The research was performed in the Bafra Agriculture Research Station of Ondokuz Mayis University (41˚ 33’ 50’’ N; 35˚ 52’ 21’’ E; altitude 20 m) along two years, 2021 and 2022. A hot and humid climate in summer and a cool climate in winter is prominent in the research area, and precipitation mainly occurs in late autumn and early winter. Generally, the annual max, min, and mean temperature are 26.2 ˚C, 3.3 ˚C and 14.1 ˚C respectively (TSMS, 2022). Soil properties of the study area were: 2.73-10% clay, 13.21-20% silt, 6.5-20% sand, pH 7.5, 0.2-0.3 dS m^{-1} salt, 0.3-0.5% organic matter, 3-6% lime ($CaCO_3$), 0.03-0.06% N, 5-10 ppm P level, and soil depth > 1 m.

Plant material

In this study, ‘Santa Maria’ ‘Williams’, and ‘Deveci’ pear cultivars were grafted on eight different rootstocks in 2018: two semi-dwarf quince clonal rootstocks (BA29, QA) and six pear clonal rootstocks (FOX9, OH×F87 –both semi-dwarf–; FOX11, OH×F333, FAROLD40 –semi-vigorous– and *Pyrus communis* semi-vigorous seedlings).

In the case of quince rootstocks (BA29 and QA), trees were planted at a distance of 3.5 m × 1.5 m (1910 tree ha^{-1}), while in the case of pear rootstocks at 3.5 m × 3.0 m (952 tree ha^{-1}). Trees were pruned during the research according to the modified leader system. To support the quince saplings, a system of metal poles was established in the blocks where rootstocks were planted, but they were not used for pear rootstocks. Depending on the water requirement, irrigation of the trees was done with pressure compensating drippers at 1.20 m intervals, with two pipes per row on both sides of the trees. Weeds were controlled with a cultivator.

Growth attributes

Based on previous studies (Massai et al., 2008; Akcay et al., 2009), the annual shoot length (cm) was measured in 25 current-year developed shoots from different parts of a tree canopy at the end of the growing season (one month after leaf fall).

To calculate the canopy volume (CV, m^3): (i) the canopy width (m) was measured in the east-west direction with a tape measure at the end of the growing season of all trees in each replication; (ii) the canopy height (m) was measured from the first branch to the tip of the canopy at the end of the growing season; (iii) using the formula reported by Ozturk et al. (2022) and Kul et al. (2022), CV was calculated as:

$$CV = (\text{½ canopy width in m})^2 * 3.14 * (\text{½ canopy height in m})$$

Yield attributes

Fruit weight (g) was measured using 30 fruits randomly harvested in each replication with 0.01 g sensitive digital balance (CAMRY L-500) as described by Ozturk et al. (2022). Yield per tree (kg $tree^{-1}$) was obtained by multiplying the total number of fruit per tree by the average fruit weight. Yield per hectare (kg ha^{-1}) was calculated by multiplying yield per tree with the total number of trees per hectare.

Chlorophyll and carotenoid determinations

Pure methanol solvent (99.8%, Sigma-Aldrich) was used for chlorophyll extraction. For chlorophyll contents analysis, leaves were collected from upper, middle and down parts of trees at the fruiting time (in August) from the east side of the tree without considering whether branches were fruiting or not, then all leaves brought to the laboratory for analysis. Measurements were made from 5 healthy mature leaves in each replication. For this purpose, 100 mg of these five leaves were measured and grinded with 10 mL of 99.8% methanol, then concentrations of pigments were detected with a spectrophotometer by taking 1 mL of the prepared solution in the PS cuvettes (Lichtenthaler & Wellburn, 1983; Ghasemi et al., 2011). Finally, we calculated the amount of chl a, chl b, total chl and total carotenoids (all in µg mL^{-1} of plant extract) the formulas below:

$$\text{Chl a} = 15.65\, A_{666} - 7.34\, A_{653}$$
$$\text{Chl b} = 27.05\, A_{653} - 11.21\, A_{666}$$
$$\text{Total chl} = \text{chl a} + \text{chl b}$$
$$\text{Total carotenoids} = (1000\, A_{470} - 2.86\, \text{chl a} - 129.2\, \text{chl b}) / 245$$

Table 1. Effects on photosynthetic pigments of combination of different rootstocks × pear cultivars.

Rootstocks	Cultivars	chl a/chl b	chl a	chl b	Total chl	Carotenoids
			(µg mL^{-1} of plant extract)			
Quince						
BA29	Santa Maria	1.59	13.57	10.76	24.33	0.76
	Williams	1.91	18.66	10.15	28.82	0.99
	Deveci	1.85	17.98	10.69	28.67	0.83
QA	Santa Maria	1.57	19.28	12.29	31.57	0.30
	Williams	2.17	18.07	8.67	26.75	1.33
	Deveci	2.05	19.54	10.24	29.78	1.24
Pear						
FOX9	Santa Maria	2.08	20.48	10.13	30.61	0.62
	Williams	1.36	17.42	12.84	30.26	0.33
	Deveci	1.70	15.73	10.35	26.08	0.60
FOX11	Santa Maria	2.22	16.53	8.25	24.78	0.63
	Williams	1.78	15.29	8.93	24.22	0.46
	Deveci	1.85	19.74	11.42	31.16	0.27
OH×F333	Santa Maria	1.86	17.84	10.40	28.23	0.19
	Williams	2.28	16.87	7.52	24.38	1.59
	Deveci	1.85	21.39	12.17	33.56	0.81
OH×F87	Santa Maria	1.87	18.88	11.18	30.05	0.95
	Williams	2.15	18.68	9.83	28.51	0.95
	Deveci	1.98	21.87	11.31	33.18	1.81
FAROLD40	Santa Maria	2.60	18.69	7.31	26.01	1.45
	Williams	1.91	18.49	10.69	29.18	0.24
	Deveci	1.95	20.54	11.13	31.66	1.09
Seedling	Santa Maria	2.29	16.87	8.20	25.07	0.88
	Williams	2.50	19.38	7.72	27.10	2.09
	Deveci	2.13	22.25	11.37	33.62	1.01
Significance		0.623 ^{ns}	0.578 ^{ns}	0.913 ^{ns}	0.892 ^{ns}	0.198 ^{ns}

**: Highly significant (p<0.01). *: significant (p<0.05). ns: not significant (p>0.05).

Table 2. Main effects of rootstocks and cultivars on the chlorophyll characteristics.

Main effects	chl a/chl b	chl a	chl b	Total chl	Carotenoids
		(μg mL^{-1} of plant extract)			
Rootstocks					
BA29	1.78 ab	16.74	10.53	27.27	0.35
QA	1.92 ab	18.96	10.40	29.37	0.76
FOX9	1.71 b	17.88	11.10	28.98	0.29
FOX11	1.95 ab	17.19	9.54	26.72	0.45
OH×F333	1.99 ab	18.70	10.03	28.73	0.86
OH×F87	1.99 ab	19.81	10.77	30.58	0.60
FAROLD40	2.15 ab	19.24	9.71	28.95	0.92
Seedling	2.30 a	19.50	9.09	28.60	1.33
Cultivars					
Santa Maria	2.01	17.77 b	9.81	27.58	0.21 b
Williams	2.01	17.86 b	9.54	27.40	0.91 a
Deveci	1.92	19.88 a	11.08	30.96	0.95 a
Significance					
Rootstocks	0.023 *	0.501 ns	0.958 ns	0.954 ns	0.550 ns
Cultivars	0.807 ns	0.049 *	0.337 ns	0.123 ns	0.046 *

Means in the same column with different letters are significantly different. **: highly significant ($p<0.01$). *: significant ($p<0.05$). ns: not significant ($p>0.05$).

Data analysis

The experiment was carried out as a factorial randomized complete block design. There were two factors in the study including rootstocks and cultivars. There were three replications; each replication consisted of 10 trees in the case of quince rootstocks (high-density plantation) or 5 trees in the case of pear rootstocks (low-density plantation). The data, showing the average of two research years, were analyzed with IBM SPSS 21.0 program (SPSS Inc. Chicago, ABD) and mean comparison was made with Duncan multiple comparison test at $p<0.05$. Pearson correlation coefficient and principal component analysis (PCA) of evaluated characteristics were done with the IBM SPSS and XLSTAT statistical program.

Results

Chlorophyll and total carotenoids

The rootstocks and cultivars' combination effect on the photosynthetic pigments of pear trees is given in Table 1. These combinations did not have effect on carotenoids and chlorophyll contents. Chl a ranged 13.57-22.25 μg mL^{-1}, chl b 7.31-12.84 μg mL^{-1}, total chl 24.22-33.62 μg mL^{-1}, the ratio chl a/chl b between 1.36 and 2.60, and carotenoids from 0.19 to 2.09 μg mL^{-1}.

The main effects of rootstocks and cultivars on the chlorophyll characteristics are showed in Table 2. Chl a/chl b in the case of rootstocks, and chl a and total carotenoids in the case of cultivars were statistically significant, while the other characteristics were not significant. The highest value recorded for the ratio chl a/chl b was in the seedling (2.30) and the lowest in the FOX9 rootstock (1.71). In the case of cultivars, the highest chl a and carotenoid contents were recorded in cv. 'Deveci' (19.88 and 0.95 μg mL^{-1}, respectively) and the lowest in cv. 'Santa Maria' (17.77 and 0.21 μg mL^{-1}, respectively).

Growth and yield characteristics

The combined effect of 8 rootstocks and 3 cultivars on the growth and yield performances is illustrated in Table 3. Except the CV, which was found statistically not significant, all remaining growth and yield properties were found significant. Annual shoot growth ranged between 9.57 and 38.48 cm, the highest in 'Santa Maria'/BA29 and the lowest in 'Williams'/seedling combination. In the case of CV data varied from 0.08 to 1.98 m^3. Fruit weight ranged 135.49-269.19 g, the highest recorded in the combination 'Williams'/seedling and the lowest in 'Williams'/OH×F333. Yield ranged 1.06-59.40 kg tree^{-1} and 172.65-144833.69 kg ha^{-1}, the highest yield found in both cases in the combination 'Deveci'/BA29, while lowest in 'Deveci'/OH×F87.

Regarding growth and yield performances, all evaluated factors in the rootstocks and cultivars were significant, except annual shoot growth and CV in the case of cultivars which were not significant (Table 4). In the case of rootstocks, we detected the highest annual shoot growth (35.43 cm) on BA29, CV (1.44 m^3) on FOX11, fruit weight (202.09 g) on seedling, yield per tree (34.73 kg $tree^{-1}$) on BA29 and yield per hectare (86137.70 kg ha^{-1}) on BA29. The respective lowest values were: 15.92 cm on seedling, 0.10 m^3 on FOX9, 152.05 g on OH×F333, 1.14 kg $tree^{-1}$ on FOX9, and 1603.19 kg ha^{-1} on FOX9. In the case of cultivars, the highest fruit weight (199.65 g), yield per tree (19.60 kg $tree^{-1}$), and yield per hectare (39033.54 kg ha^{-1}) were all found in cv. 'Deveci'; while the lowest values observed respectively were 158.60 g on 'Santa Maria', 8.83 kg $tree^{-1}$ on 'Williams', and 15412.44 kg ha^{-1} on 'Williams'.

Correlation and principal component analysis (PCA) of evaluated characteristics

Pearson correlation coefficients between chlorophyll, carotenoid, morphological and yield characteristics are illustrated in Figure 1. The correlation coefficients were calculated using a total number of ten evaluated features. The correlation between total chl and carotenoids (-0.248*) was significantly negative. Moreover, our study found negative correlations between CV and photosynthetic pigments. In contrast, CV and annual shoot growth (0.422**) showed a significantly positive correlation. We found a negative correlation between fruit weight and morphological characteristics.

PCA of dependent variables is shown in Figure 2. As a result of PCA, all dependent variables were divided into three components. The contribution to component 1

Table 3. Combination effects of rootstocks × pear cultivars on growth and yield performances.

Rootstocks	Cultivars	Annual shoot growth (cm)	CV (m^3)	Fruit weight (g)	Yield	
					(kg $tree^{-1}$)	(kg ha^{-1})
Quince						
BA29	Santa Maria	38.48 a	1.50	152.51 b	21.54 b	54720.39 ab
	Williams	29.95 b	0.96	163.50 b	23.28 b	58859.04 b
	Deveci	37.88 a	1.59	222.15 a	59.40 a	144833.69 a
QA	Santa Maria	31.99 b	1.67	183.14 b	33.14 b	82331.65 ab
	Williams	27.35 b	0.44	149.92 c	10.08 c	27446.66 ab
	Deveci	28.52 b	1.14	239.83 a	44.96 ab	110464.72 a
Pear						
FOX9	Santa Maria	16.56 d	0.12	150.59 c	1.57 e	2210.33 d
	Williams	17.28 d	0.08	242.34 a	0.73 e	172.65 e
	Deveci	21.19 c	0.13	170.70 b	1.14 e	2426.61 d
FOX11	Santa Maria	35.84 a	1.60	160.98 b	18.52 b	18938.42 bc
	Williams	34.76 a	1.40	204.21 a	9.33 d	10205.67 bcd
	Deveci	32.70 b	1.32	194.34 a	14.30 c	14927.51 c
OH×F333	Santa Maria	22.08 c	0.90	161.50 b	25.95 b	25998.23 ab
	Williams	18.78 d	1.15	135.49 c	11.74 c	12500.19 ab
	Deveci	29.36 b	1.98	159.18 b	15.39 b	15965.71 abc
OH×F87	Santa Maria	26.07 c	0.22	174.78 c	2.73 e	3936.27 cd
	Williams	34.54 a	0.32	179.00 b	1.20 e	619.56 e
	Deveci	22.35 c	0.14	219.93 a	1.06 e	1409.53 bcd
FAROLD40	Santa Maria	17.70 d	1.18	143.72 c	22.79 b	22995.86 b
	Williams	29.06 b	1.37	204.36 a	12.60 c	13314.79 c
	Deveci	30.31 b	1.33	195.63 a	18.27 b	18700.69 bc
Seedling	Santa Maria	24.22 c	1.55	141.63 c	8.28 d	9207.68 d
	Williams	9.57 e	0.47	269.19 a	1.74 e	181.01 e
	Deveci	13.99 d	0.67	195.48 a	2.31 e	3539.95 d
Significance		0.001**	0.148 ns	0.001 **	0.001 **	0.001 **

CV: canopy volume. Means in the same column with different letters are significantly different. **: highly significant (p<0.01). *: significant (p<0.05). ns: not significant (p>0.05).

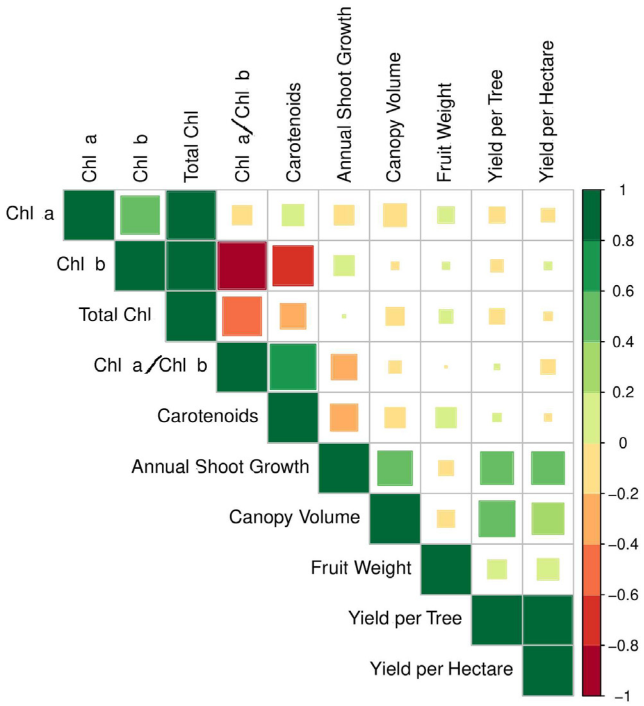

Figure 1. Pearson correlation analysis of chlorophyll, carotenoid, growth and yield of different rootstocks × pear cultivars combinations.

was 33.16%, to component 2, 26.92% and to component 3, 16.58%.

Discussion

Chlorophyll and total carotenoids

Chlorophyll content is vital in the photosynthesis process for the absorption and transfer of light energy. It can change in response to biotic and abiotic stress factors in the leaves, so quantification of chlorophyll provides important information about the trees' physiological situations (Hu et al., 2013). In our study, considering the combination effects of rootstocks and cultivars, CV was found not significant. Also, CV was not significant in the case of rootstocks' main effects. This can be the reason for less variation in the chlorophyll content of rootstocks, cultivars and their combinations due to the equality in the absorption of light. The same finding was also reported by Bosa et al. (2016). Carotenoids have two important roles in plants: first, they absorb light energy for use in photosynthesis, and second, as critical antioxidants, they reduce photo-damage and photo-inhibition (Adadi et al., 2018; Simkin et al., 2022). In this study, significant differences in the chl a and carotenoid contents of the cultivars were found, probably due to variations in natural hormone contents of the cultivars (Mosa et al., 2022), organic acids content of the cultivars (Olaetxea et al., 2020; Nargesi et al., 2022), or nutrient uptake capacity of the rootstocks and grafted cultivars on them (Mosa et al., 2022). Our findings revealed that there were variations in the content of carotenoid and chl a between cultivars. The same findings were reported by Zhao et al. (2022) in pears and by Wojdylo et al. (2021) in leaves of various fruit tree species (apple, pear, quince, apricot, peach, plums, sweet cherry, and sour cherry) and their cultivars. In our study, chlorophyll and carotenoid contents were found not significant, except for chl a and carotenoid in the case of cultivar main effect and chl a/chl b ratio in the case of the rootstock's main effect. This is related to the CV and tree shapes which were managed properly to receive an appropriate amount of sunlight energy and macro/micro elements, as well as trees ages that were so young and there was not any interference for absorption of light and between them. Later on, when trees become older a significant variation in the photosynthetic rate and chlorophyll content may occur, as it was observed by Zhao et al. (2022) in pear cv. 'Zaosu'. In order to ensure the accuracy of the determination of chlorophyll, extra care must be taken at all phases, particularly during the extraction period to avoid the hydrolase enzyme chlorophyllase from converting chlorophyll to chlorophyllide (Hu et al., 2013). Photosynthetic pigment contents and the chl a/chl b ratio in apple leaves are related with crop load, higher crop load is consequence of higher photosynthetic pigment content, and lower chl a/chl b ratio (Sabajeviene et al., 2006).

The chl and carotenoid contents may be differ based on the extractant, as there are various methods to determine the chl and carotenoid contents (Lichtenthaler & Wellburn, 1983; Ghasemi et al., 2011; Paul et al., 2017). They include the use of several solvents (water-saturated diethyl ether, pure diethyl ether, pure methanol, 96% ethanol, 80% or 100% acetone, di-methyl-formamide (DMF), dimethyl sulfoxide solvent (DMSO) and estimation by instruments (SPAD-502, CCM-200) which also called non-destructive methods of chlorophyll estimation. In our study, we used methanol, as it is a well extractant for chlorophylls specially in case of recalcitrant vascular plants, which is less volatile and less flammable compared to the acetone. However, it is notoriously toxic and readily adsorbed by inhalation as well as via the skin. Methanol also fogs PS cuvettes leading to false readings and cannot be used with PMMA cuvettes (Porra, 2002). According to some researchers, ethanol is better than acetone or methanol, but it is not used very often for the analysis of chlorophylls. Ethanol is flammable but not very toxic and it doesn't attack PS cuvettes (Ritchie, 2006). Although acetone is a good solvent to assay chlorophylls, it has been reported not to be an ideal solvent for extraction. The reason it that, in most practical situations, it is inefficient for large sample sizes and can lead to inevitable loss and oxidation. From the safety point of view, acetone is highly volatile and flammable. It is narcotic in high concentrations and

Table 4. Main effects of rootstocks and cultivars on growth and yield performances.

Main effects	Annual shoot growth (cm)	CV (m^3)	Fruit weight (g)	Yield	
				(kg tree^{-1})	(kg ha^{-1})
Rootstocks					
BA29	35.43 a	1.35 a	179.38 b	34.73 a	86137.70 a
QA	29.28 b	1.08 a	190.96 ab	29.39 a	73414.34 a
FOX9	18.34 d	0.10 b	187.87 ab	1.14 c	1603.19 b
FOX11	34.43 a	1.44 a	186.50 ab	14.05 b	14690.53 b
OH×F333	23.40 c	1.34 a	152.05 c	17.69 b	18154.71 b
OH×F87	27.65 bc	0.22 b	191.23 ab	1.66 c	1988.45 b
FAROLD40	25.68 bc	1.29 a	181.23 b	17.88 b	18337.11 b
Seedling	15.92 d	0.89 a	202.09 a	4.10 c	4309.54 b
Cultivars					
Santa Maria	26.62	1.09	158.60 b	16.81 a	27542.35 b
Williams	25.16	0.78	193.50 a	8.83 b	15412.44 c
Deveci	27.04	1.04	199.65 a	19.60 a	39033.54 a
Significance					
Rootstocks	0.001 **	0.001 **	0.001 **	0.001 **	0.001 **
Cultivars	0.410 ns	0.091 ns	0.001 **	0.001 **	0.001 **

CV: canopy volume. Means in the same column with different letters are significantly different. **: highly significant ($p<0.01$). *: significant ($p<0.05$). ns: not significant ($p>0.05$).

can cause headache and skin irritation. Acetone also can destroy PS and PMMA. Therefore, PS and PMMA cuvettes cannot be used for acetone-based chlorophyll evolutions (Ritchie, 2006). Using dimethyl sulfoxide solvent (DMSO) for chlorophyll extraction of Asian pear (*Pyrus serotina* Rehd.) leaves; Ghasemi et al. (2011) reported chl a, chl b and total chl contents of 0.0221 mg cm^2, 0.0182 mg cm^2, and 0.0403 mg cm^2, respectively. Küçükyumuk (2020) reported leaf chlorophyll index of 65.4, 58.0, and 52.6, in 2-yr old young pear saplings of cvs. 'Deveci', 'Ankara' and 'Margarita', respectively, which were grafted on OH×F333 rootstocks, measured with SPAD chlorophyll meter. Tatari et al. (2020) reported chlorophyll index of *Pyrus salicifolia*, *Pyrus syriaca*, and *Pyrus communis* (cv. 'Khoji1', 'Khoji2', and 'Spadona') pear species 53.1, 50.5, 45.1, 49.6, and 46.1 respectively, measured by SPAD. Using pure acetone as chlorophyll extractant, Ciobotari et al. (2010) found the following amounts of chl a, chl b and carotenoid of pear cultivars, respectively: 1.48, 0.42, 0.65 mg g^{-1} in cv. 'Comtesse de Paris'; 1.38, 0.43, 0.42 mg g^{-1} in cv. 'Williams'; 1.55, 0.45, 0.45 mg g^{-1} in cv. 'Trivale'; and 1.35, 0.39, 0.40 mg g^{-1} in cv. 'Triumf'.

Growth and yield characteristics

Rootstocks affect the morphological characteristics of pear cultivars at various levels (Sugar & Basile, 2011; Dondini & Sansavini, 2012; Francescatto et al., 2014). Limitation of annual shoot growth of pear trees on quince rootstocks is due to unfavorable conditions like dry and excessively hot weather (Sansavini et al., 2007; Musacchi et al., 2021). Annual shoot length was observed to differ in the case of different rootstocks (Pasa et al., 2020). When there is an incompatibility between the rootstock and cultivar, this situation tends to early cropping and consequently causes limitations in the growth of annual shoots (Dondini & Sansavini, 2012). In high-fruiting years, less carbohydrates are available to the shoots because they are needed for fruit production, which lead to a decline in shoot growth (Pasa et al., 2012). Dalzochio et al. (2021) reported that there were differences in the annual shoot growth between pear cvs. 'Packhams Triumph' (34.3 cm) and 'Hosui' (80.4 cm). Engin (2011) observed annual shoot lengths in cv. 'Santa Maria' grafted on QA ranged between 35.56 and 49 cm and in 'Santa Maria' on OH×F333 ranged from 15.69 to 37.90 cm.

Canopy management of fruit trees, is important for light penetration and regular flower and fruit production. Otherwise, naturally there is an adverse effect between fruit set and CV of a tree (Close & Bound, 2017; Costa et al., 2019; Einhorn, 2021). Moreover, canopy chlorophyll content, that can actively change by the penetrated light inside of canopy to stored chemical energy, is extraordinarily considerable. We found a negative correlation

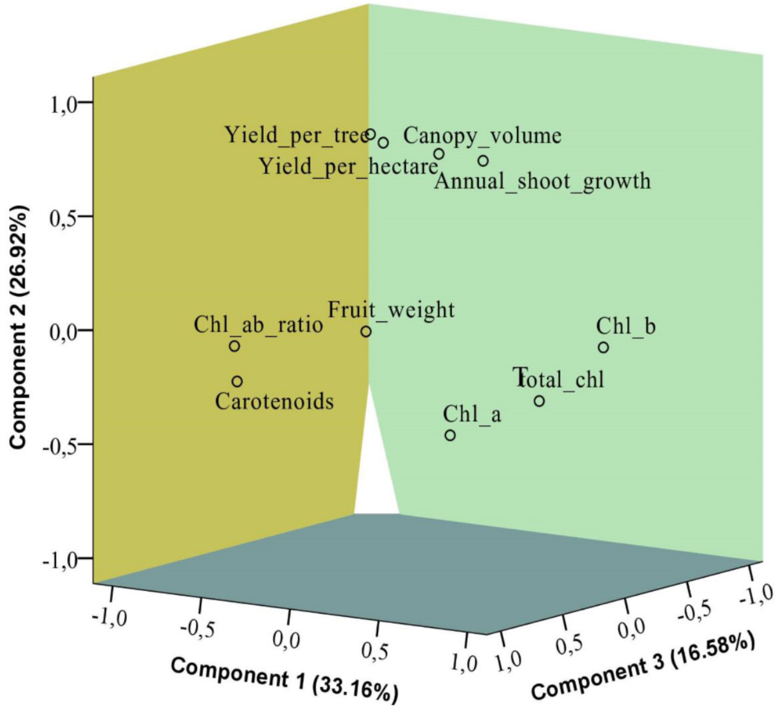

Figure 2. Principal component analysis of chlorophyll, carotenoid, growth and yield of different rootstocks × pear cultivars combinations.

between CV and chlorophyll contents, that indicate the management of CV is important to increase photosynthetic pigments by providing an ideal canopy structure for light penetration. Consequently, this negative correlation causes more production per CV, similar to findings reported by Bound (2021). Engin (2011) reported a tree crown volume of 0.26-1.02 m^3 in 'Santa Maria' grafted on QA and of 0.23-0.53 m^3 in 'Santa Maria' grafted on OH×F333. It was determined that the CV of pear trees on quince MC rootstock was low, as it is a dwarf rootstock (Ozturk, 2021), so it can be debated that dwarf rootstocks decreased the CV and are able to achieve more sunlight than semi-dwarf and vigor rootstocks. So, their photosynthetic system work more actively for yield production due to availability of nutrients especially N for photosynthetic pigments formation. While, trees with huge CV are consume nutrients for vegetative growth instead of using them in the photosynthesis system and its processes. In our study, we found similar results that semi-dwarf (QA, FOX9 and OH×F87) rootstocks even statistically were not significantly different in case of chl contents, but had higher values of chl contents than semi-vigorous rootstocks that we used in our study.

Suitable rootstocks for pear cultivars are necessary for increasing cultivars average fruit weight (Askari-Khorosgani et al., 2019). Lepaja et al. (2014) reported a fruit weight of 195.18 g in cv. 'Santa Maria'. **Ö**ztürk & Faizi (2022) calculated the following fruit weights of some Turkish local pear cultivars grafted on BA29 rootstock: 'Karpuz' 195.47 g, 'Kadın Parmak' 53.44 g, 'Karga' 63.44 g, 'Kuşak' 111.75 g, 'Gelin' 83.24 g, 'Macar' 205,03 g, 'Harman' 114.07 g, 'Rıza' 128.73 g, 'Kara' 141.44 g, and 'Eşek' 154.60 g.

In summary, in this research, CV was found to be negatively correlated with the chlorophyll and carotenoid contents. This means the increase in CV will cause a decrease in the chlorophyll content of the trees. Considering this correlation, management of the canopy is a vital practice that must be applied regularly in the pear orchards to increase photosynthetic pigments and consequently, it causes an increase in the yield and a decrease in vegetative growth, especially annual shoot length.

Authors' contributions

Conceptualization: Z.A. Faizi, A. Ozturk.
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Formal analysis: Z.A. Faizi.
Funding acquisition: Not applicable.
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Project administration: Z.A. Faizi, A. Ozturk.
Resources: Z.A. Faizi, A. Ozturk.
Software: Not applicable.
Supervision: A. Ozturk.
Validation: Z.A. Faizi.
Visualization: Z.A. Faizi.

Writing – original draft: Z.A. Faizi.
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References

Adadi P, Barakova NV, Krivoshapkina EF, 2018. Selected methods of extracting carotenoids, characterization, and health concerns: A review. J Agr Food Chem 66(24): 5925-5947. https://doi.org/10.1021/acs.jafc.8b01407

Aikman DP, 1989. Potential increase in photosynthetic efficiency from the redistribution of solar radiation in a crop. J Exp Bot 40(8): 855-864. https://doi.org/10.1093/jxb/40.8.855

Akcay ME, Buyukyilmaz M, Burak M, 2009. Marmara Bölgesi için ümitvar armut çeşitleri-IV. Bahçe 38(1): 1-10.

Askari-Khorosgani O, Jafarpour M, Hadad MM, Pessarakli M, 2019. Fruit yield and quality characteristics of 'Shahmiveh' pear cultivar grafted on six rootstocks. J Plant Nutr 42(4): 323-332. https://doi.org/10.1080/01904167.2018.1555592

Bosa K, Jadczuk-Tobjasz E, Kalaji MH, 2016. Photosynthetic productivity of pear trees grown on different rootstocks. Annali di Botanica 6: 69-75.

Bound SA, 2021. Managing crop load in European pear (*Pyrus communis* L.). A review. Agriculture 11(7): 637. https://doi.org/10.3390/agriculture11070637

Ciobotari G, Brinza M, Morariu A, Gradinariu G, 2010. Graft incompatibility influence on assimilating pigments and soluble sugars amount of some pear (*Pyrus sativa*) cultivars. Not Bot Hort Agrobotanici Cluj-Napoca 38(1): 187-192.

Close DC, Bound SA, 2017. Advances in understanding apple tree growth: The manipulation of tree growth and development. In: Achieving sustainable cultivation of apples; Evans K (Ed); Burleigh Dodds Sci Publ Ltd., Cambridge, UK, pp: 1-32. https://doi.org/10.19103/AS.2016.0017.29

Costa G, Botton A, Vizzotto G, 2019. Fruit thinning: advances and trends. Hortic Rev 46: 185-226. https://doi.org/10.1002/9781119521082.ch4

Dalzochio OÂ, Silvestre WP, Pauletti GF, 2021. Effect of the application of prohexadione-calcium on the growth of 'Packhams Triumph' and 'Hosui'pears (*Pyrus communis* L.). Res Soc Dev 10(8): e 3 110816801. https://doi.org/10.33448/rsd-v10i8.16801

Dondini L, Sansavini S, 2012. European pear. In: Fruit breeding, Handbook of Plant Breeding; Badenes ML, Byrne DH (eds), Vol. 8. Springer Science+Business Media, New York, pp: 363-413. https://doi.org/10.1007/978-1-4419-0763-9_11

Einhorn TC, 2021. A review of recent Pyrus, Cydonia and Amelanchier rootstock selections for high-density pear plantings. Acta Hortic 1303: 185-196. https://doi.org/10.17660/ActaHortic.2021.1303.27

Engin K, 2011. OHF 333 ve quince A anaçları üzerine aşılı 'Santa Maria' ve 'Deveci' armut çeşitlerinde farklı terbiye sistemlerinin vejetatif ve generatif gelişim üzerine etkisi. (Master's thesis, Fen Bilimleri Enstitüsü), Gaziosmanpasa universitesi, 37 pp.

FAOSTAT, 2022. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor. [15 May 2022].

Francescatto P, Pazzin D, Gazolla Nero A, Fachinello J, Giacobbo C, 2014. Evaluation of graft compatibility between quince rootstocks and pear scions. Acta Hortic 872: 253-259. https://doi.org/10.17660/ActaHortic.2010.872.34

Ghasemi M, Arzani K, Yadollahi A, Ghasemi S, Khorrami SS, 2011. Estimate of leaf chlorophyll and nitrogen content in Asian pear (*Pyrus serotina* Rehd.) by CCM-200. Not Sci Bio 3(1): 91-94. https://doi.org/10.15835/nsb315623

Hancock JF, Lobos GA, 2008. Pears. In: Temperate fruit crop breeding: germplasm to genomics; Hancock JF (ed.). pp: 299-335. Springer, New York. https://doi.org/10.1007/978-1-4020-6907-9

Hu X, Tanaka A, Tanaka R, 2013. Simple extraction methods that prevent the artifactual conversion of chlorophyll to chlorophyllide during pigment isolation from leaf samples. Plant Meth 9(1): 1-13. https://doi.org/10.1186/1746-4811-9-19

Küçükyumuk C, 2020. Drought response of young pear trees (*Pyrus communis*). Appl Ecol Environ Res 18(6): 7769-7781. https://doi.org/10.15666/aeer/1806_77697781

Kul YM, Öztürk A, Faizi ZA, 2022. Evaluation of different rootstocks and cultivars on pruning weight in young pear trees. BSJ Agri 5(4): 440-447. https://doi.org/10.47115/bsagriculture.1167288

Kurt T, Öztürk A, Faizi ZA, 2022. Determination of phenological and morphological characteristics of some standard pear cultivars on quince clonal rootstocks. KFBD 12(2): 782-801. https://doi.org/10.31466/kfbd.1153780

Lepaja L, Kullaj E, Lepaja K, Shehaj M, Zajmi A, 2014. Fruit quality parameters of five pear cultivars in Western Kosovo. Agr Food 2: 245-250.

Lichtenthaler HK, Wellburn AR, 1983. Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. Meeting No 603, Liverpool 11: 591-592. https://doi.org/10.1042/bst0110591

Massai R, Loreti F, Fei C, 2008. Growth and yield of 'Conference' pears grafted on quince and pear rootstocks. Acta Hortic 800: 617-624. https://doi.org/10.17660/ActaHortic.2008.800.82

Mosa WFA, Abd EL-Megeed NA, Ali MM, Abada HS, Ali HM, Siddiqui MH, et al., 2022. Preharvest foliar applications of citric acid, gibberellic acid and humic acid improve growth and fruit quality of 'Le Conte' pear (*Pyrus communis* L.). Horticulturae 8(6): 507. https://doi.org/10.3390/horticulturae8060507

Musacchi S, Iglesias I, Neri D, 2021. Training systems and sustainable orchard management for European pear (*Pyrus communis* L.) in the Mediterranean area: A review. Agronomy 11(9): 1765. https://doi.org/10.3390/agronomy11091765
Nargesi MM, Sedaghathoor S, Hashemabadi D, 2022. Effect of foliar application of amino acid, humic acid and fulvic acid on the oil content and quality of olive. Saudi J Biol Sci 29(5): 3473-3481. https://doi.org/10.1016/j.sjbs.2022.02.034
Naumann JC, Young DR, Anderson JE, 2008. Leaf chlorophyll fluorescence, reflectance, and physiological response to freshwater and saltwater flooding in the evergreen shrub, Myrica cerifera. Environ Exp Bot 63: 402-409. https://doi.org/10.1016/j.envexpbot.2007.12.008
Olaetxea M, Mora V, Baigorri R, Zamarreño AM, García-Mina JM, 2020. The singular molecular conformation of humic acids in solution influences their ability to enhance root hydraulic conductivity and plant growth. Molecules 26(1): 3. https://doi.org/10.3390/molecules26010003
Ozturk A, 2021. The effects of different rootstocks on the graft success and scion development of some pear cultivars. Int J Fruit Sci 21(1): 932-944. https://doi.org/10.1080/15538362.2021.1948376
Öztürk A, Faizi ZA, 2022. Quality performance of some local pear cultivars on BA29 rootstock under high density planting. Int J Agr Wildlife Sci 8(3): 440-449. https://doi.org/10.24180/ijaws.1179193
Ozturk A, Faizi ZA, Kurt T, 2022. Performance of some standard quince varieties under ecological conditions of Bafra, Samsun. Yuzuncu Yıl Univ J Agr Sci 32(2): 320-330. https://doi.org/10.29133/yyutbd.1058908
Pasa MDS, Fachinello JC, Schmitz JD, Souza ALKD, Franceschi ÉD, 2012. Desenvolvimento, produtividade e qualidade de peras sobre porta-enxertos de marmeleiro e *Pyrus calleryana*. Rev Bras Fruticult 34(3): 873-880. https://doi.org/10.1590/S0100-29452012000300029
Pasa MDS, Schmitz JD, Rosa Júnior HFD, Souza ALKD, Malgarim MB, Mello-Farias PCD, 2020. Performance of 'Williams' pear grafted onto three rootstocks. Ceres 67: 133-136. https://doi.org/10.1590/0034-737x202067020006
Paul V, Sharma L, Kumar R, Pandey R, Meena RC, 2017. Estimation of chlorophylls/photosynthetic pigments their stability is an indicator of crop plant tolerance to abiotic stresses. Manual of ICAR sponsored training programme for technical staff of ICAR institutes on physiological techniques to analyze the impact of climate change on crop plants, pp: 8-14.
Porra RJ, 2002. The chequered history of the development and use of simultaneous equations for the accurate determination of chlorophylls a and b. Photosyn Res 73: 149-156.
Proietti S, Paradiso R, Moscatello S, Saccardo F, Battistelli A, 2023. Light intensity affects the assimilation rate and carbohydrates partitioning in spinach grown in a controlled environment. Plants 12(4): 804. https://doi.org/10.3390/plants12040804
Ritchie RJ, 2006. Consistent sets of spectrophotometric chlorophyll equations for acetone, methanol and ethanol solvents. Photosyn Res 89: 27-41. https://doi.org/10.1007/s11120-006-9065-9
Sabajeviene G, Kviklys D, Duchovskis P, 2006. Rootstock effect on photosynthetic pigment system formation in leaves of apple cv. 'Auksis'. Sodininkystė ir daržininkystė 25(3): 357-363.
Sansavini S, Ancarani V, Neri D, 2007. Overview of intensive pear culture: planting density, rootstocks, orchard management, soil-water relations and fruit quality. X Int Pear Symp 800: 35-50. https://doi.org/10.17660/ActaHortic.2008.800.1
Simkin AJ, Kapoor L, Doss CGP, Hofmann TA, Lawson T, Ramamoorthy S, 2022. The role of photosynthesis related pigments in light harvesting, photoprotection and enhancement of photosynthetic yield in planta. Photosyn Res 152(1): 23-42. https://doi.org/10.1007/s11120-021-00892-6
Sugar D, Basile SR, 2011. Performance of 'Comice' pear on quince rootstocks in Oregon, USA. Acta Hortic 909: 215-218. https://doi.org/10.17660/ActaHortic.2011.909.23
Tatari M, Jafari A, Shirmardi M, Mohamadi M, 2020. Using morphological and physiological traits to evaluate drought tolerance of pear populations (*Pyrus* spp.). Int J Fruit Sci 20(4): 837-854. https://doi.org/10.1080/15538362.2019.1697410
TSMS, 2022. Turkish State Meteorological Service. https://www.mgm.gov.tr/tahmin/il-ve-ilceler.aspx?m=SAMSUN#/. [15 May 2022].
Wojdylo A, Nowicka P, Tkacz K, Turkiewicz IP, 2021. Fruit tree leaves as unconventional and valuable source of chlorophyll and carotenoid compounds determined by liquid chromatography-photodiode-quadrupole/time of flight-electrospray ionization-mass spectrometry (LC-PDA-qTof-ESI-MS). Food Chem 349: 129156. https://doi.org/10.1016/j.foodchem.2021.129156
Wu C, Niu Z, Tang Q, Huang W, 2008. Estimating chlorophyll content from hyperspectral vegetation indices: Modeling and validation. Agr For Meteorol 48: 1230-1241. https://doi.org/10.1016/j.agrformet.2008.03.005
Zhao M, Sun W, Li H, Wang W, Cao G, Wang F, 2022. The effects of the tree structure of 'Zaosu' pear on the transport and distribution of photosynthetic assimilates and fruit quality under desert-area conditions. Agronomy 12(10): 2440. https://doi.org/10.3390/agronomy12102440