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Research Article

Effects of rootstocks on fruit yield and quality, antioxidant capacity, and total phenol content of almond cultivars 'Ferragnes' and 'Ferraduel'

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Abstract

Almond is a temperate fruit tree whose yield and quality are strongly influenced by rootstocks. This study evaluated pomological traits, yield, antioxidant capacity, total phenol content, and fatty acid composition of the cultivars 'Ferragnes' and 'Ferraduel' grafted onto Garnem, GF-677, and seedling rootstocks over two years. The assessed pomological traits included shelled fruit and kernel weight, fruit dimensions, and kernel ratio. Palmitic, palmitoleic, stearic, oleic, linoleic, and linolenic acids were identified as the major fatty acids. Antioxidant activity and total phenol content ranged from 4.80 to 9.50 µmol TE g^{-1} fresh weight (FW) and from 56.21 to 133.14 mg GAE 100 g^{-1} FW, respectively, with seedling rootstocks showing higher values than Garnem and GF-677. Average shelled fruit and kernel weights were highest in the seedling/'Ferraduel' combination (7.43 g and 1.63 g, respectively) and lowest in Garnem/'Ferragnes' (4.71 g and 1.53 g, respectively). In this study, both seedling and GF-677 rootstocks led to higher shell and kernel weights than Garnem in both varieties. Compared to Garnem and GF-677 rootstocks, the Ferraduel and Ferragnes grafted onto seedling rootstock produced the lowest yield. Although Garnem rootstock produced the highest yield, GF-677 resulted in higher shelled and kernel weights and better fruit dimensions. Overall, GF-677 rootstock was identified as the most suitable option for the cultivation of both 'Ferragnes' and 'Ferraduel', as it combined high yield with favourable pomological characteristics.

Keywords: almond variety; fatty acid; kernel quality; *Prunus dulcis*; yield efficiency

Introduction

The almond tree belongs to the subgenus *Amygdalus* and is scientifically known as *Prunus dulcis* (Mill.) D.A. Webb. It is a member of the genus *Prunus* L. within the family *Rosaceae*, native to south-central Asia and cultivated in Mediterranean-type climates. There are about 30 types of wild almonds in addition to

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commercially grown almonds, and they are typically bitter than the cultivated varieties (Hojjati *et al*., 2016; Massantini and Frangipane, 2022).

Almonds are one of the most important agricultural products among the hard-kernel fruits. Globally, approximately 3.5 million tonnes of shelled almonds are produced annually (FAO, 2023). Due to consumer belief that almonds offer considerable health benefits, almond production has increased over the past decade. Almonds have remarkable nutritional and organoleptic properties, so it is vital to examine their quality properly. Almonds are healthy and nutritious due to their high content of fats, proteins, minerals, vitamins, and phytonutrients, which offsets their relatively low total sugar content (4.35 g 100 g^{-1} of almonds) (Massantini and Frangipane, 2022).

The rootstock is one of the most important factors that affect the profitability of the production. The use of rootstocks is the most economical method for managing tree vigor, with the added benefit of broad applicability. Breeding programs are in progress on rootstock varieties all around the world. Many studies are conducted on hard-shelled fruit rootstocks, including almonds (Moreno and Webster, 2004). As one of the investigated rootstocks, *Prunus* spp. significantly impacts grafted varieties by modulating water relations, leaf gas exchange, mineral absorption, vegetative growth (tree height), reproductive development (flowering time, fruit bud density), and productivity (yield efficiency and vigor) (Albás *et al*., 2004; Zarrouk *et al*., 2005). The root system of the plants is required to absorb the soil nutrients and water into the plant. Many studies have shown that rootstock usage directly affects nutrient and water intake, as well as the proportion of fruit quality parameters (Loreti and Massai, 2002; Albás *et al*., 2004; Giorgi *et al*., 2005; Remorini *et al*., 2008).

Almond × peach hybrid 'Garnem' (which was derived from the cross between 'Garfi' almond × 'Nemared' peach) shows high vigour, nematode resistance, and adaptability to calcareous soils. The 'Garnem' unbudded trees are robust and have no discernible size differences. Grafted cultivars exhibit vigour equal to that of 'GF-677' or 'Hansen 536', with a comparable level of production. Nongrafted plants are vigorous and in the nursery exhibit an erect growth with little or no feathering during the first season. The leaves are large, lanceolate, and intermediate in form between almond and peach. The first-year shoots have little to no lateral branching and are straight. The three rootstocks demonstrate comparable low chilling requirements and bloom early (Felipe, 2009).

One of the best rootstocks for almond and peach trees, particularly in calcareous soils, is GF-677, a hybrid of *Prunus amygdalus* and *P. persica*, which helps resist lime-induced chlorosis. This rootstock is resistant to Fe deficiency and perfectly suited to soils with low water availability, high $CaCO_3$ content, and poor fertility. This hybrid produces strong roots, which also have a low risk of diseases and pests. Vegetative procedures (cuttings and tissue culture) can be used to propagate it. Using this approach, large quantities of disease-free GF 667 plants can be rapidly and successfully propagated (Antonopoulou *et al*., 2007; Aghaye and Yadollahi, 2012).

Almond quality has become a key breeding objective, considering not only the chemical composition conferring a specific organoleptic quality but also physical traits related to industry processing, despite the challenges in defining a kernel quality ideotype due to the substantial differences in consumer preferences. As a result, a different kind of shell is favoured based on the industry in each region, with California and other places with a comparable growth system favouring a soft shell over a hard one in the majority of Mediterranean countries. In addition to the organoleptic quality of almonds, their high content of oleic acid among the fatty acids, and their fibre content all contribute to the almonds' beneficial effects on human health. Consequently, the chemical composition of almond kernels represents a new breeding goal. Although these elements have not yet been included in the new releases, consumers, producers, the industry, and almond breeders are all paying more attention to them (Socias i Company *et al*., 2010).

Almonds contain a significant amount of antioxidants such as phenols, flavonoids, phenolic acids, tannins, and vitamin E (Rao, 2012), and their kernels contain high amounts of unsaturated oils providing energy, which makes them a highly nutritious and very satiating food (Hollis and Mattes, 2007). Almonds

contain high amounts of phenolic compounds, which protect the fruit's fatty acids against oxidative stress (Maestri *et al*., 2015). The effect of rootstocks on fruit quality characteristics may be different for the same varieties. The selection of rootstocks significantly influences fatty acid profiles in almonds, prompting modern orchard establishment to prioritize these parameters for optimized quality and production efficiency (Sabaté and Hook, 1996). Rootstock choice affects the yield per tree, fruit quality parameters, water-soluble organic matter, fruit hardness, and phenol content, total antioxidant capacity (Remorini *et al*., 2008; Shahkoomahally *et al*., 2020). Moreover, rootstocks directly affect vegetative development and fruit size (Giorgi *et al*., 2005; Rato et *al*., 2008). But some studies report that the rootstocks did not affect the water-soluble mass and acidity (Reynolds and Wardle, 2001; Rato *et al*., 2008; Williams, 2010).

The cultivation of almond varieties grafted onto diverse rootstocks significantly influences pomological traits, yield, fruit quality, and nutrient dynamics-key factors in sustainable orchard management. Achieving long-term productivity and environmental compatibility requires careful selection of rootstock–variety combinations suited to local ecological conditions. In almond orchards, commonly used rootstocks include almond seedlings, GF-677, and Garnem, while the French varieties 'Ferragnès' and 'Ferraduel' are among the most widely planted for their yield potential and adaptability. However, optimizing orchard performance under varying conditions depends on selecting rootstock-scion combinations that support both productivity and resilience. Despite their widespread use, limited data exist on how these rootstocks affect the fruit quality of 'Ferragnès' and 'Ferraduel'. This study evaluates the ecological performance and fruit quality of these varieties specifically pomological traits, yield components, fatty acid profiles, total antioxidant capacity, and total phenolic content, when grafted onto seedling, GF-677, and Garnem rootstocks.

Materials and Methods

Materials

This study was conducted in two consecutive years at a commercial almond orchard located in Koprubasi town (38°45'N; 28°21'E), Manisa city, Türkiye. The experimental area has a Mediterranean-continental climate where the maximum and minimum temperatures reach up to 41 °C during summer and -11 °C during winter. The average rainfall is 744 mm/year. The soil type of the experimental area mainly consists of clayey and loamy soil (38% clay, 32% sand, and 30% silt). Since the almond farm has an automatic irrigation system, all nutrients except solid organic fertilizers and soil regulators are applied by fertigation. The almond trees were 9 years old at the start of the experiment, and the distance between the trees was 6 m x 5.5 m. The almond varieties of 'Ferragnes' and 'Ferraduel' grafted on rootstocks of seedling, GF-677, and Garnem varieties were used.

Garnem was developed in Spain's CITA program by crossing Garfi almond (as the female parent) with Nemared peach rootstock (as the pollen donor) (Felipe, 2009). Meanwhile, GF-677, a hybrid of *Prunus dulcis* and *Prunus persica*, was created by INRA in France (Bernhard and Grasselly, 1981). Furthermore, the French cultivars 'Ferragnès' and 'Ferraduel' were introduced in 1967 from a cross between the local almond variety 'Ai' and the Apulian cultivar 'Cristomorto' (Grasselly and-Crossa Raynaud, 1980).

Method

Pomological properties

Almond cultivars were harvested in early to mid-September. Three almond trees were randomly selected per variety and rootstock combination. The total yield per tree and the yield efficiency of each rootstock were calculated from the harvested samples. At each harvest, 500 g of almond fruits were sampled from each tree. Nut (shelled fruit) and kernel weights were measured with an electronic balance of 0.001 g. Nut and kernel

dimensions (width, length, and thickness) were measured with a digital caliper ±0.01 mm. Kernel ratio and the ratio of kernel weight to shelled fruit weight were determined as a percentage.

Total phenolic content and antioxidant activity

Five grams of samples were mixed with 25 mL of methanol and homogenized using an Ika Ultra-Turrax homogenizer. The homogenates were kept at +4 °C and in the dark for 14 - 16 h and then filtered using a Whatman No. 4 filter paper. The supernatants were recovered and stored at -20 °C until analysis (Thaipong *et al*., 2006). The total phenolic content of the almond extract was determined using the Folin-Ciocaltaeu method with some modifications (Swain and Hillis, 1959). The absorbance of the supernatant was recorded at 725 nm by a spectrophotometer (Bio 100, Varian, Australia). Gallic acid was used as a standard. The total phenolic content in the extract was expressed as gallic acid equivalents (GAE) in mg 100 g^{-1}. The ferric reducing antioxidant power (FRAP) assay was applied to determine the antioxidant activity in almond extracts (Benzie and Strain, 1996). The absorbance of the supernatant was recorded using a spectrophotometer at 593 nm. Trolox was used as a standard, and the results were expressed as Trolox equivalents (μmol TE g^{-1}).

Fatty Acids

The fatty acid composition was determined by using the lipid extracts after methylation, which forms fatty acid methyl esters (FAME), according to the IUPAC Method No: 2.301 (IUPOC, 1990) using a Hewlett Packard 6890N gas chromatograph (Agilent, Polo Alto, CA), equipped with a Supelco SP2380 capillary column (60 m x 0.25 mm i.d., 0.20 μm film thickness; Supelco, Bellefonte, PA) and flame ionization detector (FID). Fatty acid™ 37 Component FAME mix (Supelco, Bellefonte, PA) was used for the determination of fatty acid fractions. Helium was used as the carrier gas at a flow rate of 1.1 ml min^{-1} and a split ratio of 1:20. An autosampler/injector HP7683 B Series was used, and the injector and detector temperatures were 220 °C. The oven temperature was programmed to 165 °C for 35 min; the temperature was then elevated 5 °C per min up to 195 °C and kept for 15 min.

Statistical Analysis

The experiments were conducted as a completely randomized block design with three replicates, and each replicate was evaluated separately. All computation and statistical analyses were done using IBM SPSS Statistics 19.0 (IBM, NY, USA). Significant differences between the means for every treatment were determined by Duncan's multiple range test at the level of $P < 0.05$.

Results and Discussions

Pomological characteristics of nuts and kernels

Pomological data of almond fruits for both years are given in Table 1. First-year nut weights were found to be the highest (8.51 g) in the 'Ferraduel' cultivar grown on seedling rootstock (Table 1). The GF-677 rootstock produced in second-highest (7.47 g), and the Garnem rootstock produced the lowest (6.27 g) nut weights. While rootstocks were shown to have a significant impact on kernel weights ($P < 0.01$), the seedlings' (1.76 g) and the GF-677's (1.72 g) rootstocks' kernel weights were determined to be the highest. On the Garnem rootstock, 'Ferraduel' almonds have a low kernel weight (1.39 g). 'Ferraduel' almond kernel ratio rates were found to be 20.73% on seedling rootstock, 22.57% on Garnem rootstock, and 23.01% on GF-677 rootstock. The kernel ratio rate of both clone rootstocks was found to be higher than that of the seedling rootstock

The seedling rootstock was found to have the largest nut and kernel fruit length and fruit width, followed by the GF-677 and the Garnem rootstocks, respectively. The thickness of the nut and kernel occurred in the same order, although the thicknesses of the almond fruits grown on all three rootstocks were found to

be quite similar. It was determined that the GF-677 and seedling rootstock fruits were larger in width, height, and thickness than the Garnem rootstock fruits.

The kernel weights obtained from the GF-677 rootstock and seedling rootstock were the biggest when the properties of the kernel of the 'Ferraduel' cultivar were investigated ($P < 0.01$). The kernel weights produced from both rootstocks are high, as expected, given that the nut weights of the seedling rootstock's almonds are 12.22% higher than those of the GF-677 rootstock. This demonstrates that almonds grown on the GF-677 rootstock have a greater rates of kernel ratio. The Garnem rootstocks were observed to have shorter kernel lengths than the GF-677 and seedling rootstocks ($P < 0.01$).

The cultivar rootstocks exhibited a substantial impact on nut weights and kernel weights, as evidenced by the finding that almonds produced on the GF-677 (5.57 g) and seedling (5.36 g) rootstocks had higher weights than those planted on the Garnem rootstock ($P < 0.01$). The weights of 'Ferragnes' almond fruits in seedling rootstock were found to be 13.80% higher than almonds in the Garnem rootstock in the first year, and almond fruits in GF-677 rootstock were found to be 17.05% higher than almonds in the Garnem rootstock. In comparison to the Garnem rootstock (1.53 g), the GF-677 (1.98 g) and seedling (1.89 g) rootstocks were shown to have significantly higher kernel weights for the 'Ferragnes' cultivar of almonds.

The length and width of nuts and kernels were higher in seedling rootstocks and the GF-677 rootstocks than in the Garnem rootstocks.

When compared to the 'Ferraduel' cultivar, the 'Ferragnes' cultivar produced a higher kernel ratio. The 'Ferraduel' cultivar generated a kernel ratio of 20.73% for almonds on seedling rootstocks, 22.57% for Garnem, and 23.11% for GF-677, whereas the 'Ferragnes' cultivar generated a kernel ratio of 35.27%, 33.16%, and 35.70% for almonds on seedling rootstocks.

In the second year, fruit weights and fruit lengths were found to be lower in both cultivars compared to the first year (Table 1).

Table 1. Pomological characteristics of nuts and kernels in the first and second year

Year	Cultivar	Rootstok	Nut				Kernel				
			Weight (g)	Lenght (mm)	Width (mm)	Thickness (mm)	Weight (g)	Lenght (mm)	Width (mm)	Thickness (mm)	Kernel ratio (%)
First	'Ferraduel'	Seedling	8.51 a^{z**}	43.42 a**	30.39 a**	18.88 a**	1.76 a**	27.62 a**	17.62 a*	7.76^{NS}	20.73 b*
		Garnem	6.27 c	38.79 b	26.48 b	17.88 b	1.39 b	25.29 b	16.68 b	7.43	22.57 a
		GF-677	7.47 b	41.30 ab	28.99 ab	18.73 ab	1.72 a	27.9 a	17.87 a	7.60	23.01 a
	'Ferragnes'	Seedling	5.36 a**	40.54 a**	26.47 a*	17.31 ab	1.89 a**	29.59 a**	15.61 a**	8.64^{NS}	35.27^{NS}
		Garnem	4.62 b	38.18 b	23.64 b	16.80 b	1.53 b	28.16 b	14.39 b	7.75	33.16
		GF-677	5.57 a	39.5 ab	25.74 a	17.61 a	1.98 a	29.47 a	16.11 a	8.55	35.7
Second	'Ferraduel'	Seedling	6.35^{NS}	37.94 a^{z*}	27.51^{NS}	17.55^{NS}	1.49^{NS}	27.14 a*	17.24 a*	4.13 c*	23.55^{NS}
		Garnem	5.86	35.76 b	26.33	16.57	1.39	25.92 b	16.24 b	4.49 b	23.85
		GF-677	5.92	37.66 ab	25.61	17.93	1.43	26.29 b	16.64 ab	4.80 a	24.18
	'Ferragnes'	Seedling	5.41^{NS}	39.14 ab*	25.88 ab*	18.08^{NS}	1.75 a**	28.96^{NS}	15.84 ab*	4.33^{NS}	32.37^{NS}
		Garnem	4.8	38.27 c	24.54 b	17.70	1.53 b	28.87	15.42 b	4.95	31.99
		GF-677	5.4	39.74 a	26.19 a	17.35	1.75 a	29.15	16.13 a	5.11	32.54

^{z}The differences in the means were determined by the Duncan test according to *$P < 0.05$ level; **$P < 0.01$ denotes a statistically significant difference, or ^{NS} non-significant

Ecological factors are considered to be effective on pomological characteristics of the almond. GF-677 and seedling rootstocks in 'Ferraduel' cultivars exhibited larger nut and kernel weights than Garnem rootstocks, even though the difference in weights was not significant. The sizes of the fruits obtained from the seedling and GF-677 rootstocks were found to be greater than those obtained from the Garnem rootstock. The Mediterranean site showed typical temperature extremes and rainfall variability, aligning with Nanos *et al*. (2002)'s findings for the region.

In the second year, 'Ferragnes' cultivar seedlings and GF-677 rootstocks yielded the same results with nut and kernel weights of 5.40 g and 1.75 g, respectively (Table 1). Almonds grown on the GF-677 rootstock

were found to have the longest and widest nuts, whereas almonds grown on the Garnem rootstock were the shortest and narrowest.

In this study, both the seedling and GF677 rootstocks resulted in higher shell and kernel weights than the Garnem rootstock in both varieties. The fruit sizes of 'Ferragnes' and 'Ferraduel' varieties grown on seedling and GF-677 rootstock were also found to be larger than those grown on Garnem rootstock. In their study on Marinada and Vairo almond varieties, Lordan *et al*. (2019) reported that GF-677 rootstock increased fruit weight and size. Different rootstocks show varying water and nutrient uptake capabilities due to their deep root systems, leading to significant differences in canopy growth, height, trunk circumference, and overall nutrient absorption (Brar *et al*., 2022). Rootstocks such as GF-677 generally show better tree development and higher fruit yields (Giorgi *et al*., 2005). Furthermore, GF-677 rootstock ensures balanced growth and nutrient distribution with almond trees (Kester and Graselly, 1987).

Both seed rootstocks and the GF-677 rootstock in this study were found to increase fruit size in almonds. It is commonly noted that seed rootstocks promote larger fruit sizes by enhancing tree growth (Giorgi *et al*., 2005). However, almonds grown on GF-677 rootstock produced larger fruits (Table 1), which can be attributed to their balanced water uptake and tolerance to calcareous soils (Mestre *et al*., 2015).

The kernel ratio of 'Ferragnes' is significantly higher than that of 'Ferraduel'. Thanks to its genetic characteristics, 'Ferragnes' offers a better kernel ratio and internal development, resulting in a higher kernel ratio when paired with a suitable rootstock (Giorgio *et al*., 2005). 'Ferragnes' is often the preferred variety for commercial almond production due to its higher kernel ratio. Kernel ratio did not show a significant difference between the various rootstocks, indicating that factors such as maintenance practices or ecological conditions may have a greater influence on almond cultivation

Rootstock selection affects the morphology and phenology of the varieties (Socias i Company *et al*., 2011). The limited rootstock influence on kernel ratio reinforces the predominance of cultivar-specific characteristics in determining certain quality parameters, corroborating the findings of Barbera *et al*. (1994).

Fatty acid contents of almond varieties

Other than water, the major components of almond kernels include the lipid fraction, protein fraction, carbohydrates, and mineral fraction. Several compounds called phytochemicals should also be added, because even though they appear in low quantities, they play a major role in almond quality. According to the cultivars, the growing system, and the geographical origin, the proportion of these compounds varies. Precise characterization of almond kernel composition holds significant commercial, industrial, and nutritional relevance, particularly given the well-documented compositional variability among cultivars (Roncero *et al*., 2020).

Mono- and polyunsaturated fatty acids represent the majority of the lipids found in almond kernels, which are a significant source of these lipids. The genotype has an impact on oil content, but the year also has a significant impact (Kodad *et al*., 2011). In addition, irrigation (Nanos *et al*., 2002), harvest time (Piscopo *et al*., 2010), and rootstock (Colic *et al*., 2018) all have an impact on it. Almond oil, a rich source of macronutrients and micronutrients, is extracted for food flavorings and the cosmetics industry (Ouzir *et al*., 2021).

The primary fatty acids in almond samples were found to be palmitic acid (C16:0), palmitoleic acid (C16:1), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3) (Table 2). Except for linolenic acid, the 'Ferraduel' variety rootstocks produced no discernible impact on fatty acids throughout the first year. In the first year, it was discovered that the 'Ferraduel' variety produced a palmitic acid content of 6.26% and an average palmitoleic acid content of 0.72%. The average level of oleic acid was 74.47%, linoleic acid was 16.33%, and stearic acid was 1.86%. The 'Ferraduel' cultivar grafted on several rootstocks was shown to have a substantial ($P < 0.05$) impact on the linolenic acid content. Linolenic acid content was found

to be higher in Garnem and GF-677 rootstocks than in seedling rootstocks. Oleic/linoleic acid ratios were between 4.36 and 4.81 in the first year (Table 2).

Table 2. Effect of cultivars and rootstocks on relative fatty acid content (%) in the first year

Year	Cultivar	Rootstock	Palmitic Acid (C16:0)	Palmitoleic Acid (C16:1)	Steraic Acid (C18:0)	Oleic Acid (C18:1)	Linoleic Acid (C18:2)	Linolenic Acid (C18:3)	Oleic/ Linoleic Ratio
First	'Ferraduel'	Seedling	6.34^{NS}	0.73^{NS}	1.90^{NS}	75.09^{NS}	15.62^{NS}	0.03 b^{z*}	4.81^{NS}
		Garnem	6.13	0.68	1.77	74.55	16.47	0.10 a	4.53
		GF-677	6.30	0.74	1.90	73.77	16.91	0.07 a	4.36
	'Ferragnes'	Seedling	6.64 a**	0.58 a*	2.05 a*	72.85 b**	17.48 a**	0.15^{NS}	4.17^{NS}
		Garnem	6,25 b	0.54 b	1.96 b	75.20 a	15.69 b	0.97	4.79
		GF-677	6.11 c	0.59 a	1.80 c	75.24 a	15.89 b	0.86	4.74
Second	'Ferraduel'	Seedling	6.33^{NS}	0.63^{NS}	2.02^{NS}	73.78^{NS}	16.90^{NS}	0.09^{NS}	4.37^{NS}
		Garnem	6.21	0.60	1.87	74.45	16.54	0.09	4.50
		GF-677	6.24	0.63	1.95	74.20	16.63	0.09	4.46
	'Ferragnes'	Seedling	6.64^{NS}	0.58^{NS}	1.94^{NS}	74.55^{NS}	16.18^{NS}	0.05^{NS}	4.61^{NS}
		Garnem	6.40	0.56	1.75	74.97	16.00	0.07	4.69
		GF-677	6.21	0.53	1.78	74.94	16.22	0.08	4.62

^{z}The differences in the means were determined by the Duncan test according to *P < 0.05 level; **P < 0.01 denotes a statistically significant difference, or ^{NS} non-significant

In the study of Yada *et al*. (2011), total lipid values were between 40 and 67 g 100 g^{-1} of dry almond weight and between 35 and 66 g/100 g of almond fresh weight. In the 'Ferragnes' variety, it was discovered that the rootstock effect on palmitic acid content was significant (P < 0.01). In seedling, Garnem, and GF-677 rootstocks, it was found to be 6.64%, 6.25%, and 6.11%, respectively. The amount of palmitoleic acid was discovered to be higher in almonds grafted on the seedling and GF-677 rootstocks than the Garnem rootstocks (P < 0.05). With a 95% confidence level, the influence of rootstocks on stearic acid content was found to be substantial, with values of 2.05% for seedling rootstock, 1.96% for Garnem rootstock, and 1.80% for GF-677 rootstock. With a 99% confidence level, it was determined that the influence of rootstocks on the amount of oleic and linoleic acids in the 'Ferragnes' variety was significant. It was discovered that the oleic acid concentration of the Garnem and GF-677 rootstocks was 75%, greater than the oleic acid content of the seedling rootstocks (72.85%). Linoleic acid was discovered to be present in seedling rootstocks at a level of 17.48%, higher than that of GF-677 and Garnem rootstocks. On linolenic acid concentration, rootstocks were found to have no impact. In the first year, oleic/linoleic acid ratios ranged from 4.17 to 4.79 (Table 2).

For the second year, it was determined that the impact of various rootstocks on the fatty acid content of the 'Ferraduel' and 'Ferragnes' cultivars was not significant. Oleic and linoleic acid ratios, essential fatty acid ratios, were found to be between 4.37 and 4.69 (Table 2). Yada *et al*. (2011) state that almond oil contains high levels of monounsaturated fatty acids (MUFAs), particularly oleic and linoleic acids. Oleic and linoleic acids showed significant differences among cultivars. Only the level of oleic acid significantly differed between rootstocks, with GF677 having a higher value.

Almond quality evaluation emerges as a critical parameter, particularly regarding oil concentration and compositional quality. Indicators of quality include the concentration of oleic/linoleic acid ratio and the amount of oleic acid in the almond oil (Kodad and Socias, 2008; Kodad *et al*., 2011). As it is significant and has an anti-oxidation impact, the oleic/linoleic acid ratio is used to assess the quality of kernels.

According to genotypes, the concentration of the 26 almond genotypes studied in Türkiye (Askin *et al*., 2007) ranged from 50.41% to 81.2% oleic acid, from 6.21% to 37.13% linoleic acid, from 5.46% to 15.78% palmitic acid, from 0.80% to 3.83% stearic acid, and from 0.36% to 2.52% palmitoleic acid. According to studies, the Pons almond type had 6.5% palmitic acid, 0.5% palmitoleic acid, 1.5% stearic acid, 62.5% oleic acid, and 29.0% linoleic acid (Soler *et al*., 1988). It was reported that Ferragnes and Tuono almond varieties contain

5.88-6.19% palmitic acid, 0.88-0.93% palmitoleic acid, 1.85-2.09% stearic acid, 72.17-71.83% oleic acid, and 19.19-18.91% linoleic acid in their kernels (Barbera *et al*., 1994). In other studies of almond kernels, Woody Colony, Monterey, Padre, Butte, Nonpareil, Carmel, LeGrand, Fritz, Mission, Price, Sonora, Ne Plus Ultra, and Aldrich almond varieties were found to contain 5.0-6.4% palmitic acid, 64.7%-76.0% oleic acid, and 16.3-26.9% linoleic acid (Gradziel *et al*., 2000).

Antioxidant activity and total phenol contents of almond varieties

According to Rao *et al*. (2012), almonds are a substantial source of antioxidants like phenols, flavonoids, phenolic acids, tannins, and vitamin E. Milbury *et al*. (2006) highlighted that polyphenols, phenolic acids, flavonoids, and tannins are a part of what gives almonds their antioxidant capabilities. Variation alone determines the chemical composition and quantity of these molecules (Milbury *et al*., 2006; Barriera *et al*., 2008). The high concentration of phenolic antioxidants in almonds prevents fruit fatty acids from oxidative damage (Maestri *et al*., 2015).

One of the most crucial components of organoleptic quality, which is directly related to the chemical and physical composition of fruits, is antioxidants. We discovered that rootstocks showed a significant impact on antioxidant activity. The findings demonstrate that antioxidant activity varies greatly depending on the seedling rootstock and variety combination (Table 3).

Table 3. Effect of different rootstocks on antioxidant activity (µmol TE g^{-1}) and total phenol content in almond varieties (mg GAE 100 g^{-1})

Cultivar	Rootstock	First-year		Second-year	
		Antioxidant activity	Total phenol content	Antioxidant activity	Total phenol content
'Ferraduel'	Seedling	9.31^{NS}	116.46^{NS}	9.50^{NS}	133.14^{NS}
	Garnem	8.33	78.33	6.63	106.65
	GF-677	9.31	80.52	8.10	124.55
'Ferragnes'	Seedling	6.85 a[z*]	89.45^{NS}	6.30^{NS}	94.87 a*
	Garnem	5.19 ab	63.31	5.78	75.01 ab
	GF-677	4.80 c	85.16	5.15	56.21 c

[z]The differences in the means were determined by the Duncan test according to *P < 0.05 level denotes a statistically significant difference, or [NS] non-significant

The first year's analyses revealed discernible differences between the antioxidant capacities of the two types when grown on different rootstocks. The highest value was determined with a result of 9.31 µmol TE g^{-1} in the 'Ferraduel' variety grafted on the seedling rootstock. The antioxidant capacity of 6.73 µmol TE g^{-1}, the lowest value, was obtained in the 'Ferraduel' variety grafted on the GF677 rootstock, while the 8.33 µmol TE g^{-1} value was obtained in the rootstocks on which the 'Ferraduel' variety was grafted on the Garnem rootstock. In 'Ferragnes' variety almonds, 6.85 µmol TE g^{-1} was obtained when grafting on seedling rootstock, 5.19 µmol TE g^{-1} when grafting on Garnem rootstock, and 4.80 µmol TE g^{-1} when grafting on GF-677.

Trees of both varieties grafted on seedling rootstock exhibited consistently higher antioxidant activity across sampling years, though the difference was not statistically significant in the second year of evaluation. The investigations on the 'Ferragnes' variety indicated that the samples grafted on the GF-677 rootstock and the Garnem rootstock, as in the previous year, had a higher antioxidant capacity. In contrast to the previous investigation, the 'Ferraduel' variety's antioxidant capacity was shown to be higher in the samples taken from the trees grafted on GF-677 rootstock than in the variety grafted on Garnem rootstock.

The results of the first-year analysis of the rootstocks in which the 'Ferraduel' variety was grafted were found to be 78.33 and 116.46 mg 100 GAE g^{-1}. The total phenol content of the rootstocks grafted with the 'Ferragnes' cultivar was determined as 63.31 to 89.45 mg GAE 100 g^{-1} (Table 3). When the analysis results of

the samples taken in the second year were evaluated, the total phenol content of the varieties grafted on the seedling rootstock was again measured to be higher. Considering the data we obtained, the value of the total phenol content indicates that almonds are rich in phenols.

According to an evaluation of 10 commercial and regional almond cultivars by Barreira *et al*. (2008), the phenolic content of extracts from almond kernels with brown skin varies from 9.22 to 163.71 mg GAE g^{-1}.

Yields

Both years, the impacts of rootstocks on the Ferraduel and 'Ferragnes' cultivars produced similar results and were determined to be significant ($P < 0.01$) (Table 4). When compared to Garnem and GF-677 rootstock, the 'Ferraduel' cultivar's yield values on seedling rootstock were the lowest at 6.23 kg $tree^{-1}$ in the first year and 6.53 kg $tree^{-1}$ in the second. In the first and second years, the amount of almonds produced on the Garnem rootstock per tree was 14.67 kg and 14.93 kg, respectively. 'Ferraduel' almond yields were found to be 15-17% lower in GF-677 rootstock than in Garnem rootstock. The 'Ferragnes' cultivar's lowest yield values were produced by seedling rootstocks, which ranged from 5.7 to 3.07 kg $tree^{-1}$. Garnem rootstock, on the other hand, gave the highest yield value with 15.93 kg $tree^{-1}$ in the first year and 16.76 kg $tree^{-1}$ in the second year. The yields of 'Ferraduel' almonds in GF-677 rootstock have a yield value of 17.38-19.86% less than those in Garnem rootstock, and the yield value was determined as about 13 kg $tree^{-1}$. Compared to Garnem and GF-677 rootstocks, the 'Ferraduel' and 'Ferragnes' grafted onto seedling rootstock produced the lowest yield.

Table 4. The Effect of different rootstocks on yield values of 'Ferragnes' and 'Ferraduel' almond varieties (kg $tree^{-1}$)

Cultivar	Rootstock	First-year	Second-year
'Ferraduel'	Seedling	6.23 c[z]**	6.53 c**
	Garnem	14.67 a	14.93 a
	GF-677	12.13 b	12.60 b
'Ferragnes'	Seedling	5.73 c**	6.07 c**
	Garnem	15.93 a	16.76 a
	GF-677	13.16 b	13.43 b

[z]The differences in the means were determined by the Duncan test according to ** $P < 0.01$ is statistically significant

With two promising almond cultivars like 'Marinada' and 'Vairo', Lordan *et al*. (2019) evaluated the performance of Cadaman®, Garnem®, INRA GF-677, IRTA-1, IRTA-2, Ishtara®, Adesoto, Rootpac® 20, Rootpac® 40, and Rootpac® R rootstocks. Garnem® (14 kg $tree^{-1}$) and INRA GF-677 (10 kg $tree^{-1}$) produced the highest cumulative yields for 'Marinada' over the first three years (2013-2015); Rootpac® 20 (3 kg $tree^{-1}$) and Ishtara® (4 kg $tree^{-1}$) produced the lowest yields. The highest yields for 'Marinada' during full production (2016–2018) were on Garnem® (27 kg $tree^{-1}$), Cadaman® (25 kg $tree^{-1}$), and INRA GF-677 (23 kg $tree^{-1}$). Ishtara® and Rootpac® R, both with 11 kg $tree^{-1}$, were in the third group, followed by IRTA-2 (16 kg $tree^{-1}$), Rootpac® 40 (14 kg $tree^{-1}$), and IRTA-1 (13 kg $tree^{-1}$) in the second. The lowest yields were achieved by Rootpac® 20 (7 kg $tree^{-1}$) and Adesoto (9 kg $tree^{-1}$). In terms of cumulative kernel yield over immature plus mature stages (2013-2018), the highest values were on Garnem® (~18 t ha^{-1}), INRA GF-677 (~14 t ha^{-1}), and Cadaman® (~13 t ha^{-1}), followed by IRTA-2 (~10 t ha^{-1}), Rootpac® R (~9 t ha^{-1}), Rootpac® 40 (8 t ha^{-1}), IRTA-1 (7 t ha^{-1}), Adesoto and Ishtara® (6 t ha^{-1}), and Rootpac® 20 (4 t ha^{-1}).

Conclusions

This two-year study evaluated the influence of three rootstocks (seedling, Garnem, and GF677) on fruit quality parameters and yield performance across multiple almond cultivars. In the first year, rootstocks had no significant effect on the fatty acid composition of 'Ferraduel'. Among 'Ferragnes' combinations, the

seedling/'Ferragnes' pairing showed higher levels of palmitic, palmitoleic, stearic, and linoleic acids. In the second year, rootstock effects were again minimal for both cultivars, indicating limited impact on their fatty acid profiles overall. Seedling rootstocks exhibited higher levels of antioxidants and phenols compared to both GF-677 and Garnem rootstocks. The 'Ferragnes' cultivar had a significantly higher kernel ratio than 'Ferraduel', with 'Ferragnes' showing a higher kernel ratio due to its characteristics. Rootstock did not affect this kernel ratio. Compared to Garnem and GF-677 rootstocks, the 'Ferraduel' and 'Ferragnes' grafted onto seedling rootstock produced the lowest yield. In this study, both seedling and GF-677 rootstocks led to higher shell and kernel weights than Garnem in both varieties. Moreover, fruit sizes of 'Ferragnes' and 'Ferraduel' grown on seedling and GF-677 rootstocks were larger compared to those grown on Garnem. Overall, seedling and GF-677 rootstocks were shown to increase almond fruit size. Although the Garnem rootstock generated the highest yield, GF-677 produced superior results in key qualitative metrics, including shelled weight, kernel weight, and fruit dimensions. Consequently, GF-677 was identified as the most suitable rootstock for both 'Ferragnes' and 'Ferraduel' cultivars, as it effectively combined high yield with favourable pomological characteristics.

Authors' Contributions

Conceptualization: DC, DE; Data curation: DC; Formal analysis: DC, DE, MdCM; Funding acquisition: DE, MdCM; Investigation: DE, MdCM; Methodology: DC, DE, MdCM; Project administration: DE, MdCM; Resources: DC, DE, MdCM; Software: DC, DE; Supervision: DC, DE, MdCM; Validation: DE, MdCM; Visualization: DC, MdCM; Roles/Writing - original draft: DE, MdCM; and Writing - review & editing: DC, DE, MdCM.

All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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