Research Article

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Phenotypic characterization of qualitative parameters and antioxidant contents in peach and nectarine fruit and changes after jam preparation

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Abstract

BACKGROUND: Sugars and antioxidants in peaches contribute to fresh fruit quality and nutrition; however, information on widely grown cultivars and changes induced after peach jam preparation is limited. In the present study, colour, sugars and antioxidant parameters were determined in fruit and jam from 45 peach and nectarine cultivars.

RESULTS: Pronounced varietal differences were found in sorbitol (42-fold range), total phenolics (TPs) and antioxidant capacities (10- to 19-fold range). Sorbitol levels were greater in non-melting peach, followed by nectarine, and lower values were found in melting peach cultivars. Late-harvested peach and nectarine cultivars tended to have a higher soluble solid content and antioxidant potential. Cultivars with relatively high antioxidant contents produced darker and redder jams, containing more antioxidants, than the jam or the fruit from the other cultivars. Jam-TPs were reduced by 48% compared to fruit-TPs, with greater reduction being noted in high antioxidant cultivars. The most favorable jam organoleptic characteristics were found in 'Morsiani 90', 'Amiga', 'Romea' and 'Alirosada', as well as in non-melting compared to melting peach cultivars.

CONCLUSION: The best cultivars for each fruit flesh type and jam were identified. Peach jam could be an alternative substitute when fresh fruit is not available and when it is prepared with high antioxidant cultivars.

Supporting information may be found in the online version of this article.

Keywords: antioxidants; fruit; jam; *Prunus persica*; sensorial analyses; sugars

INTRODUCTION

Peach, being the second most important temperate fruit crop worldwide, constitutes an important part in the human nutrition. It is widely consumed, both as fresh and as an ingredient in processed products, mainly juice, cans and jams. The beneficial effects of peach on human health are attributed to a range of natural metabolites or phytochemicals from which phenolics are by far the most important.[1] Phenolics are also known to contribute to peach sensorial qualities (flavour and taste) and browning potential.[2] Genotypic variation in the phytochemical content among different peach cultivars may be considerable and therefore it is important to define cultivars with the highest total phenolics (TPs) content from a breeding perspective.[3−13] More importantly, such information on the phytochemical content of widely cultivated peach and nectarine cultivars could be valued by health-concerned consumers and dieticians.

Currently, because of the high competition in the market as a result of the many newly released of peach and nectarine cultivars and other fruit species, peach quality has become fundamental for increasing consumption. Fruit size, colour and firmness are important characteristics influencing consumers to buy the fruit for the first time, although the soluble solid content (SSC) and titratable acidity (TA) have a major influence on whether there will be a repeat purchase.[14] Consumer acceptance was always greater for non-acid than acid cultivars not only in Eastern, but also in European markets.[15]

Sugars are the main source of energy in peach and SSC is a reasonable surrogate of total sugar content.[16] Sucrose is the

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predominant sugar, whereas others, such as glucose, fructose and sorbitol, are also present at lower concentrations. The overall sugar amount and the specific sugar profile both affect sweetness intensity.[17,18] Sucrose and sorbitol are highly correlated with the overall taste and aroma,[19] whereas particular interest is being paid to sorbitol because it can be used as a glucose substitute for diabetics and as an alternative natural sweetener instead of sucrose.[20]

Peaches are not available all year round and their shelf life is limited. Jams are popular and consumed in significant quantities. The qualitative profile of carotenoids, flavonoids and other phenolics present in different jams of various fruit, including peach, generally did not differ from those found in the natural fruits.[21] The thermal treatment during jam or canning processing causes a loss of phenols and the magnitude of such a loss depends on the commodity and the processing conditions.[22,23,24] Surprisingly, information on the changes occurring during peach jam processing is limited.

The present study aimed to (i) characterize fruit quality and phytochemicals in widely cultivated peach and nectarine cultivars in Greece and dissect potential correlations among the examined parameters; (ii) identify the changes induced after jam preparation; and (iii) apply multivariate analysis to identify the cultivars with the optimum quality characteristics for fresh fruit and jam consumption.

MATERIALS AND METHODS

Fruit material and experimental design

The present study was conducted in 45 peach and nectarine cultivars that are currently cultivated and distributed by the 'Agricultural Cooperative of Naoussa' and 'Venus growers' cooperatives, located in Imathia, Greece (Table 1). The area is characterized by dry summers and sufficient chilling. During the experimental year 2013, 1442 chilling hours (0–7.2 °C) were calculated, the annual precipitation was 591 mm and the average temperature was 16.7 °C. During the summer months, the maximum and minimum temperatures were 32.4 and 18.8 °C, respectively, and precipitation was only 75.5 mm.

The cultivars origin was from various countries and breeding programs: 51% of cultivars were from the USA, 40% were from Italy, 7% were from Greece and 2% were from France (Table 1).

For each cultivar, fruit at commercial maturity stage and of premium quality standards were selected the day of harvest, upon arrival to the cooperatives. Fruit quality assessment and jam preparation was made after an approximately 3-day maintenance at room temperature (23 ± 2 °C) in ripe fruit (approximately 9.5 N flesh firmness).

Sugar and antioxidant analyses were made in three five-fruit lots per cultivar. Two wedged-shaped slices from the intact peach fruit were dissected, had the exocarp removed, and were crashed into a fine powder, using liquid nitrogen and a pestle and mortar. Samples were immediately stored at −80 °C until needed. Antioxidant analyses in jams were made in three replicate samples from the jam produced.

Quality attributes

The CIE colour parameters L^* (brightness or lightness; 0 = black, 100 = white), a^* ($-a^*$ = greenness, $+a^*$ = redness) and b^* ($-b^*$ = blueness, $+b^*$ = yellowness), hue (calculated as $\tan^{-1} b^*/a^*$; 0° = red–purple, 90° = yellow, 180° = bluish–green, 270° = blue) and chroma [calculated as $(a^{*2} + b^{*2})^{1/2}$; degree of departure from grey to pure chromatic colour were measured in the exocarp at both sides and the flesh (of six fruit replicates) using a Minolta chromatometer (CR-300; Minolta, Ramsey, NJ, USA).

SSC and TA were determined in juice extracted using a food processor in three replicates of four fruit. SSC was measured using a digital refractometer (model PR-1; Atago, Tokyo, Japan) and data were expressed as °Brix. TA was measured using an automatic titrator (Titrometic 25; Crison Instruments SA, Barcelona, Spain) and determined by titrating 5 mL of juice with 0.1 N NaOH to a pH end point of 8.2. Results were expressed as g malic acid L^{-1}. Ripening index was calculated as the SSC/TA ratio.

Sugar analyses using high-performance liquid chromatography (HPLC)

Samples were homogenized in a Waring blender at low speed for 60 s and then at high speed for 30 s and the homogenates were centrifuged at 10 000 × *g* for 2 min. The juice, diluted at 1:4 (v/v) with water (HPLC grade), was centrifuged again at 10 000 × *g* for 2 min, filtered through a nylon syringe filter (pore size 0.2 μm) and analyzed by HPLC, as described by Roussos *et al.*[25] In particular, the sugars and polyols were separated on a Hamilton HC-75 cation exchange column, calcium form (Hamilton Bonaduz AG, Bonaduz, Switzerland) at 80 °C, operating with a Water 510 isocratic pump (Waters, Milford, MA, USA) at a flow of 0.6 mL min^{-1}. Detection of soluble sugars and polyol was achieved by a refractive index detector for HPLC (HP 104 7A; Hewlett-Pachard, Waldbronn, Germany) system. Peaks for sucrose, glucose, fructose and sorbitol were identified and quantified with standards, using a data processing system (Peak Simple, version 3.25; SRI Instruments, Torrance, CA, USA), and expressed on a fresh weight (FW) basis.

The equisweet parameter was determined considering that fructose is 1.75 times sweeter than sucrose, whereas glucose and sorbitol are less sweet than sucrose by 0.75- and 0.60-fold, respectively.[17,18]

Jam preparation

Jam was prepared by mixing 225 g of peach puree, prepared by blending 1 kg of peeled fruit with 275 g of sucrose, 1.7 g of commercial pectin, 2.0 g of citric acid and 100 mL of water. The mixture was cooked at 70 ± 5 °C until 68 ± 1% SSC was achieved (Reichert Abbe Mark II Plus refractometer; AMETEK GmbH, Munich, Germany). The cooking was carried out with constant stirring. Jams were transferred to glass containers and kept at 4 °C until further use. The jam preparation was made once.

Extraction and determination of antioxidant parameters in fruit and jam

Approximately 1 g of fresh fruit fine powder or jam was homogenized with 7 mL of 80% $MeOH/H_2O$ (v/v) at 15 000 rpm in a micro-dismembranator (B. Braun Biotech Intern, Melsungen, Germany). The samples were centrifuged for 10 min at 10 000 × *g* at 5 °C. The supernatant was carefully recovered to prevent contamination from the pellet.

TPs content was measured using the Folin–Ciocalteu colorimetric method.[26] The reaction mixture consisted of 0.3 mL of extract, 0.2 mL of distilled water and 2.5 mL of 10% Folin–Ciocalteu reagent. The tube was vortexed and then allowed to stand at room temperature for 3 min when 2 mL of saturated sodium carbonate solution was added. The solution was incubated for 5 min at 50 °C and the absorbance was measured at 760 nm against a blank solution. Each measurement was repeated in duplicate and

Table 1. Country, year of release, flesh type, flesh colour and harvest date of the cultivars evaluated

Cultivar	Cultivar abbreviation	Country	Year of release	Flesh type	Flesh colour	Harvest date
Alirosada	AL	Italy	2004	MPE	WR	20 July
Aurelia	AU	Italy	1983	MPE	YR	17 August
Crest Haven	CH	USA	–	MPE	Y	10 August
Fayette	FY	USA	1966	MPE	Y	22 August
Flaminia	FL	Italy	1983	MPE	Y	18 September
Gladys	GL	USA	1986	MPE	WR	3 September
June Gold	JG	USA	1958	MPE	YR	26 June
Maria Bianca	MB	Italy	1980	MPE	W	9 July
Maria Luisa	ML	Italy	1980	MPE	Y	29 June
Maria Marta	MM	Italy	1991	MPE	Y	20 July
Maura	MA	USA	1997	MPE	WR	20 July
O' Henry	OH	USA	1968	MPE	YR	3 September
Octavia	OC	USA	2006	MPE	W	17 August
Patty	PA	USA	2000	MPE	WR	25 June
Profiti Ilia	PI	Greece	–	MPE	Y	3 September
Rich Lady	RL	USA	1990	MPE	YR	30 June
Rome Star	RS	Italy	1993	MPE	Y	26 July
Royal Gem	RGE	USA	1985	MPE	Y	18 June
Royal Glory	RGL	USA	1987	MPE	Y	4 July
Spring Belle	SB	Italy	1985	MPE	Y	12 June
Summer Rich	SR	USA	1989	MPE	YR	20 July
Sun Crest	SC	USA	1959	MPE	Y	20 July
Symphonie	SY	France	1984	MPE	YR	23 July
Tardibelle	TB	Italy	–	MPE	Y	18 September
Tardired	TR	Italy	2000	MPE	Y	13 September
Amiga	AM	Italy	2000	NE	Y	20 July
Big Top	BT	USA	1984	NE	Y	27 June
Caldesi 2000	CAL	Italy	1984	NE	WR	4 July
Fantasia	FN	USA	1969	NE	YR	10 August
Gaia	GE	Italy	2002	NE	YR	20 July
Morsiani 51	M51	Italy	1990	NE	Y	22 August
Morsiani 90	M90	Italy	1994	NE	YR	6 September
Orion	OR	Italy	1989	NE	Y	7 August
Red Gold	RGO	USA	1956	NE	Y	15 July
Royal Queen	RQ	USA	2001	NE	WR	26 June
Tasty Free	TF	USA	1974	NE	Y	3 September
Venus	VE	Italy	1986	NE	Y	12 August
Andross	AD	USA	1953	NMPE	Y	10 August
Catherina	CAT	USA	–	NMPE	Y	19 July
Everts	EV	USA	–	NMPE	Y	31 August
Fortuna	FO	USA	1941	NMPE	Y	20 July
Loadel	LO	USA	–	NMPE	Y	26 July
PI-A37	A37	Greece	1985	NMPE	Y	25 July
Andromeda	IB42	Greece	1985	NMPE	Y	15 August
Romea	RO	Italy	1987	NMPE	Y	4 July

Y, yellow; YR, yellow red; W, white; WR, white-red.

TPs content was expressed as mg gallic acid (GAE) kg^{-1} FW in fruit (TPs-F) and jam (TPs-J).

Total antioxidant capacity (TAC) was evaluated using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) assays.

For the DPPH assay, reaction mixtures containing 0 or 20 μL of fruit or 40 μL of jam extract, 2300 μL of 106.5 μmol L^{-1} DPPH in MeOH were diluted with distilled water to 3000 μL of H_2O, the samples were vortexed, and then held at room temperature for 2 h when the absorbance of the reaction mixtures were measured at 517 nm.[27]

The FRAP assay was developed to measure the ferric reducing ability of plasma at low pH.[28] A sample containing 3 mL of freshly prepared FRAP solution (0.3 mol L^{-1} acetate buffer (pH 3.6) containing 10 mmol L^{-1} 2,4,6-tripyridyl-s-triazine and 40 mmol L^{-1} $FeCl_3$ $10H_2O$) and 100 μL of peach or 200 μL of jam extract was incubated at 37 °C for 4 min and the absorbance was measured at 593 nm.

For the DPPH and FRAP assays, a standard curve was obtained using ascorbic acid standard solution and, accordingly, the results were expressed as mg ascorbic acid kg^{-1} FW in fruit (TAC_{DPPH} – F and TAC_{FRAP}-F) and jam (TAC_{DPPH} – J and TAC_{FRAP}-J).

To account for evaporation losses during jam making, the jam TPs and antioxidant capacities were expressed on a FW basis, based on a mass balance of SSC, using the equations described in Kim and Padilla-Zakour.[29] The calculated amount of fresh fruit equivalent in kg of jam per cultivar were used to convert the concentration of TPs, TAC_{DPPH} and TAC_{FRAP} in jams to fresh FW basis (TPs-FJ, TAC_{DPPH}-FJ and TAC_{FRAP}-FJ, respectively).

Jam aroma and preference test

Jam aroma sensory evaluation and a consumer preference test were carried out using 20 experienced panellists who were staff members of the Department of Agriculture, Aristotle University of Thessaloniki. The sensory assessment was performed in individual booths. The panellists were asked to smell and rank the jam samples according to a nine-point intensity scale: not detectable (0), medium (5) and strong (9) aroma. For the consumer preference test, the panellists were asked to rank the samples in order of preference and to indicate the extent of their preference: dislike extremely (1) and like extremely (9).

Statistical analysis

The mean, range and coefficient variation (CV%) values were calculated for the entire plant material. Data were subjected to one-way analysis of variance and then significant differences among individual means were determined using the least significance difference calculated at the 5% level, among cultivars or fruit types [melting peach (MPE), nectarine (NE) or non-melting peach (NMPE) and yellow or white flesh colour]. Pearson's correlation analysis was used to determine correlation coefficients and their statistical significance. Principal component analysis was applied to mean values of each measurement trait for each fruit type and all jams. Statistical analyses were performed using SPSS, version 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Fruit characteristics

Extensive variation in all measured traits was observed. The harvesting period extended from 12 June to 18 September (Tables 1 and 2). NMPE cultivars had brighter (greater L^*) and more yellow-colored (greater b^*) peel and redder flesh (higher a^*) compared to MPE cultivars, as also reported by Karakurt *et al.*[30]

The majority of cultivars contained SSC in the range of 9.8 – 16.3 °Brix; lowest values in the range of 7.5 – 8.9 °Brix were found in 'Spring Belle', 'June Gold', 'Sun Crest' and 'Patty' (Table 3). Late harvested cultivars tended to produce fruit with higher SSC ($r = 0.590$) (see Supporting information, Table 1), probably resulting from a greater fruit developmental time enabling fruit to become sweeter over a longer period. Similar observations were found in other studies.[7,10 – 12]

TA ranged between 2.2 and 8.3 g malic acid L^{-1}; most cultivars (46.7%) were sweet ($3.3 < TA < 6.0$ g malic acid L^{-1}) or equilibrated (28.9%) ($6.0 < TA < 8.0$ g malic acid L^{-1}), according to the classification made in the study by Iglesias and Echeverria[14] (Table 3). Cultivars 'Maria Bianca', 'Rich Lady', 'Amiga', 'Morsiani 51', 'Morsiani 90' and 'Orion' were acid ($8.0 < TA < 10.0$ g malic acid L^{-1}), whereas consumer preference is greater for non-acid cultivars.[15] NE cultivars were more acid, followed by MPE and NMPE cultivars (6.3, 5.2 and 4.0 g malic acid L^{-1}, respectively); similar observations were previously reported between NE and MPE.[7,11,12]

The flavour intensity of peach is mainly linked to the SSC/TA ratio and appears to be a key factor influencing the taste perception and consumer acceptance.[14] The majority of cultivars contained SSC/TA in the range of 1.3 and 3.6; greatest values were found only in GEA (4.4), 'Octavia' (5.1) and PI-A37 (5.8).

The total sugar content, calculated as the sum of sucrose, glucose, fructose and sorbitol contents, ranged between 51.2 and 159.2 g kg^{-1} FW (Tables 2 and 3) which is in agreement with results reported previously.[6,8,11,19] The total content of sugars was positively correlated with SSC ($r = 0.783$, $p < 0.010$) (see Supplementary Table 1), suggesting that the estimation of SSC is a practical and reasonable surrogate measure of sugar content and the overall evaluation of peach fruit quality.[16]

Apart from the total sugars affecting the sweetness intensity, it is the individual sugars that also play an important role[16] and thus these were analyzed separately. The dominant sugar in all cultivars was sucrose (67.6 g kg^{-1} FW), followed by 7.7 times lower levels of relatively equal amounts of fructose and glucose (11.6 and 9.3 g kg^{-1} FW, respectively; mean glucose/fructose ratio = 0.8) and sorbitol (5.0 g kg^{-1} FW). The sugar profile may be used for the differentiation of fruit species; identical sugar patterns were observed for cultivated peach from various environments, as well as for different varieties.[16]

Sucrose is important as energy source and preservative of fruit flavours;[31] the highest sucrose level was found in 'Venus' (115.9 g kg^{-1} FW). Fructose is important in terms of fruit flavour because it is 1.75 times sweeter than sucrose, and also is reported to have beneficial effects on gastrointestinal health.[32] The highest values of fructose were found in 'Profiti Ilia', followed by 'Fantasia' and 'Venus' (20.3, 19.6 and 16.4 g kg^{-1} FW, respectively). In accordance with fructose levels ($r = 0.793$, $p < 0.001$), the equisweet parameter was greatest in 'Venus' and 'Cresthaven'.

The glucose/fructose ratio varied between 0.6 and 1.0 and a greater variability (0.4 – 2.5) was previously found when 205 peach breeding progenies were assayed.[33] Low values are favourable because fructose is rated higher (1.75) than sucrose (1) and glucose (0.75) in sweetness.[16,17]

Sorbitol is beneficial with respect to diet control, dental health and gastrointestinal problems and can be used as a glucose substitute for diabetics.[20] Among sugars, the greatest variation was found in sorbitol (CV% = 75). The highest values of sorbitol and percentage sorbitol were found in 'Andromeda' (20.6 g kg^{-1} FW and 15.4%, respectively), which is a selected seedling of 'Andross' (coded as 'PI-IB42') with good agronomical characteristics released for cultivation from the Department of Deciduous Fruit Trees in Naoussa.[9] A higher sorbitol content (35 g kg^{-1} FW) was only found in the study by Font i Forcada *et al.*,[11] whereas lower values were reported in other studies (up to 10.6 g kg^{-1} FW).[32,34] Sorbitol levels and percentage sorbitol were greater in NMPE (mean 9.9 g kg^{-1} FW and 9.0%, respectively), followed by NE (mean 6.4 g kg^{-1} FW and 6.0%, respectively) and lower values were found in MPE (mean 4.4 g kg^{-1} FW and 4.5%, respectively).

Fruit TPs (TPs-F) content ranged between 157.6 and 1573.5 mg GAE kg^{-1} FW (Fig. 1). Values in the highest range (861.2 – 1574.1) were found in descending order in 'Aurelia', 'Crest Haven', 'Maria Bianca', 'Everts', 'Andross', 'Venus' and 'Gladys', whereas the majority of cultivars contained these compounds in the range from 223.9 to 781.1 mg kg^{-1} FW. 'Patty', 'June Gold',

Table 2. Mean, range and CV% values for peach and nectarine fruit and jam quality traits, and mean values for MPE, NE and NMPE flesh types

				Mean		
	Mean	Range	CV%	MPE (25 Cvs)	NE (12 Cvs)	NMPE (8 Cvs)
Fruit traits						
HD	213.8	164.0–262.0	13.6	213.3	214.8	219.9
Peel-*L**	54.0	34.8–76.2	22.0	51.3 b	49.2 b	69.6 a
Peel-*a**	26.5	7.8–43.6	29.5	27.3 a	32.0 a	15.8 b
Peel-*b**	28.6	4.8–59.9	51.6	23.1 b	27.3 b	47.9 a
Peel-Hue	43.1	8.7–76.6	48.1	37.1 b	37.4 b	70.6 a
Peel-Chroma	42.6	26.6–61.6	19.8	38.4 b	45.6 a	51.0 a
Flesh-*L**	71.6	66.2–79.2	4.1	71.5	71.4	71.7
Flesh-*a**	5.9	−0.4 to 13.7	60.4	5.1 b	6.3 ab	8.4 a
Flesh-*b**	39.3	3.6–56.2	37.3	36.8	38.7	48.5
Flesh-Hue	78.9	32.2–91.9	13.7	79.6	76.5	80.3
Flesh-Chroma	40.1	4.4–57.8	35.6	37.6	39.2	49.3
SSC	11.9	7.5–16.3	19.4	11.1	12.8	12.6
TA	5.3	2.2 – 8.3	28.0	5.2 b	6.3 a	4.0 c
SSC/TA	2.5	1.3 – 5.8	36.0	2.3 b	2.2 b	3.3 a
Sucrose	68.9	38.6–115.9	22.4	66.3	70.3	74.8
Glucose	9.4	4.8–15.5	27.5	9.1	9.8	9.7
Fructose	11.7	5.2–20.3	28.5	11.3	12.3	11.9
Sorbitol	5.9	0.5–20.6	63.5	4.4 b	6.4 ab	9.9 a
Total sugars	95.8	51.2–159.2	22.6	91.1	98.8	106.4
Equisweet	10.0	5.5–16.3	22.0	9.6	10.3	10.9
Sucrose/glucose	7.7	4.4–14.8	28.3	7.6	7.6	8.0
Glucose/fructose	0.8	0.6–1.0	15.7	0.82	0.79	0.83
% Sorbitol	5.7	0.8–15.4	51.9	4.5 b	6.0 b	9.0 a
TPs-F	550.9	157.6–1573.5	65.2	591.4	480.3	661.6
TAC_{DPPH}-F	1141.8	240.6–3345.2	71.7	1366.0	911.0	1355.5
TAC_{FRAP}-F	416.1	106.9–1076.9	60.8	532.3	436.4	536.0
Jam-traits						
*L**	59.8	43.2–73.5	11.1	59.7	59.7	60.4
*a**	14.1	2.9–27.1	47.7	14.3	14.4	13.0
*b**	39.1	19.0–52.3	22.2	37.5 b	37.2 b	46.9 a
Hue	69.5	34.6–85.3	16.6	68.5	68.4	74.2
Chroma	42.4	24.5–52.9	17.6	41.0	40.9	48.8
TPs -J	257.6	115.0–626.2	50.5	284.6	280.2	322.9
TAC_{DPPH} -J	262.2	135.1– 619.4	42.0	231.0	176.5	216.6
TAC_{FRAP} -J	156.2	63.1–494.3	65.8	158.0	136.7	179.8
TPs –FJ	506.8	218.0 – 1220.8	51.2	493.8	494.6	566.7
TAC_{DPPH}-FJ	507.5	215.3 – 1178.6	42.6	536.6	444.0	512.9
TAC_{FRAP}-FJ	307.3	119.5 – 940.6	66.0	306.8	271.3	362.6
Aroma	5.1	3.2–7.2	21.7	5.0	5.2	5.3
Acceptance	5.4	3.7–7.7	17.0	5.2	5.6	5.8

Cvs, cultivars; HD, Harvest date (Julian date); SSC, soluble solid content (^{0}Brix); TA, titratable acidity (g malic acid L^{-1}); Individual soluble sugars (g kg^{-1} FW); TPs, total phenols (mg GAE kg^{-1} FW); TAC_{DPPH} and TAC_{FRAP}, total antioxidant capacity using the DPPH and FRAP methods, respectively (mg ascorbic acid kg^{-1} FW); –F, –FJ and -J, on fresh fruit, fruit in jam and jam basis, respectively. Means with different lowercase letters are significantly different ($P = 0.05$).

'Big Top' and 'Royal Gem' contained TPs in the lowest values (157.8–196.2 mg kg^{-1} FW). In the present study, higher TPs were found for 'Maria Bianca', 'Gladys' and 'Venus' compared to our previous study,[10] which may be attributed to their more advanced maturation stage, considering that substantial positive or negative effects may be induced during ripening. There were no significant differences in antioxidant contents among different fruit types; nevertheless, a trend of greater values in MPE compared to NE was reported in previous studies.[3,5,10]

Late-harvested peach and nectarine cultivars tended to have higher antioxidant potential ($r = 0.395–0.431$; $P < 0.010$) (see Supporting information, Table 1) and this was also previously documented in other studies,[9–11] although not in the study by Font i Forcada[11] when 120 peach and nectarine cultivars were analyzed. Strong positive correlations were found between TPs and TAC_{DPPH} or TAC_{FRAP} ($r = 0.919–0.969$) antioxidant assays, suggesting that phenolics are important contributors to the antioxidant capacity.[3,10]

Table 3. Mean values and least significant difference at $P < 0.01$ for sugar and acid parameters

Cultivar	Sucrose	Glucose	Fructose	Sorbitol	Total sugars	equisweet	SSC	TA	SSC/TA
Melting peach									
AL	81.6	9.8	10.9	4.7	107.0	11.1	10.6	6.1	1.7
AU	65.7	10.0	15.7	9.0	100.3	10.6	12.5	7.0	1.8
CH	105.0	10.4	13.4	7.9	136.7	14.1	15.6	5.2	3.0
FY	61.4	6.6	9.4	5.2	82.6	8.6	11.1	5.7	2.0
FL	68.4	9.2	13.0	6.0	96.7	10.2	10.5	3.7	2.9
GL	54.3	10.0	10.8	3.2	78.4	8.3	10.3	4.4	2.3
JG	39.1	6.6	7.9	3.0	56.6	6.0	7.5	5.0	1.5
MB	73.3	12.5	12.6	2.6	100.9	10.6	13.7	8.3	1.7
ML	57.3	9.5	9.9	0.8	77.4	8.2	9.8	5.1	1.9
MM	69.5	8.1	12.2	2.6	92.4	9.8	11.2	6.3	1.8
MA	77.5	8.0	11.0	5.9	102.4	10.6	12.1	5.4	2.2
OH	72.6	9.9	12.6	9.4	104.4	10.8	12.6	6.8	1.9
OC	79.1	5.4	7.4	4.7	96.5	9.9	12.5	2.5	5.1
PA	52.1	7.8	7.6	0.5	68.0	7.1	7.6	5.5	1.4
PI	65.2	14.8	20.3	6.2	106.5	11.6	12.8	5.6	2.3
RL	63.9	9.2	9.4	2.6	85.1	8.9	10.8	8.2	1.3
RS	69.7	8.6	15.1	5.1	98.5	10.6	11.1	6.7	1.7
RGE	69.2	7.5	9.4	2.3	88.4	9.3	10.0	3.5	2.8
RGL	54.5	10.5	12.8	1.7	79.5	8.6	10.0	4.3	2.3
SB	40.6	5.7	5.8	1.2	53.4	5.6	6.5	3.6	1.8
SR	59.6	7.9	8.8	4.2	80.6	8.4	11.7	3.9	3.1
SC	38.6	5.2	6.7	0.7	51.2	5.5	7.9	3.1	2.5
SY	75.8	12.6	14.0	3.5	106.0	11.2	12.2	3.4	3.6
TB	84.3	8.4	12.9	6.3	111.9	11.7	12.1	4.3	2.8
TR	79.0	12.3	13.1	10.3	114.8	11.7	16.0	5.1	3.1
Nectarine									
AM	56.6	9.3	10.7	3.8	80.4	8.5	10.2	7.5	1.4
BT	60.1	7.5	9.0	2.4	78.9	8.3	11.0	4.8	2.3
CAL	65.0	9.4	9.6	1.0	85.0	8.9	10.9	7.3	1.5
FN	80.5	13.6	19.6	13.9	127.7	13.3	14.3	6.0	2.4
GE	71.0	5.2	7.1	3.6	86.8	8.9	15.4	3.5	4.4
M51	55.9	12.6	13.3	2.4	84.2	9.0	12.7	7.7	1.6
M90	77.5	10.4	15.6	16.7	120.2	12.3	15.2	7.5	2.0
OR	66.5	8.0	13.5	7.6	95.6	10.1	12.2	7.9	1.6
RGO	64.6	9.8	10.8	3.5	88.7	9.3	11.6	6.5	1.8
RQ	70.1	10.1	12.0	2.6	94.8	10.0	11.2	5.9	1.9
TF	60.3	6.2	9.8	8.1	84.3	8.7	13.9	5.3	2.5
VE	115.9	15.5	16.4	11.5	159.2	16.3	15.0	5.7	2.7
Non-melting peach									
AD	71.0	9.9	12.3	16.5	109.8	11.0	14.0	4.2	3.3
CAT	52.7	4.8	5.2	6.1	68.8	6.9	8.9	2.9	3.1
EV	71.4	9.9	11.3	14.6	107.2	10.7	16.3	5.0	3.3
FO	81.3	11.5	12.9	3.8	109.5	11.5	11.7	4.1	2.8
LO	83.7	9.3	14.3	4.4	111.7	11.8	11.4	3.9	3.0
A37	81.6	9.7	13.8	11.6	116.6	12.0	13.0	2.2	5.8
IB42	85.3	12.4	15.9	20.6	134.2	13.5	14.2	4.5	3.2
RO	71.6	9.8	9.6	1.8	92.9	9.7	11.2	5.2	2.1
LSD	7.2	1.6	2.1	1.7	10.4	1.1	1.1	1.1	0.4

Units and abbreviations as shown in Tables 1 and 2.

Jam characteristics

Wide variability was found in physical, antioxidant and organoleptic properties of jams examined (Figs 1 and 2 and Table 2). Lighter colour jams (high L^* values) were from the white-flesh 'Caldesi 2000' (73.5) and 'Maura' (71.3), whereas darkest colour jams were from the yellow-flesh 'Aurelia' (43.2) and 'Fantasia' (46.4). Cultivars with more vivid coloured flesh also produced vivid coloured jams, as suggested by a significant positive correlation between flesh-Chroma and jam-Chroma ($r = 0.789$). Fruit antioxidant parameters negatively correlated with jam-L^* [$r = (-0.604)$ to (-0.485)] and positively with the jam-a^* parameter ($r = 0.429-0.499$), suggesting that darker and redder jams were

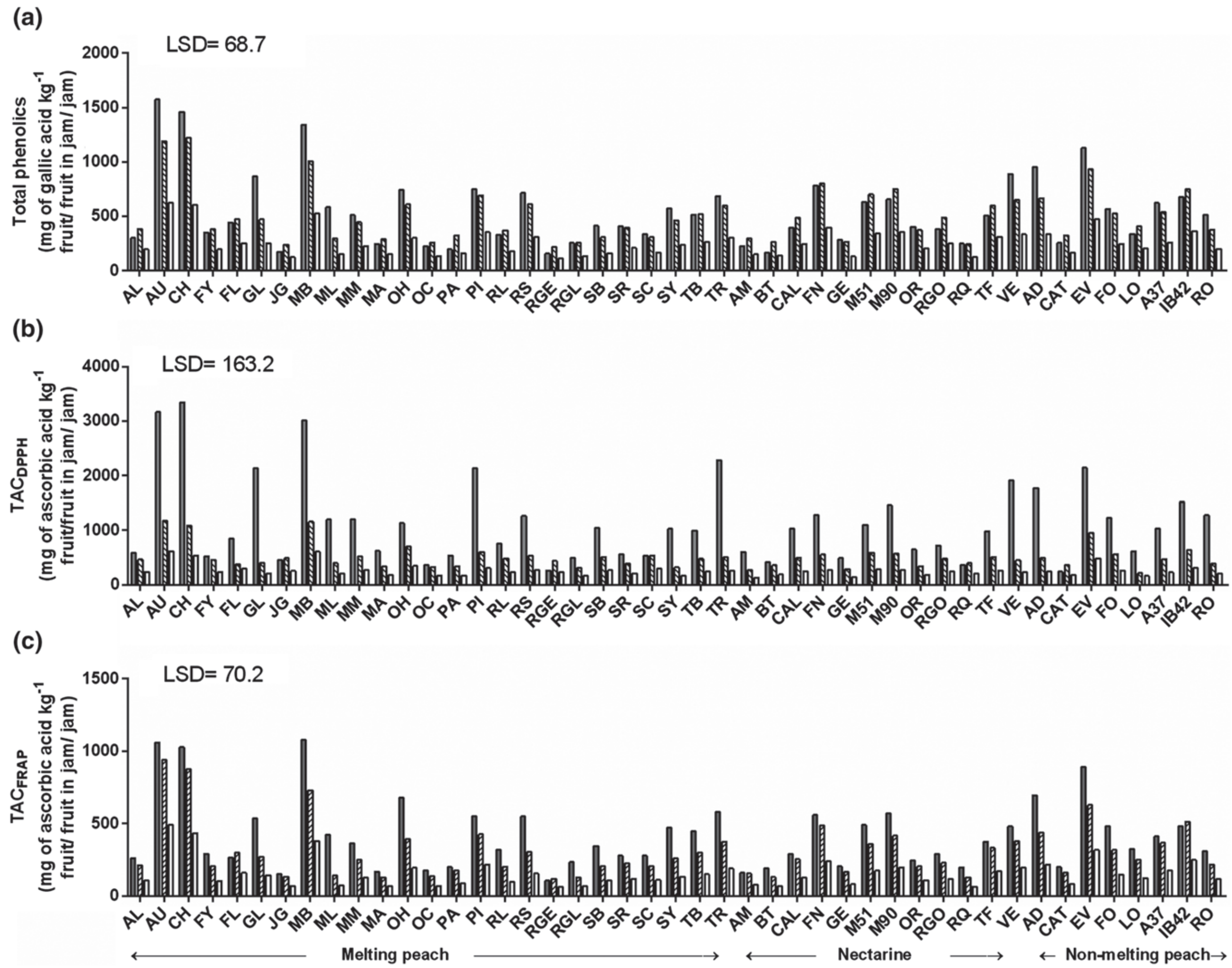

Figure 1. (a) Total phenolics, (b) total antioxidant capacity using the DPPH method (TAC_{DPPH}) and (c) total antioxidant capacity using the FRAP method (TAC_{FRAP}) in fruit, fruit in jam, and jam of peach and nectarine cultivars. LSD, least significant difference. Cultivar name abbreviations are as shown in Table 1.

produced by peaches with high antioxidant content. The higher amount of phenolic compounds available in fruit may act as a substrate for the induction of enzymatic browning,[35] although high temperatures inhibit the activity of polyphenol oxidase.[2] Consumers usually prefer lighter coloured jams; nevertheless, the results from the present study suggest these may contain less antioxidants.

TPs-J varied considerably with values ranging from 115.0 to 626.2 mg GAE kg^{-1} FW (CV% = 50.5). The above values were similar to those reported for cherry, apricot, fig and orange jams (291.4–544.9 mg GAE kg^{-1} FW)[36] and lower than strawberry (578.3–1360.0 mg GAE kg^{-1} FW),[36–38] plum, raspberry, sour cherry (1329.0–2189.0 mg GAE kg^{-1} FW);[29] the latter fruits are considered as having higher antioxidant contents compared to peach. In the present study, the greatest values of TPs-J were found in 'Aurelia' and 'Crest Haven' (mean 615.0 mg GAE kg^{-1} FW), being greater than the TPs found in fruit from other 29 assayed cultivars. Therefore, peach jam could be an allowable and favourable substitute for phenolic intake when fresh fruit is not available, and when prepared with cultivars with high antioxidant content and appropriate sugar formulations.

TPs-J were reduced by 48.3% compared to TPs-F, whereas antioxidant capacities were reduced to a greater extent compared to TPs losses after jam preparation (TAC_{DPPH}–F was reduced by 70.1% in TAC_{DPPH}–J; TAC_{FRAP}-F was reduced by 61.4% in TAC_{FRAP}–J). A greater reduction in TPs-J was found in cultivars with the initial highest TPs values ($r = -0.647$, $P < 0.001$), which was also found for the TAC_{DPPH} ($r = -0.642$, $P < 0.001$,) but not the TAC_{FRAP} losses. Levaj *et al.*[38] similarly found the greatest TPs losses after jam processing in strawberry cultivars with the initial highest values. The reduction in TPs during jam preparation could at least be partially explained by the sugar addition diluting the phenol content or other. The jam produced in the present study contained a relatively high percentage fruit (63.5–73.7%) (Table 3), classifying the peach jam as 'Extra jam' (EU Council Directive 2001/113/EC) and was prepared at 70 ± 5 °C, which is a low temperature for cooking, considering that extended heating could further influence the content of phytochemicals.[23–26]

Although peach jam preparation was reported not to alter the carotenoid, flavonoid and other phenolic profiles in peach,[21] to our knowledge, there is no report on quantitative effects on phenolic compounds. In the present study, a diverse response in the TPs on a fruit basis (TPs-F versus TPs-FJ) was found; no effect was noted in most cultivars (26 cultivars), whereas a reduction of 23.4% was found in 12 cultivars and an increase of 40.8% was found in seven cultivars. Kim and Padilla-Zakour[29] reported no effect or

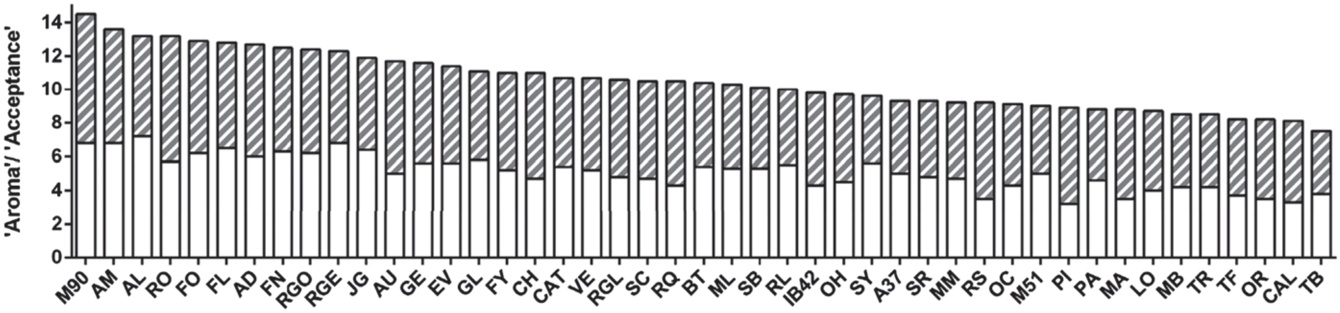

Figure 2. Sensory attributes of 'aroma' and 'acceptance' in jams prepared from peach and nectarine cultivars. Open bars represent 'aroma', hatched bars represent 'acceptance'. $LSD_{aroma} = 2.2$, $LSD_{acceptance} = 2.1$. LSD, least significant difference. Cultivar name abbreviations as shown in Table 1.

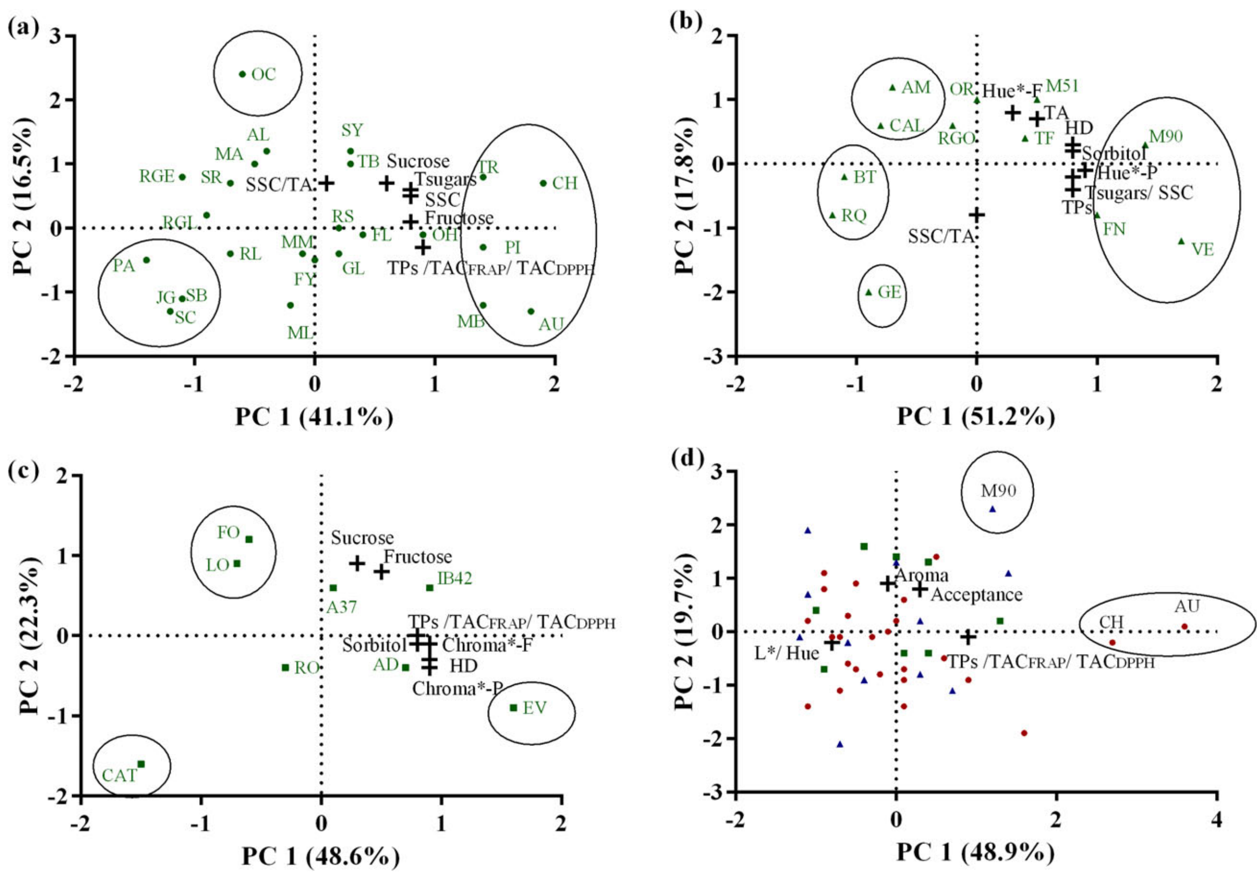

Figure 3. Segregation of (a) 25 melting peach, (b) 12 nectarine and (c) eight non-melting peach cultivars on the basis of harvest date and fruit quality characteristics and (d) 45 peach and nectarine cultivars, according to jam quality characteristics, determined by principal component analysis. Circles, triangles and squares, represent melting peach, nectarine and non-melting peach cultivars, respectively. Abbreviations as shown in Tables 1 and 2.

a slight decrease (−17.0%) in TPs-FJ compared to TPs-F in sour cherry, plum and raspberries. Moreover, a similar diverse response in the TPs content was reported during the shelf life ripening of 26 peach and nectarines cultivars[10] and this may be attributed to differences in their phenolic composition because the content of some compounds increased and others decreased.[39] Cooking effects on phytochemical contents may also be diverse among species, as a result of thermal degradation (decrease) or better extractability (increase).[24]

Jams were subject to organoleptic test and the 'aroma' and 'acceptance' were characterized (Fig. 2). Because the flavour of jams strongly depends on the ripeness of the processed fruits, ripe fruit was used in the present study. Jams scored as having high 'aroma' were from 'Alirosada' (7.2), 'Morsiani 90' (6.8) and 'Amiga' (6.8), whereas minimum scores were given to 'Maura' (3.5) and 'Rome Star' (3.5). The 'acceptance' of jams was greatest in 'Morsiani 90' (7.7) and 'Romea' (7.5) and lowest in 'Tardibelle' (3.7), 'Morsiani 51' (4.0) and 'Symphonie' (4.0). When 'aroma' and 'acceptance' scores were summed, jams from 'Morsiani 90', 'Amiga', 'Romea' and 'Alirosada' were the most favourable. Mean values of 'acceptance' were generally greater in NMPE (5.8), followed by NE (5.6), and lower in MPE (5.2), although differences were not significant ($P = 0.162$). There was a significant correlation between 'aroma' and 'acceptance' ($r = 0.508$, $P < 0.010$), as well as with any other measured parameter (data not shown).

Principal component analysis

In MPE cultivars, PC1 and PC2 accounted for 41.1% and 16.5% of total variability, respectively (Fig. 3a). 'Aurelia', 'Crest Haven', 'Maria Bianca', 'Profiti Ilias' and 'Tartired' were separated with high values in PC1, being positively correlated with phytochemicals, fructose, total sugars and SSC. PC2 was positively correlated with sucrose and SSC/TA; cultivar 'Octavia' was separated with high values.

In NE cultivars, the first component (51.2% of total variability) was positively correlated with TPs, harvest date, peel-Hue°, sorbitol total sugars and SSC (Fig. 3b); 'Venus', 'Morsiani 90' and 'Fantasia' belonged to this group with positive values, whereas 'Royal Queen' and 'Big Top' showed the opposite behavior. PC2 (17.8%) was positively correlated with TA and flesh-hue and negatively with SSC/TA. 'GEA' was separated with low TA and flesh-Hue values.

In NMPE cultivars, the most important variables integrated in PC1 (48.6%) were sorbitol, TPs, TAC_{DPPH} and TAC_{FRAP}, flesh-chroma, peel-chroma and harvest date; 'Everts' separated with positive values and 'Catherina' with negative values (Fig. 3c). PC2 (22.3%) was positively correlated with sucrose and fructose; 'Fortuna' and 'Loadel' belonged to this group with positive values.

In jams, the variance explained by the two PCs accounted for 68.6% of the total variance (Fig. 3d). PC1 (48.9%) was positively correlated with the jam phytochemical contents and negatively with the L^* and Hue° colour parameters, whereas PC2 (19.7%) was positively correlated with 'aroma' and 'acceptance' sensorial attributes. The data points were intermingled in the scatter plot, so that there was no relationship between traits that may be attributed to the greater variability found. The peach cultivars 'Aurelia' and 'Crest Haven' were separated with the greatest antioxidant contents and darker and redder colored jams. The nectarine 'Morsiani 90' also separated with the greatest 'aroma' and 'acceptance' values.

CONCLUSIONS

The results obtained in the present study can be considered of particular interest with respect to better defining fruit quality variations among widely cultivated peach and nectarine cultivars in Greece and other Mediterranean countries. Considerable differences were found in the contents of sugars, phenolic content and antioxidant capacities among the peach and nectarine cultivars and different flesh types, which were also depicted in the quality of jams produced. Although jams are often regarded as less nutritious than fresh fruit, the present study reveals that peach jam can still represent an appreciable source of antioxidant compounds, depending on the cultivar. Peach jams prepared especially from 'Aurelia' and 'Crest Haven' peach cultivars had considerable higher antioxidant contents compared to the fruit of other peach cultivars.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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