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ORIGINAL PAPER

Physicochemical and nutritional properties and volatile constituents of six Japanese plum (*Prunus salicina* Lindl.) cultivars

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Abstract The aim of this study is to contribute to the qualitative characterisation of six cultivars of Japanese plum (*Prunus salicina* Lindl.), i.e. 'Black Amber', 'Suplumeleven', 'Fortune', 'Larry Ann', 'Suplumsix' and 'Songold', by investigating their physicochemical and nutritional properties and their volatile fractions. The results indicate that the plum has a mean sugar content of 15% (between 12.3 and 17.8%), dietary fibre 1.2% (from 0.84 to 1.50%) and a mean energy value of 255 kJ 100 g^{-1} of fresh produce (from 183 to 331 kJ 100 g^{-1}). 'Black Amber' has the highest phenolic and anthocyanin contents and the greatest total antioxidant activity. In terms of their volatile fraction, Japanese plums are relatively poor in volatile compounds in comparison with other stone fruits. However, there are significant differences between the cultivars studied, with 'Fortune' standing out as the richest in volatile compounds and especially in esters.

Keywords Plum · Volatile compounds · Dynamic headspace · Physicochemical characteristics

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Introduction

The Japanese plum (*Prunus salicina* Lindl.) is grown in a number of the autonomous regions of Spain and especially in Extremadura, Valencia, Murcia, Andalucia, Aragon and Catalonia. In recent years, this species has been the object of a remarkable expansion and specialisation in Extremadura, giving it an important role in exports, primarily to countries within Europe.

The cultivation of the Japanese plum has enjoyed a constant increase in yields over the last 20 years, but is now thought to have reached the limit of production. There are programmes for the introduction and evaluation of new cultivars that investigate their agronomic performance in terms of flowering and harvesting periods, yields, fruit sizes and qualitative characteristics, comparing them against established reference varieties [1]. However, there are few studies of their suitability for commercialisation. Previous investigations of the nutritional properties of Japanese plum cultivars produced in Extremadura have shown differences above all in total soluble solid content (°Brix) and in acceptability index, i.e. the ratio of total soluble solids to acidity (TSS/acidity) [2].

Other authors have studied the physicochemical and sensory characteristics of Japanese-type plum cultivars grown in Georgia and Alabama (USA) and also the development of these characteristics during ripening [3]. Their results demonstrate that the various cultivars differ in their physicochemical properties. The varieties awarded the highest scores by panelists in sensory evaluation tests are also those with the greatest acceptability indices.

In the European plum (*Prunus domestica* L.), the sugar content varies between cultivars. The mean percentage of total sugars is approximately 10–12%, making this the majority nutrient when the results are given for dry matter

[4]. The main sugars are the monosaccharides glucose and fructose, the disaccharide sucrose and sorbitol. The values given for glucose often include sorbitol because of the difficulty in separating the two by high-performance liquid chromatography (HPLC). Also of interest are the plum's functional properties, attributed partly to its dietary-fibre content, which presents mean values approaching 1.5%, and to its high content in phenolic and other compounds with antioxidant properties [5].

Many authors have studied the composition of the volatile fraction of plum cultivars grown in the USA. A total of 36 different chemical compounds have been identified in this way [6], 34 of which have been isolated previously [7]. The most representative compounds were the families of esters and lactones and the most abundant in the majority of cultivars were hexanal, butyl acetate, (*E*)-2-hexenal, butyl butyrate, hexyl acetate, linalool, γ-decalactone and γ-dodecalactone. Other authors have analysed the volatiles obtained by simultaneous distillation–extraction of the plum cultivars 'Friar' and 'Black Amber', as well as of apricots and of plum–apricot hybrids [8]. There are marked differences in the composition of the volatile fractions of plums and apricots, the latter being richer in aromatic compounds. The plum is characterised by an abundance of C_6 compounds such as hexanal, (*E*)-2-hexenal, hexanol, (*Z*)-3-hexen-1-ol and their esters. 'Black Amber' exhibited greater concentrations than 'Friar' of most of the identified compounds. Hydrocarbons were more frequent in plums than in apricots, probably as a result of the waxes present in the skin of the plum. Hybrids of apricots and plums retain the capacity to produce volatile compounds typical of both progenitor species.

Some of the Japanese-type plums most widely grown in Extremadura (Spain) are: 'Black Amber', 'Suplumeleven', 'Fortune', 'Larry Ann', 'Suplumsix' and 'Songold'. All of them have a medium-large size and firm flesh, with red to purple skin expect 'Songold' that is yellow in colour. The flesh colour is yellow except for 'Suplumeleven', a red flesh variety. In general, large size and homogeneous colour plums, purple or yellow, are preferred by consumers.

The aim of this study is an analysis of the physicochemical and nutritional characteristics and of the volatile fraction of the six Japanese plum cultivars most representative of those grown in Spain.

Materials and methods

Plant material

During the 2006 season, plums grown in Extremadura (Spain) of the cultivars 'Black Amber', 'Suplumeleven', 'Fortune', 'Larry Ann', 'Suplumsix' and 'Songold' were harvested at commercial maturity. The fruit was obtained from a Fruit Growers Association (AFRUEX) at Badajoz, Spain. These plums are exported to Northern Europe markets, mainly United Kingdom and Germany. Commercial maturity criteria used were size and uniform colour, 12–14 °Brix minimum and flesh firmness ranging between 40–20 N, using a manual penetrometer with a 8-mm tip. According to Crisosto [9], firmness by itself is not an accurate tool to define a high quality plum. On their arrival at the laboratory, a homogeneous sample of 50 fruits was taken for each cultivar. Physical data on colour and texture were collected from 20 fruits from each sample and 10 more were stoned and macerated to produce a homogenate on which the chemical analyses were performed. A further six fruits were used to study the volatile fraction. The remaining fruits were frozen whole, vacuum packed and kept at −80 °C until the nutritional analyses were complete.

The various cultivars were harvested on different dates during the season, ranging from the beginning of July ('Black Amber') to mid-September ('Suplumsix').

Physicochemical analysis

The soluble solids content of a homogenate obtained from ten fruits was determined by refractometry using an RE40 refractometer (Mettler Toledo, S.A.E., Coslada, Madrid, Spain). Values for pH and acidity were obtained using a DL50 Graphix automatic titrator (Mettler Toledo, S.A.E., Coslada, Madrid, Spain). Three grammes of homogenate were mixed with 50 mL of deionised water and titrated with sodium hydroxide 0.1 N to pH 8.1. The results were expressed as percentage of malic acid.

Firmness was determined using a TA.XT2i texture analyser (Aname, Pozuelo, Madrid, Spain) with a 6-mm diameter cylindrical probe and a compression speed of 2 mm s^{-1}. Each of the ten intact fruits was tested twice, at diametrically opposite sites, by advancing the probe until the skin ruptured. Force/deformation curves were recorded using the computer programme of the texture analyser and the maximum force (N) and the slope (N mm^{-1}) were calculated.

The colour of the fruits was measured with a Minolta CM-2500d spectrophotometer (Aquateknica, S.A., Valencia, Spain) using the illuminant D65, diffuse illumination, a viewing angle of 8° and a measurement area of 30 mm. Two readings were taken at diametrically opposite positions in the equatorial regions of each of ten fruits to obtain the parameters L*, a*, b*, C* and h*. Subsequently, a transverse cut was made in each of the fruits, stopping short of the stone, and the colour of the pulp was recorded.

Nutritional analysis

The moisture content was determined by the loss of weight of 3 g of homogenate in a Selecta Vaciotem vacuum oven

(Andaluza de Instrumentación, S.L., Mairena del Aljarafe, Seville, Spain) at 70 °C [10]. Dietary fibre was measured using enzymatic digestion of 1 g of freeze-dried homogenate [11]. The protein content was determined by the Kjeldahl method, using a Gerhardt Kjeldatherm digestor and a Gerhardt Vapodest distillation system (Izasa, S.A., Seville, Spain). The ash content was measured by calcination of 1 g of freeze-dried homogenate in a Selecta muffle furnace (Andaluza de Instrumentación, S.L., Mairena del Aljarafe, Seville, Spain) at 550 °C for 24 h. The total carbohydrate content of each cultivar was calculated by difference and the energy value assessed in accordance with EU Directive 90/496/EEC [12].

The glucose, fructose and sucrose contents were measured by making up 1 g of homogenate to 10 mL with deionised water, passing it through a 0.45-μm filter and injecting it into an HP 1050 chromatograph (Agilent Technologies, Inc., Palo Alto, CA, USA) using a Zorbax NH2 5 μm 4.6 × 250 mm column and a refractive index detector. Calibrations were carried out for each sugar [D(+)-anhydrous glucose Merck 8337.0250, D(−)-fructose Fluka 47739, sucrose Sigma S5016]. Sorbitol could not be separated from glucose because they have the same retention time and were quantified together.

Phenolics were extracted from 5 g of homogenate following the method described by Lima et al. [13] and were determined using the Folin–Ciocalteu reagent in a UV-2401 PC Shimadzu spectrophotometer (Shimadzu Scientific Instruments, Inc., Columbia, 136 MD, USA). Gallic acid was used as standard and the results were expressed as mg 100 g^{-1} fresh weight.

Anthocyanins were extracted from 10 g of homogenate in 50 mL of methanol with 1% HCl for 24 h under refrigeration. The absorbance of this extract was measured at 560 nm in a UV-2401 PC Shimadzu spectrophotometer (Shimadzu Scientific Instruments, Inc., Columbia, MD, USA). Quantification was carried out using cyanidin 3-*O*-rutinoside as standard, and the results were expressed as mg 100 g^{-1} fresh weight.

Total antioxidant activity (TAA) was determined according to Serrano et al. [14], on freshly prepared plum juice. The measurement was carried out in a UV-2401 PC Shimadzu spectrophotometer (Shimadzu Scientific Instruments, Inc., Columbia, MD, USA). The results were expressed as mg of Trolox 100 g^{-1} of fresh weight.

Volatile compounds analysis

Six fruits were cut into pieces of approximately 1 cm^3 and 5 g of sample were weighed into each test tube. The freshly prepared aliquots were placed in the automatic head space Tekmar 2016. Volatile isolation was carried out using a helium flow rate of 100 mL min^{-1}, and the purging time was 90 min at room temperature. The identification and quantification of the volatile compounds were performed on a Varian Star 3400 gas chromatograph coupled with a Varian Saturn 3 mass spectrometer detector (Varian Ibérica S.L., Avda. Pedro Diez, 25, Madrid). Injector and detector were held at 260 °C. Mass spectra were obtained by ion trap and spectra range of 15–400 m/z was used. The GC–MS apparatus was linked to a PC running software Varian MS Workstation. Identification of some compounds was confirmed by comparison of the collected mass spectra with those of authenticated reference standards and all spectra in the Nist 2.0d mass spectra library. Besides, comparison of some compounds experimental retention index with that of authentic reference standards was carried out. Six replicates were performed for each plum cultivar.

Statistical analysis

The data obtained were analysed statistically by an analysis of variance and Tukey's multiple range test for comparison of means and least significant differences (LSD) ($P < 0.05$) using the SPSS 13.0 (SPSS Inc, Chicago, IL, USA).

Results and discussion

Physicochemical results

Values for pH, acidity and total soluble solids (TSS) for each of the various cultivars are given in Table 1, together with the acceptability indices (TSS/acidity) and the firmness data (maximum force and slope). There are significant differences in the TSS content, with 'Larry Ann' and 'Suplumsix' the cultivars with the greatest values at 17.7 and 17.8 °Brix, respectively and 'Fortune', at only 12.3 °Brix, that with the lowest. These values are greater than the 10–12 °Brix given in the literature for *Prunus domestica* [4]. Organic acids play an important role in the flavour of fruit, a sensory attribute that is determined by the ratio of sugar to acid [15]. Because 'Suplumsix' is the cultivar in this study with the least acid and the greatest concentration of soluble solids, it returns an acceptability index, at more than 20, that is significantly greater than the rest. The values for TSS and acidity found in this study are similar to others given for this type of fruit [3].

The firmness of fruit does not depend only on the resistance of the skin. It is also influenced by the pulp, such that the overall firmness value is derived from a combination of both components [16]. The maximum force is the force (N) necessary to break the skin and the slope (N mm^{-1}) of the force/deformation curve provides an indication of the firmness of the fruit. Both force and slope differ significantly between the cultivars studied here, as can be seen in

Table 1 Physicochemical properties of 6 cultivars of *Prunus salicina* Lindl.

Cultivar	pH[1]	Acidity[1] (% malic acid)	TSS[1] (ºBrix)	TSS/acidity[1]	Maximum force[2] (N)	Slope[2] (N mm^{-1})
'Black Amber'	3.20b ± 0.01	1.85f ± 0.01	13.6b ± 0.06	7.34a ± 0.08	5.50a ± 1.35	1.74a ± 0.42
'Suplumeleven'	3.42f ± 0.01	1.20b ± 0.00	16.2c ± 0.17	13.56a ± 0.16	9.92 cd ± 0.54	2.72c ± 0.11
'Fortune'	3.22c ± 0.01	1.33e ± 0.00	12.3a ± 0.06	9.26a ± 0.06	8.77bc ± 0.95	2.14ab ± 0.26
'Larry Ann'	3.26d ± 0.01	1.23c ± 0.01	17.7d ± 0.00	14.39a ± 0.07	10.96d ± 1.02	3.41d ± 0.40
'Suplumsix'	3.37e ± 0.00	0.85a ± 0.01	17.8d ± 0.06	20.85b ± 0.25	7.57b ± 1.27	2.36bc ± 0.33
'Songold'	3.14a ± 0.00	1.26d ± 0.00	13.4b ± 0.00	10.63a ± 0.02	8.54bc ± 1.47	2.40bc ± 0.44

Values in a given column followed by different letters are significantly different from one another ($P < 0.05$); values are given as mean ± SD

[1] Mean of 4 independent replicates

[2] Mean of 10 independent replicates

Table 1. The cultivar 'Larry Ann' has the greatest firmness, with a value for maximum force of 10.96 N and a slope of 3.41 N mm^{-1}. 'Black Amber' is the least firm, with values of 5.5 N and 1.74 N mm^{-1}, respectively. The firmness of these cultivars may indicate their resistance to damage during the post-harvest handling and transport. Because the fruit is intended primarily for export, it is of interest that it has a high firmness value.

The values obtained for the various colour parameters are given in Table 2. The yellow cultivar 'Songold' shows the highest skin lightness (L^*), whereas the cultivars with red-black skins, such as 'Black Amber', exhibit lower values. All of the cultivars show similar values for the lightness of the pulp, except for 'Suplumeleven', which, at 44.18, has the darkest pulp of the cultivars studied.The values obtained for the various colour parameters are given in Table 2. The yellow cultivar 'Songold' shows the highest skin lightness (L^*), whereas the cultivars with red-black skins, such as 'Black Amber', exhibit lower values. All of the cultivars show similar values for the lightness of the pulp, except for 'Suplumeleven', which, at 44.18, has the darkest pulp of the cultivars studied.

The hue angle (h^*) of the skin varies from 90.80 for the yellow variety 'Songold' to 7.77 for the dark purple 'Black Amber'. These values are close to those given for these fruits by other authors [3]. In terms of the hue angle of the pulp, 'Suplumeleven', with a value for h* of 38.42 (red flesh), is significantly different from the other cultivars, which vary between 72.12 and 78.13 (yellow flesh). Chroma (C^*) defines the colour intensity, showing values

Table 2 CIELab parameters of 6 cultivars of *Prunus salicina* Lindl.

Cultivar	Skin colour				
	L*(D65)[1]	a*(D65)[1]	b*(D65)[1]	C*(D65)[1]	h*(D65)[1]
'Black Amber'	22.08a ± 1.08	3.01b ± 1.03	0.45a ± 0.37	3.05a ± 1.07	7.77a ± 4.89
'Suplumeleven'	24.16a ± 2.35	10.28c ± 3.86	2.93a ± 1.73	10.72b ± 4.16	14.81a ± 4.09
'Fortune'	32.71b ± 6.34	27.75e ± 4.71	13.77b ± 5.28	31.38d ± 4.90	25.94ab ± 9.38
'Larry Ann'	31.29b ± 5.47	18.96d ± 5.00	11.44b ± 6.58	22.54c ± 7.03	28.71ab ± 10.74
'Suplumsix'	29.46b ± 4.39	9.97c ± 4.32	2.99a ± 4.46	10.74b ± 5.58	11.02a ± 13.48
'Songold'	55.28c ± 1.40	−0.47a ± 2.00	39.17c ± 2.08	39.22e ± 2.07	90.80c ± 2.94
Cultivar	Flesh colour				
	L*(D65)[1]	a*(D65)[1]	b*(D65)[1]	C*(D65)[1]	h*(D65)[1]
'Black Amber'	68.83de ± 1.89	8.24a ± 1.34	36.75b ± 2.08	37.68a ± 2.24	77.40c ± 1.58
'Suplumeleven'	44.18a ± 3.53	38.14c ± 4.36	30.08a ± 2.86	48.77c ± 2.55	38.42a ± 5.34
'Fortune'	69.55e ± 0.96	9.61a ± 1.59	45.43c ± 3.12	46.46bc ± 3.29	78.09c ± 1.43
'Larry Ann'	61.65b ± 1.20	17.74b ± 2.57	54.83d ± 3.12	57.66d ± 3.46	72.12b ± 2.09
'Suplumsix'	66.98cd ± 2.14	9.63a ± 3.02	45.19c ± 3.98	46.26bc ± 4.37	78.13c ± 3.03
'Songold'	65.09c ± 2.66	10.38a ± 2.06	43.78c ± 2.78	45.03b ± 2.98	76.72c ± 2.27

Values in a given column followed by different letters are significantly different from one another ($P < 0.05$); values are given as mean ± SD

[1] Mean of 10 independent replicates

between 3.05 and 39.22 for the skin and between 37.68 and 57.66 for the plum flesh. Higher chroma values mean higher colour intensity.

Nutritional results

As in all fruits, water is the most abundant constituent of plums, ranging from 80.65% in 'Larry Ann' to 89.40% in 'Suplumeleven' (Table 3).

One of the more remarkable characteristics of the plum is its unrivalled capacity as an intestinal regulator, an effect of its dietary-fibre content. Well-known physiological properties ascribed to this material include among other benefits stimulating satiation, helping to maintain and develop intestinal bacterial flora, and contributing to glycaemic-index reduction. The cultivars studied here with the greatest fibre contents are 'Black Amber' and 'Larry Ann' with values, at 1.5%, similar to those given in the literature [5].

Proteins in fruit usually represent less than 1% of fresh weight and do not function as reserves as they do in cereals and nuts. Instead, most are involved in various metabolic processes, principally as enzymes. The protein content of the cultivars studied here varies significantly between 0.38% in 'Suplumeleven' and 0.96% in 'Suplumsix'. The ash content is very low at generally less than 0.5%. 'Larry Ann' and 'Suplumsix', with the highest amounts of ash, differ significantly from all of the other cultivars except 'Black Amber'.

The carbohydrate content, calculated by difference, is greater than 10% and some cultivars, i.e. 'Larry Ann' and 'Suplumsix', contain 17% and more.

The main sugar is the monosaccharide glucose. It varies in abundance among cultivars, with 'Suplumeleven' that with the highest content (10.27%) and 'Fortune' that with the lowest (4.41%). The sucrose and fructose contents also vary greatly among cultivars. In *Prunus domestica* the disaccharide sucrose is the principal sugar and there are important variations among cultivars both in the total sugar content and in the proportions of the four main sugars (glucose, fructose, sucrose and sorbitol) [4].

The energy that these fruits provide varies between 183.04 kJ 100 g^{-1} for 'Suplumeleven' and 331.10 kJ 100 g^{-1} for 'Larry Ann' (Table 3).

Phenolic and anthocyanin contents and total antioxidant activity (TAA) are shown in Table 4. The phenolic content is high in all of the plum cultivars studied, ranging between 94.54 mg 100 g^{-1} in 'Suplumeleven' and 202.46 mg 100 g^{-1} in 'Black Amber'. These values are similar to or lower than those found in other plum cultivars by other researchers [17–19].

No anthocyanins were detected in 'Songold', a cultivar with yellow skin and yellow flesh. The highest anthocyanin contents were found in 'Black Amber' and 'Fortune' (28.93

Table 3 Nutritional composition of 6 cultivars of *Prunus salicina* Lindl.

Cultivar	Moisture[1] (%)	Fibre[1] (%)	Protein[1] (%)	Ash[1] (%)	Carbohydrates[1] (%)	Glucose[1,2] (%)	Fructose[1] (%)	Sucrose[1] (%)	Energy1 (kJ 100 g^{-1})
'Black Amber'	85.57c ± 0.05	1.47d ± 0.09	0.86d ± 0.00	0.38bc ± 0.01	13.19c ± 0.05	5.74a ± 0.02	4.07c ± 0.03	0.65a ± 0.01	247.27c ± 1.05
'Suplumeleven'	89.40e ± 0.83	0.84a ± 0.07	0.38a ± 0.01	0.19a ± 0.01	10.04a ± 0.82	10.27c ± 1.18	4.79d ± 0.54	2.41b ± 0.28	183.04a ± 14.46
'Fortune'	86.85d ± 0.05	1.23c ± 0.06	0.77c ± 0.04	0.27ab ± 0.18	12.11b ± 0.17	4.41a ± 0.19	2.08a ± 0.09	4.16cd ± 0.20	226.35b ± 2.51
'Larry Ann'	80.65a ± 0.38	1.50d ± 0.09	0.90e ± 0.01	0.52c ± 0.01	17.93e ± 0.39	7.82b ± 0.04	1.82a ± 0.01	4.34d ± 0.02	331.10e ± 6.77
'Suplumsix'	81.59b ± 0.07	1.05b ± 0.05	0.96f ± 0.00	0.53c ± 0.07	16.92d ± 0.09	9.48c ± 0.27	2.18a ± 0.03	3.70c ± 0.25	314.29d ± 1.50
'Songold'	86.07cd ± 0.10	1.29c ± 0.05	0.57b ± 0.00	0.32ab ± 0.01	13.04c ± 0.10	5.44a ± 0.14	3.13b ± 0.10	2.03b ± 0.14	239.22bc ± 1.80

Values in a given column followed by different letters are significantly different from one another ($P < 0.05$); values are given as mean ± SD

[1] Mean of 4 independent replicates

[2] Glucose + sorbitol

Table 4 Phenolic and anthocyanin compounds and Total Antioxidant Activity (TAA) of 6 cultivars of *Prunus salicina* Lindl.

Cultivar	Phenolic[1] (mg 100^{-1} g)	Anthocyanin[1] (mg 100^{-1} g)	TAA[1] (mg Trolox 100^{-1}g)
'Black Amber'	202.46d ± 9.22	28.93c ± 3.17	946.52d ± 97.72
'Suplumeleven'	94.54a ± 6.45	24.30bc ± 1.76	645.84c ± 62.40
'Fortune'	144.64bc ± 19.94	23.78b ± 2.75	274.63a ± 46.89
'Larry Ann'	103.04a ± 6.41	11.15a ± 0.38	258.6a ± 42.76
'Suplumsix'	135.30b ± 10.77	10.93a ± 1.13	479.16b ± 30.58
'Songold'	170.15c ± 3.68	–	425.27b ± 33.64

Values in a given column followed by different letters are significantly different from one another ($P < 0.05$); values are given as mean ± SD

[1] Mean of 4 independent replicates

and 23.78 mg 100 g^{-1}, respectively), both of which have dark purple skins, and in 'Suplumeleven' (24.30 mg 100 g^{-1}), a cultivar with purple-red skin and red flesh.

The highest TAA values were obtained for 'Black Amber' and 'Suplumeleven' (946.52 and 645.84 mg Trolox 100 g^{-1}, respectively). A strong correlation between total phenolics and antioxidant capacity has been reported [19]. The main phytochemicals responsible for the antioxidant capacity of plums are phenolic acids and flavonoid compounds [18], although other compounds may be also involved [17].

Volatile compounds results

A total of 40 volatile compounds were isolated from the volatile fraction of these plum cultivars by means of the dynamic headspace technique (Table 5). This is the best method for obtaining good correlations with the results of sensory analysis [20]. The results of volatile compounds differ from those of other authors, perhaps because of the isolation technique employed (distillation–extraction with solvents) or because of the respective sample sizes. The differences suggest that fewer compounds were identified in this study but because these are generally compounds with lower molecular weights, they are presumably more involved in the sensory characteristics perceived by consumers in tasting the fruit.

The mean values, expressed as area units 10^{-4} (AU10^{-4}), for all of the chromatographic peaks studied are given in Table 5, in ascending order of retention time. It is important to emphasise that the best represented chemical family, both in the number of compounds and in abundance, is the esters with 18 peaks. Many of these compounds have also been identified in the volatile fractions of other stone fruits such as peach [21] and cherry [22], of tropical fruits like passion fruit [23], and of plums cultivated in the USA [6, 8].

Not all of the compounds are present in all of the cultivars, nor, where they do occur, are they present at the same intensities. This results in notable differences among cultivars. Of the 40 peaks identified, 13 correspond to chemical compounds common to all of the cultivars and the remainder are found only in some. 'Fortune' is the cultivar with the greatest volatile content, substantially different from the others, with a value equivalent to the sum total of the areas of the identified peaks (174.5 AU10^{-4}) (Table 5). 'Suplumsix' and 'Songold', classified by Kruger [24] as suppressed climacteric plums, are the cultivars with the lowest volatile content (30.3 and 50.5 AU10^{-4}, respectively).

Of all the volatile compounds studied, those that are present in the greatest proportions are guanidine, 3-hexen-1-ol, and the esters 4-hexen-1-ol acetate and hexyl acetate.

The presence of a relatively important number of C_6 compounds may be due to the activity of the enzyme lipoxygenase on linoleic and linolenic fatty acids. These acids form part of the membrane phospholipids. By the action of lipoxygenase, they give rise to hydroperoxides, which are broken down by hydroperoxide lyase to produce hexanal and 2-hexenal and, in turn, 3-hexenol, 2-hexenol, etc. [25]. Considering that these C_6 compounds have aromatic notes of freshly cut grass and of green apple, and that they are present in the analysed samples in relatively important quantities, it may be said that the volatile fractions of the samples have herbaceous aromatic notes [26].

In general, esters have pleasant, fruity aromas that determine the aromatic notes characteristic of various fruits [27]. This group of compounds is especially important in the plum cultivar 'Fortune', in which it represents approximately 75% of the identified volatile fraction, and, to a lesser extent, in 'Songold', in which it comprises 41%. In the other cultivars, esters make up smaller percentages. The ester butyl butanoate, which is present in other plum cultivars [6], was not found in any of the samples analysed here. 'Fortune' is a cultivar relatively rich in acids and low in total soluble solids [2], and it is harvested early (in the second half of July). However, it is rich in esters, which may result from a greater capacity for producing ethylene, the ripening hormone that controls, in part, the synthesis of esters [28].

Table 5 Mean values of the various compounds identified in the volatile fraction of 6 cultivars of *Prunus salicina* Lindl.

RT[1]	Compounds	Area units 10^{-4}					
		'Fortune'	'Suplumsix'	'Black Amber'	'Larry Ann'	'Suplumeleven'	'Songold'
4.95	Guanidine	19.0 ± 5.8	8.1 ± 0.5	16.9 ± 4.0	13.0 ± 8.1	22.8 ± 6.5	5.0 ± 1.2
8.42	2-Butanone + hexane	4.6 ± 3.1	NQ	2.2 ± 0.7	0.4 ± 0.2	3.4 ± 0.9	0.6 ± 0.2
9.02	2-Methyl-3-buten-2-ol	0.7a ± 0.1	0.8a ± 0.1	0.5a ± 0.1	1.7b ± 0.4	0.4a ± 0.05	0.5a ± 0.1
9.26	Ethyl acetate	3.3b ± 0.9	1.0a ± 0.4	NQ	0.2a ± 0.1	NQ	0.3a ± 0.2
9.45	Trichloromethane	1.6 ± 0.4	NQ	1.9 ± 0.9	NQ	0.3 ± 0.2	0.2 ± 0.1
17.43	3-Methylbutanol	NQ	0.6 ± 0.3	1.2 ± 0.5	0.1 ± 0.0	1.2 ± 0.3	0.2 ± 0.1
22.70	Hexanal	0.1 ± 0.0	0.1 ± 0.0	0.5 ± 0.3	0.6 ± 0.4	0.3 ± 0.2	0.5 ± 0.3
22.85	Ethyl butanoate	0.2 ± 0.1	NQ	NQ	NQ	NQ	NQ
23.95	Butyl acetate	0.1 ± 0.0	NQ	NQ	NQ	NQ	NQ
27.55	*(Z)*-3-Hexen-1-ol	1.7a ± 0.7	5.2ab ± 0.7	9.3ab ± 2.1	8.4ab ± 1.1	10.6b ± 2.6	11.7b ± 2.3
28.44	*(E)*-2-Hexen-1-ol	0.6ab ± 0.2	1.5ab ± 0.4	0.4a ± 0.1	1.9bc ± 0.5	3.1c ± 0.5	NQ
28.62	Furan tetrahydro-2,4-dimethyl-trans-	0.3a ± 0.1	2.2abc ± 0.5	1.7ab ± 0.5	4.9bc ± 1.1	5.5c ± 1.1	2.4abc ± 0.6
29.11	*m*-Xylene	0.6ab ± 0.1	NQ	0.8b ± 0.3	0.2a ± 0.0	0.5ab ± 0.2	0.2ab ± 0.0
30.98	Styrene	0.2ab ± 0.0	NQ	0.3b ± 0.1	0.1ab ± 0.0	0.3ab ± 0.1	0.1a ± 0.0
31.56	Nonane	0.1 ± 0.0	0.1 ± 0.0	NQ	NQ	0.1 ± 0.0	0.1 ± 0.0
33.87	Isopropylbenzene	0.9 ± 0.8	0.1 ± 0.0	NQ	0.1 ± 0.0	0.4 ± 0.3	0.9 ± 0.7
38.85	α-Methylstyrene	3.4 ± 3.3	NQ	0.8 ± 0.5	NQ	1.7 ± 1.6	1.7 ± 1.5
39.60	Cyclotetrasiloxane octamethyl-	0.9 ± 0.8	0.2 ± 0.1	0.3 ± 0.1	0.1 ± 0.0	0.2 ± 0.1	0.7 ± 0.6
40.00	Ethyl hexanoate	0.2 ± 0.1	NQ	NQ	NQ	NQ	NQ
40.16	Decane	0.3 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.2 ± 0.0	0.3 ± 0.0	0.3 ± 0.1
40.61	4-Hexen-1-ol-acetate	64.7b ± 5.9	0.6a ± 0.1	0.4a ± 0.2	6.8a ± 1.2	3.5a ± 0.6	11.1a ± 1.8
41.10	Hexyl acetate	37.4b ± 4.4	0.4a ± 0.1	0.2a ± 0.1	3.7a ± 0.6	1.7a ± 0.2	3.7a ± 0.7
41.31	*(E)*-2-Hexen-1-ol-acetate	9.7b ± 1.3	0.4a ± 0.1	NQ	1.0a ± 0.1	1.2a ± 0.1	NQ
42.50	2-Ethyl-1-hexanol	0.1ab ± 0.0	0.1a ± 0.0	0.3b ± 0.1	0.1a ± 0.0	0.2ab ± 0.0	0.1a ± 0.0
45.94	2-Hydroxy-1-phenyl-ethanone	NQ	NQ	NQ	NQ	0.3 ± 0.2	0.4 ± 0.3
47.41	α α Dimethyl benzenemethanol	NQ	NQ	0.8 ± 0.4	0.1 ± 0.0	0.4 ± 0.2	0.3 ± 0.2
53.36	*N*,4-Dimethyl-benzenamine	NQ	NQ	NQ	NQ	NQ	0.3 ± 0.2
54.94	4-Hexenyl propanoate	1.5abc ± 0.3	0.2ab ± 0.0	2.2c ± 0.7	0.1a ± 0.0	1.9bc ± 0.4	1.5abc ± 0.4
55.27	Butyl hexanoate	0.3 ± 0.1	NQ	NQ	NQ	0.3 ± 0.2	NQ
55.33	Hexyl butanoate	0.4ab ± 0.1	0.1a ± 0.0	0.4ab ± 0.2	0.1a ± 0.0	0.6b ± 0.2	0.3ab ± 0.1
55.56	*(E)*-2-Hexenyl butanoate	NQ	NQ	NQ	NQ	0.3 ± 0.1	NQ
55.70	Ethyl octanoate	0.2 ± 0.1	NQ	NQ	NQ	NQ	NQ
56.54	Ciclodecanol	0.1 ± 0.0	NQ	NQ	0.1 ± 0.0	NQ	0.1 ± 0.0
58.45	4-Hexenyl butanoate	0.4ab ± 0.1	0.1a ± 0.0	0.1a ± 0.0	0.1a ± 0.0	0.7b ± 0.2	NQ
68.75	4-Hexenyl hexanoate	1.2ab ± 0.2	0.1a ± 0.0	1.1ab ± 0.5	0.1a ± 0.0	1.7b ± 0.6	0.4ab ± 0.2
69.04	Hexyl hexanoate	0.2 ± 0.1	NQ	0.1 ± 0.0	NQ	0.3 ± 0.1	NQ
69.03	Butyl caprylate	0.2 ± 0.1	NQ	NQ	NQ	NQ	NQ
69.24	2-Hexenyl hexanoate	NQ	NQ	NQ	NQ	0.2 ± 0.1	NQ
69.91	Tetradecane	0.1 ± 0.1	0.1 ± 0.0	NQ	NQ	NQ	0.2 ± 0.1
78.01	Butylated hydroxytoluene	NQ	0.1 ± 0.0	NQ	0.1 ± 0.0	NQ	1.5 ± 1.1
	Total area	174.5	30.3	59.6	57.3	87.4	50.5

Values in a given row followed by different letters are significantly different from one another ($P < 0.05$); values are given as mean ± SD

NQ could not be quantified

[1] Retention time

[2] Mean of 6 independent replicates in area units 10^{-4}

The chemical family of linear alcohols makes up relatively high percentages in all of the cultivars studied except for 'Fortune', in which it accounts for only 2%. The cultivar 'Suplumeleven' is the richest in alcohols, of which (*Z*)-3-hexen-1-ol and (*E*)-2-hexen-1-ol are the most abundant. Given that these compounds may originate from the oxidation of unsaturated fatty acids, they may indicate a greater activity of the enzymes involved in the oxidation process (lipoxygenase and others).

'Songold' is the only cultivar among those studied in which neither the alcohol 2-hexen-1-ol nor the ester 2-hexen-1-ol acetate were present.

No lactones were detected, in contrast to the findings of other authors [8]. Lactones, or cyclic esters, are formed by the cyclisation of hydroxy acids with the loss of one molecule of water. These compounds may be indicative of ripeness because, in some fruits such as apricots and hybrids of apricots and plums, they appear and increase during the ripening process [29]. Perhaps the samples in this study were not fully ripe when they were collected, which might explain the absence of this family of compounds. These plums are intended primarily for export and it is a common practice to harvest them before they are ripe.

Analysis of variance of the volatile fractions reveals significant differences among the cultivars in 15 variables. Of these, four esters clearly differentiate 'Fortune' from the others. The compound 2-methyl-3-buten-2-ol puts 'Larry Ann' in a category of its own, and 2-hexenyl butanoate and 2-hexenyl hexanoate distinguish 'Suplumeleven'.

Conclusions

It may be concluded that this plum has a mean sugar content of 15.16% (between 12.3 and 17.8%), made up primarily of glucose with smaller proportions of sucrose and fructose. Its dietary-fibre content is 1.2% (ranging from 0.84 to 1.50%) and its mean energy value 255 kJ 100 g^{-1} of fresh produce (from 183 to 331 kJ 100 g^{-1}). 'Suplumsix' and 'Larry Ann' are the cultivars with the highest acceptability indices (TSS/acidity) and the latter is that with the greatest firmness. 'Black Amber' stands out as the cultivar with the highest phenolic and anthocyanin contents and the greatest total antioxidant activity.

The number of volatile compounds identified in the present study, together with the area of the peaks obtained, reveals that these cultivars of Japanese plum are relatively poor in volatile compounds, with a volatile fraction composed primarily of esters. 'Fortune' stands out significantly as the cultivar richest in this type of compound. The volatile fractions of the plum cultivars analysed here differ significantly from one another.

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