Available online at www.sciencedirect.com
SCIENCE DIRECT®
Food Chemistry 96 (2006) 273–280
Food Chemistry
www.elsevier.com/locate/foodchem

Selecting new peach and plum genotypes rich in phenolic compounds and enhanced functional properties

Bolívar A. Cevallos-Casals [a], David Byrne [a], William R. Okie [b], Luis Cisneros-Zevallos [a,*]

[a] Department of Horticultural Sciences, Room 202, Texas A & M University, College Station, TX 77843-2133, USA
[b] USDA-ARS Southeastern Fruit and Tree Nut Research Laboratory, 21 Dunbar Road, Byron, GA 31008-7066, USA

Received 29 March 2004; received in revised form 15 February 2005; accepted 15 February 2005

Abstract

Fourteen red-fleshed plum (*Prunus salicina* Erhr. and hybrids) and eight peach [*Prunus persica* (Batsch) L.] genotypes were characterized for their total phenolic and anthocyanin contents. Selected rich phenolic genotypes showed high antioxidant activity, stable colour properties and good antimicrobial activity. Results indicated positive correlations between phenolic compounds ($r^2 = 0.83$) and antioxidant activity for both types of fruit. Colorants prepared from an anthocyanin rich plum genotype showed similar hue to that of synthetic colorant FD&C red 3 and higher stability than a commercial red grape colorant with respect to time, temperature and pH. Additionally, a selected rich phenolic plum genotype exhibited strong antimicrobial activity against *Salmonella* Enteritidis and *Escherichia coli* O157:H7. This study proposes that selection of crops high in phenolic compounds can be related to enhanced functional properties and opens the possibility of breeding fruits with targeted functional properties for the fresh produce and processing market.

Keywords: Anthocyanins; Phenolics; Peach; Plum; Antioxidant activity; Antimicrobial activity; Color stability

1. Introduction

Increasing recent interest in nutraceuticals and functional foods has led plant breeders to initiate selection of crops with higher than normal phenolic antioxidant contents such as blueberries (Prior et al., 1998), potatoes (Reyes, Miller, & Cisneros-Zevallos, 2004), and others (Shim, Park, Lee, & Shetty, 1999; Yoshinaga, Tanaka, & Nakatani, 2000). Similarly, the *Prunus* Breeding Program at Texas A&M University and the USDA Stone Fruit Breeding Program at Byron, GA, are working at developing red-fleshed peaches [*Prunus persica* (Batsch) L.] and plums (*Prunus salicina* Erhr. and hybrids) with high levels of beneficial phenolic compounds for the fresh produce and processing market. All these programmes aim to set the baseline for establishing breeding efforts, with the intention of adding value to fruits and vegetables with respect to the level and diversity of health benefit properties that crops could impart. However, for achieving this goal, information regarding the quantity and functional properties of the phenolic compounds present is needed.

Anthocyanins and other phenolic compounds are responsible for many health benefits (Davidson & Branen, 1981; Duthie, Duthie, & Kyle, 2000; Harborne & Williams, 2000; Moline, Bukharovich, Wolff, & Phillips, 2000; Naidu, 2000; Okuda, 1997; Wang, Cao, & Prior, 1997; Wang et al., 1999). Anthocyanins have been identified as key contributing compounds to antioxidant activity in vitro and in vivo (Igarashi, Takanashi, Makino, & Yasui, 1989; Tsuda, Horio, & Osawa, 1998; Tsuda, Ohshima, Kawakishi, & Osawa, 1994; Wang et al., 1997). Antioxidants are needed for preventing

* Corresponding author. Tel.: +1 979 8453244; fax: +1 979 8450627.
E-mail address: lcisnero@taexgw.tamu.edu (L. Cisneros-Zevallos).

0308-8146/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2005.02.032

degenerative reactions produced by reactive oxygen and nitrogen species in vivo and lipid peroxidation in foods (Cevallos-Casals & Cisneros-Zevallos, 2003). Phenolics have also been found to be natural antimicrobial compounds, which are important for increasing the shelf life of food and inhibiting the growth of pathogenic microorganisms (Bowles & Juneja, 1998; Davidson & Branen, 1981; Naidu, 2000; Payne, Rico-Munoz, & Davidson, 1989; Sofos, Beuchat, Davidson, & Johnson, 1998). In addition, anthocyanins may serve as natural colorant sources and even potential substitutes of synthetic food colorants due to their attractive orange, red and blue hues (Cevallos-Casals & Cisneros-Zevallos, 2004; Francis, 1989; Mazza & Miniati, 1993).

These benefits, among others, make anthocyanin and other phenolic compounds an interesting target for breeding programmes. We propose, in this study, that peach and plum selections, rich in phenolic and anthocyanin compounds, will yield fruits with enhanced functional properties such as antioxidant, colorant and antimicrobial properties.

The specific objectives of this study were (1) to determine the anthocyanin and total phenolic contents, and antioxidant properties of red-fleshed peach and plum genotypes, and (2) to investigate the colorant and antimicrobial properties of selected phenolic rich peach and plum genotypes.

2. Materials and methods

2.1. Materials

Eight red-fleshed peach and 14 red-fleshed plum selections from the USDA Stone Fruit Breeding Program at Byron, GA were used in this study. Fruit samples were collected in July 2000 and shipped overnight to Texas. The endocarp and seed were immediately removed and samples were frozen at −20 °C. DPPH, Folin-Ciocalteu reagent and Mueller-Hinton broth were purchased from Sigma Chemical Co. (St. Louis, Mo., USA), and McIlvaine buffer from Lab Chem Inc. (Pittsburg, PA, USA). Antho-Red Grape concentrate (03880, LOT HH861) was supplied by Warner Jenkinson (St. Louis, Missouri, USA). *Escherichia coli* O157:H7 (ATCC® 43895) was donated by Dr. Elsa Murano (Food Microbiology Laboratory at Texas A&M University, College Station, Texas), while *Salmonella enterica* subsp. *enterica* serotype Enteritidis (ATCC® 13076) was purchased from Key Scientific Products Co. (Round Rock, TX, USA).

Six fruits from each genotype were chosen, at random, for measuring anthocyanin content, total phenolics and antiradical activity. Three replicates, each using two fruits, were analyzed. Additionally, plum fruits were divided into flesh (mesocarp) and skin (exocarp) sections to determine the level of active compounds in these structural parts. All results were expressed on fresh weight basis of the flesh.

2.2. Total phenolics and anthocyanin content

Total soluble phenolic content of methanolic extracts was assayed as described by Cevallos-Casals and Cisneros-Zevallos (2003). Total phenolics were expressed as mg chlorogenic acid equivalent (CGA)/100 g fresh or dry weight, based on a standard curve. Total anthocyanin content was adapted from Fuleki and Francis (1968) by measuring the absorbance of extracts at pH 1, as described by Cevallos-Casals and Cisneros-Zevallos (2003). Hexane was added to peach and plum samples for removing any carotenoids present. Anthocyanins were expressed as mg cyanidin 3-glucoside equivalents/100 g fresh or dry weight, using a molar extinction coefficient of 25,965 M^{-1} cm^{-1} and a molecular weight of 449 g/mol (Abdel-Aal & Hucl, 1999).

2.3. Antiradical activity and kinetic assay

Antiradical activity of phenolic compounds was adapted from Brand-Williams, Cuvelier, and Berset (1995). The same methanol extract as for phenolics was used. A total of 150 μl of sample (equivalent methanol volume to control) reacted with 2850 μl DPPH (98.9 μM in methanol) in a shaker covered with aluminium foil at 25 °C. Readings at 515 nm were taken at 15 min. The change in absorbance was used and results were expressed as trolox equivalents from a standard curve. Readings at 15 min were used for calculation of the relative antiradical capacity (RAC), which indicates the antiradical capacity of the sample compared to trolox for a specific reaction time (for example, 15 min).

Second-order antiradical kinetic determinations were adapted from Espín, Soler-Rivas, Wichers, and García-Viguera (2000) using DPPH and methanolic extracts, as described by Cevallos-Casals and Cisneros-Zevallos (2003). The second-order rate constant (k_2) was obtained by having the antiradical compound (phenolics) in larger amounts than the DPPH, thus forcing the reaction to behave as first-order. From these reactions, pseudo-first-order rate constants (k_1) were obtained. The k_1 was linearly dependent on antiradical concentration, and from the slope of these plots, k_2 was determined. Determinations of k_1 were conducted in triplicate, with five different extract concentrations per sample. Fitting of the experimental data to obtain k_1 was done by using an exponential decay (single, 2 parameter) equation generated by Sigma Plot 2.01 (1994). The specific reaction conditions between DPPH and samples were as follows, 86 μM DPPH and plum extract (0.380–0.476 mg phenolics/ml); 82 μM DPPH and peach extract (0.279–0.332 mg phenolics/ml).

2.4. Chromaticity and colour stability

Plum slices from six fruit were steam-blanched at 100 °C for 10 min, quenched in an ice-water bath, and homogenized with nanopure water in an Ultra-Turrax homogenizer. Denaturation of degrading enzymes was confirmed by measuring peroxidase (POX) activity, as described by Cevallos-Casals and Cisneros-Zevallos (2003). Tube contents were filtered and centrifuged for 15 min at 29,000*g*. Each sample extract (plum and commercial red grape colorant) was prepared at five different pHs (1, 2, 3, 4, 5) with McIlvaine buffer (sodium phosphate dibasic <2%, citric acid <2%, and thymol <0.1%). Each sample was prepared initially at pH 1 with an absorbance (A) reading or tinctorial strength of 0.7–0.8 at the wavelength of maximum absorption in the visible region (λ_{max}). Later, each pH was adjusted with 0.5 N NaOH and 1.5 N HCl. Additionally, sodium azide (0.02%) was added as preservative.

Chromaticity was determined in plum extracts at pH 3, with ~10-fold higher tinctorial strength ($A_{\lambda_{max}} \times$ dilution factor). All analyses for colour stability and chromaticity were done in duplicate. Samples were allowed to equilibrate with the buffer for 1 h at 20 °C before use. Spectrophotometric readings were done using a photo diode array spectrophotometer (model 8452A; Hewlett Packard Co., Waldbronn, Germany). Chromaticity was characterized with a Minolta CT-310 colorimeter (Minolta Corporation, Ramsey, NJ, USA) for translucent liquids (light source "D"). Readings were taken on the prepared colorants inside a 2 mm cell path cuvette. Results were given in Commission Internationale de l'Eclairage L^*, a^*, and b^* (CIELAB) colour space coordinates. Hue ($\tan^{-1}$ b/a) and chroma $[(a^2 + b^2)^{1/2}]$ were calculated from a^* and $^*b$.

The effect of pH on colour stability of plum extracts was performed for 0 and 138 days at 20 °C and for 0 and 2 h at 99 °C (immersed in water bath at 99 ± 1 °C). Samples were inside capped vials covered with aluminium foil and sealed with parafilm. Commercial red grape, a commonly used natural food colorant, was studied for comparison purposes. The absorbance at the wavelength of maximum absorption ($A_{\lambda_{max}}$) was used to monitor colour changes.

2.5. Antimicrobial activity

2.5.1. Material preparation

Fruits were homogenized with methanol in an Ultra-Turrax homogenizer (IKA Works, Inc., Wilmington, NC, USA) to uniform consistency. Tube contents were filtered with cheesecloth and centrifuged for 15 min at 29,000*g*. Then, methanol was evaporated from filtered samples in a vacuum concentrator. Samples were re-diluted with sterile nanopure water to the desired concentrations. Final solutions were filtered with 0.20 μm filters into sterile glass vials.

2.5.2. Spread plate assay

Bacterial solutions of 10^3 cfu/ml were prepared in 0.1% peptone water. The actual number of cells was determined on Trypticase Soy Agar (TSA) plates. In sterile tubes, the extract (sterile nanopure water as control) was mixed with the bacterial solution in a 1:1 ratio. Then, 100 μl of the extract-bacteria solution (100 μl of the water-bacteria solution as control) were spread-plated on TSA plates. Plates were incubated at 35 °C and colonies were counted at 0, 12, 24 and 48 h.

2.5.3. Absorbance assay

Bacteria were diluted in double strength Mueller-Hinton broth to concentrations of 10^3 and 10^5 CFU/ml. One hundred microlitres extract (100 μl sterile water as control) were placed in a well with 100 μl of the diluted bacteria inoculum. Other controls used were extracts incubated with sterile water without the bacteria, for verifying any change in absorbance of the extract. Absorbances at 630 nm were taken for a period of 48 h in a plate reader. Turbidity readings were related to bacterial growth.

2.6. Analysis of variance (ANOVA)

One-way ANOVA was performed using the SAS Statistical Analysis System v8.1 (SAS Institute Inc., Cary, NC, USA). Means were compared by Duncan's multiple range test at $\alpha = 0.05$.

3. Results and discussion

3.1. Total phenolic and anthocyanin contents

Results showed a total phenolic content ranging from 298 to 563 mg CGA/100 g for plums and 100 to 449 mg CGA/100 g for peaches. The anthocyanin content in plums ranged from 33 to 173 mg/100 g, which in general was significantly higher than the anthocyanin content in peaches (6–37 mg/100 g) (Fig. 1). The phenolic content observed in the *Prunus salicina* varieties in our study is higher than that previously reported for *Prunus domestica* varieties (160–300 mg/100 g, Los, Wilska, & Pawlak, 2000) and for other commercial varieties (14–109 mg/100 g, Gil, Tomás-Barberán, Hess-Pierce, & Kader, 2002; 125–373 mg/100 g, Kim, Chun, Kim, Moon, & Lee, 2003). Additionally, the phenolic contents of the plum varieties were comparable to those of blueberries reported previously (292–672 mg CGA/100 g, Cevallos-Casals & Cisneros-Zevallos, 2004).

Plums showed a 3- to 4-fold higher phenolic concentration in the skin than in the flesh. Similarly, the

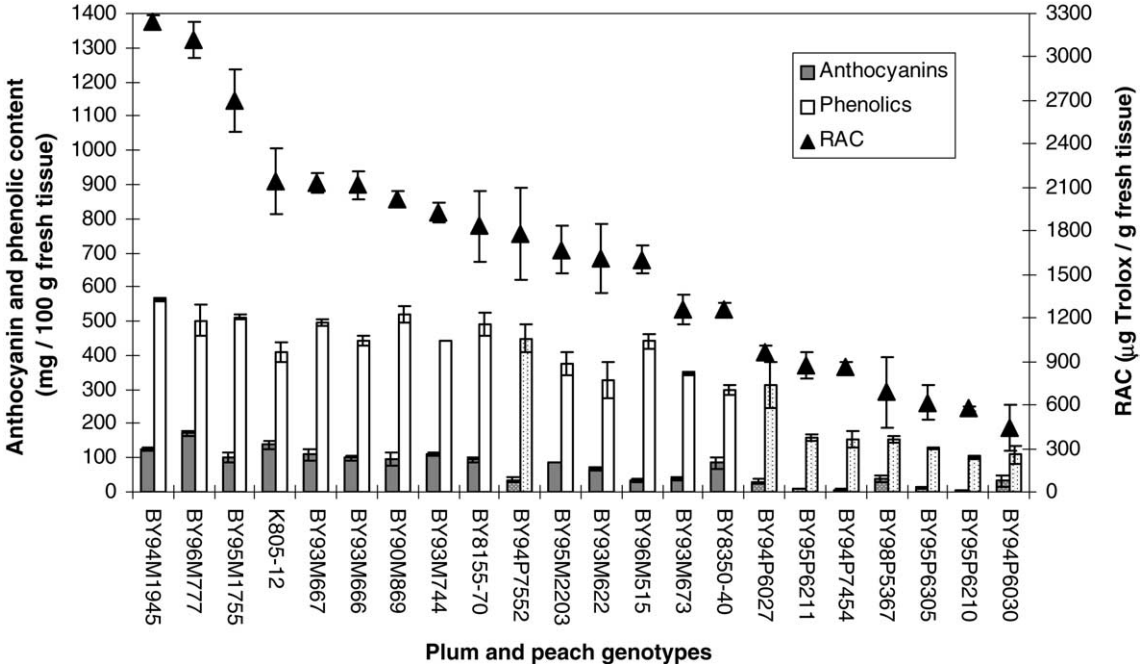

Fig. 1. Total anthocyanins, total phenolics, and RAC of new plum and peach genotypes. Peach genotypes are indicated with dotted bars. Data indicates mean ± SD of three replicates. Each replicate came from two different fruit.

anthocyanin concentration in the skin was 3- to 9-fold higher than in the flesh (Table 1). Even though the exocarp is a concentrated source of phenolic compounds, it only represents 7–9% of the fruit weight. Thus, the total distribution of phenolic compounds in skin and flesh per fruit is ~30% and 70%, respectively.

The main anthocyanins identified in *P. salicina*, the principal species in the genetic background of the studied plums, have been cyanidin 3-glucoside, cyanidin 3-rutinoside and cyanidin 3-xylosylglucosides (sambubioside) (Ahn, 1973; Draetta, Iaderoza, Baldini, & Francis, 1985; Ishikura, 1975; Itoo, Matsuo, Noguchi, & Kodama, 1982). The main anthocyanin identified in *Prunus persica* (peach) has been cyanidin 3-glucoside with contribution of cyanidin 3-rutinoside (Hsia, Luh, & Chichester, 1965; Ishikura, 1975; Van Blaricom & Senn, 1967).

Apart from anthocyanins, several hydroxycinnamates, flavan 3-ols and flavonols, predominantly chlorogenic acid, neochlorogenic acid, catechin, epicatechin, and quercetin 3-rutinoside, have been identified in peaches and plums (Kim et al., 2003; Tomás-Barberán et al., 2001).

3.2. Antioxidant activity and kinetics

The obtained RAC values varied from 1254 to 3244 μg trolox/g for plums and from 440 to 1784 μg trolox/g for peaches (Fig. 1). There was a positive correlation between phenolic content and RAC for the plum and peach genotypes studied, suggesting that phenolic compounds are responsible for the antioxidant activity (Fig. 2). A slightly higher correlation was obtained with

Table 1
Total anthocyanins and total phenolics of plum sections

Plum genotype	Section	Anthocyanin content[d]	Phenolic content[e]	% of total crop weight[f]	% anthocyanin distribution[g]	% phenolic distribution[g]
BY96M777	Skin	872[a] ± 96	2385[a] ± 14	7.2	43.7	30.1
	Flesh	87[c] ± 13	430[c] ± 43	92.8	56.3	69.9
BY94M1945	Skin	344[b] ± 12	2394[a] ± 37	9.3	29.3	30.4
	Flesh	85[c] ± 4	562[b] ± 5	90.7	70.7	69.6

Data indicate means ± SD of three replicates. Each replicate came from two different fruit.
[a–c] Means within a column with the same superscript letter are not significantly different ($p > 0.05$).
[d] In mg cyanidin-3-glucoside equiv./100 g wet basis.
[e] In mg CGA/100 g wet basis.
[f] Total weight does not include the endocarp and seed.
[g] Values indicate the contribution of the section to the total weight of the sample excluding endocarp and seed.

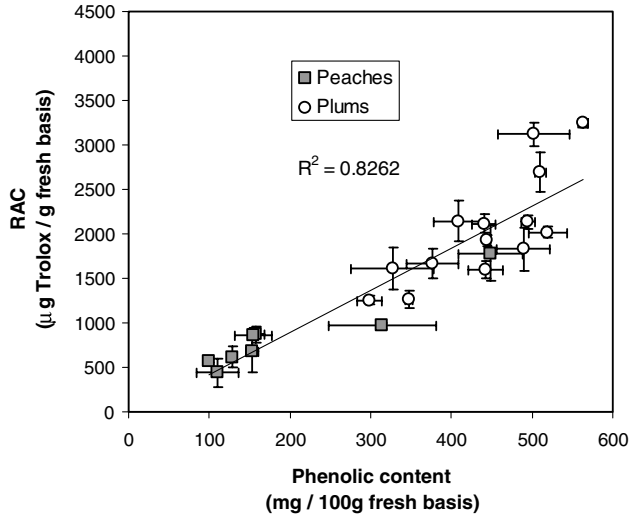

Fig. 2. Effect of phenolic content on the antiradical activity of different peach and plum genotypes. Data indicates mean ± SD of three replicates. Each replicate came from two different fruit.

total phenolics ($r^2 = 0.83$) than with anthocyanins ($R^2 = 0.77$, data not shown). Work by Gil, Tomás-Barberán et al., 2001, on commercial cultivars of nectarines, peaches and plums, showed that phenolics were the only compounds that correlated with antioxidant capacity (when compared with vitamin C and carotenoids).

These correlations are important, since they may serve as tools for crop breeders to select varieties with phenolic compounds high in antioxidant activity.

Selections of peach and plum genotypes may be done by comparison with fruits high in phenolic content, such as blueberry, which is known for its high antioxidant activity (Prior et al., 1998). For example, selected plums (BY94M1945) and peaches (BY94P7552) rich in phenolic contents show high antioxidant activities in our study. On a wet basis, the selected plum and peach have ~91% and 50% the antioxidant activity of blueberry fruit, respectively (Table 2). On a dry basis, the plum shows ~36% higher antioxidant activity than blueberry, while the peach still represents a lower content with ~46% the antioxidant activity of blueberry. However, when comparison is made by antioxidant kinetics (AK), peach shows higher AK than blueberry and plum, indicating that peach phenolic compounds may have faster reaction kinetics against radical species (DPPH radicals used in this study). Antioxidant kinetic studies are important because they indicate how much an antioxidant reduces the rate of oxidation (Shi & Niki, 1998). When compared to the kinetic rates of common antioxidants used in foods, the k_2 of peach obtained in this study was slightly lower than that of BHA (0.42) and higher than that of BHT (0.005), reported in previous work (Espín et al., 2000).

3.3. Colour stability and chromaticity

Selection of plum genotypes high in anthocyanin content may be related to colorant properties, such as colour stability and chromaticity. Colour stability evaluation can be done by comparing with grape extracts, considered a common source of food commercial anthocyanins (Malien-Aubert, Dangles, & Amiot, 2001). For example, a selected plum rich in anthocyanins (BY94M1945) shows higher colour retention than grape extracts when stored at different pHs and temperatures (Table 3). At 25 °C for 138 days, colour losses, for pH 1 and 3 plum extracts, were 21% and 23%, compared to colour losses of 30% and 31% for grape extracts, respectively. Similarly, at 99 °C for 2 h at pHs 1 and 3, colour losses were 17% and 35% for the plum extract, while colour losses were 69% and 30% for grape extracts. Additionally, red grape extracts were completely clear at pH 4 and 5, whereas plum extracts still maintained red coloration (data not shown). Regarding browning, both extracts experienced an increase in $A_{420\ nm}$ with time (Table 3). In general, colour degradation may be due to anthocyanin polymerization, the presence of sugars and their degradation products (Duhard, Garnier, & Megard, 1997). A temperature of

Table 2
Total anthocyanins, total phenolics, RAC, and AK of peach and plum, compared to blueberry

Crop	Dry matter (%)	Anthocyanin content[d]		Phenolic content[e]		RAC[f]		Ak[g]	
		Wet basis	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis	k_2	r^2
Plum BY94M1945	11.1	$125^b \pm 4$	$1127^b \pm 34$	$563^a \pm 6$	$5074^a \pm 50$	$3244^a \pm 46$	$29225^a \pm 414$	0.12^c	0.9997
Peach BY94P7552	18.0	$36^c \pm 5$	$199^c \pm 31$	$449^b \pm 40$	$2493^c \pm 224$	$1784^b \pm 318$	$991\ 1^c \pm 1767$	0.30^a	0.9995
Blueberry[h]	16.5	$276^a \pm 25$	$1675^a \pm 149$	$574^a \pm 35$	$3480^b \pm 212$	$3535^a \pm 216$	$21432^b \pm 1310$	0.26^b	0.9975

Data indicate means ± SD of three replicates. Each replicate came from two different fruit. Data for AK were conducted in triplicate with five different extract concentrations per sample.

[a–c] Means within a column with the same superscript letter are not significantly different ($p > 0.05$).

[d] In mg cyanidin-3-glucoside equiv./100 g.

[e] In mg CGA/100 g.

[f] In µg trolox equiv./g.

[g] Second-order rate constant (k_2) in $(g/l)^{-1}\ s^{-1}$, r^2 denotes the linear fitting of five different sample concentrations to their respective k_1 constants.

[h] Data for dry matter, anthocyanin content, phenolic content and AK of blueberry were taken from Cevallos-Casals and Cisneros-Zevallos (2003).

Table 3
Absorbance at λ_{max} of plum BY94M1945 extracts compared to commercial red grape at different conditions of pH and temperature

		Plum		Red grape	
	pH	1	3	1	3
	λ_{max}	514 nm	516 nm	518 nm	520 nm
Dark 20 °C	0	0.84 (0.29)	0.47 (0.20)	0.68(0.13)	0.16(0.07)
	138 days	0.66 (0.37)	0.36 (0.41)	0.47(0.15)	0.11(0.10)
Dark 99 °C	0	0.88 (0.31)	0.48 (0.20)	0.65(0.13)	0.13(0.05)
	2 h	0.73 (0.80)	0.31 (0.28)	0.20(0.10)	0.09(0.07)

Values in parentheses show the absorbances of extracts at 420 nm, an indicator of browning.

99 °C was chosen to reflect a severe heat treatment during thermal food processing operations (e.g., blanching, pasteurization, cooking).

Chromaticity evaluation was done by comparing with synthetic colorants red #3 and red #40, considered common commercial red colorants (Rodríguez-Saona, Giusti, & Wrolstad, 1998). For example, the selected plum rich in anthocyanins, formed extracts with similar hue to red #3 and slightly lower hue than red #40, at similar tinctorial strengths at pH 3 (Table 4). Lightness was similar and chroma lower than both synthetic colorants. Changing conditions of pH and tinctorial strength may aid in adjusting the chromaticity of the natural extracts to those of the synthetic colorants (Rodríguez-Saona et al., 1998).

3.4. Antimicrobial activity

Selection of plum genotypes high in phenolic content may also be related to antimicrobial properties. The antimicrobial evaluation can be done against human pathogens of significant importance to the food industry (Davidson & Parish, 1989). For example, a selected plum rich in phenolic compounds (BY96M777) had inhibitory effects against *Escherichia coli* 0157:H7 and *Samonella* Enteritidis (Fig. 3). For the absorbance assay, results showed that a phenolic concentration of 2.6 mg/ml would inhibit growth of both microorganisms, while 0.26 mg/ml had only a slight or no effect. On the other hand, for the spread plate assay, 5.6 mg/ml plated solution (~0.56 mg/plate) were needed to affect microbial growth. In general, for both assays, plum phenolics (on similar content basis) were more effective against *Salmonella* Enteritidis than against *Escherichia coli* O157:H7.

Both, the absorbance assay and the spread plate assay, showed a lag, log and stationary phase within 50 h. The selection of the assay may be related to the resemblance to the food matrix where the antimicrobial is intended to be used. In the absorbance assay, antimicrobials interact with microorganisms in a liquid matrix, as opposed to a semi-dry environment in the spread plate technique.

It has been shown that phenolic compounds, including anthocyanins, have antimicrobial activity (Beuchat & Golden, 1989; Davidson & Branen, 1981). Chlorogenic acid (3-caffeyl-quinic) has been shown to have strong antimicrobial activity (Davidson & Branen, 1981), and is usually present in plums in high amounts. The active portion of chlorogenic acid, according to Grodzinska-Zachwieja and Kahl (1966), is caffeic acid, a hydroxycinnamic acid. Several hydroxycinnamic acid derivatives have been found to have antimicrobial effects against several microorganisms, including *E. coli* (Baranowski, Davidson, Nagel, & Branen, 1980; Leifertova, Hejtmankova, Hlava, Kudrnacova, & Santavy, 1975; Valle, 1957). The general mechanism of antimicrobial activity may involve a reaction with the cell membrane or inactivation of essential cellular enzymes or a combination of the two (Davidson & Branen, 1981). Previous studies have suggested that the reactive portion of antimicrobial phenolic compounds may be the free hydroxyl group (Prindle & Wright, 1977).

In conclusion, through breeding programmes, crops may constantly be improved to have improved functional properties. The selection of crops rich in phenolic compounds, with enhanced antioxidant, antimicrobial and colorant properties, would be a first step. In this study, different assays were used to characterize these three major phenolic properties in new peach and plum genotypes. The resulting selected fruits, rich in phenolic compounds and functional properties, may be used for the fresh produce and processing market. For the latter, fruit extracts or juices may have GRAS (Generally Recognized As Safe) status and may be potential food ingredients for protecting food and consumers and for imparting colour.

Table 4
Chromaticity parameters of plum BY94M1945 extracts compared to FD&C red 40 and FD&C red 3

Colorant	pH	*L*	Hue	Chroma	Tinctorial strength
Red 40[a]	3	72	39	70	9.0
Red 3[a]	3	71	25	73	7.2
Plum	3	71	23	53	10.6

[a] Data for red 40 and red 3 taken from Cevallos-Casals and Cisneros-Zevallos (2004).

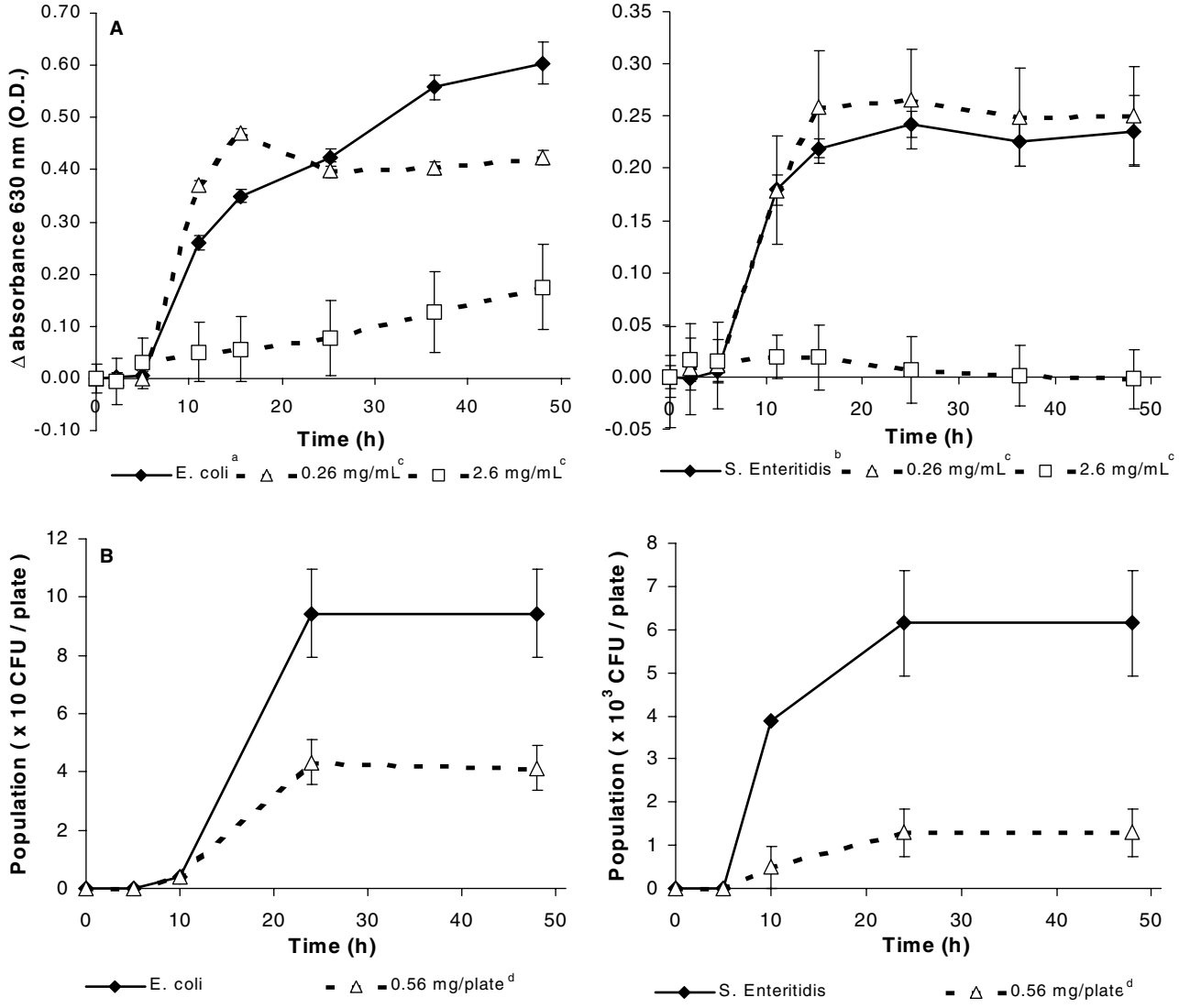

Fig. 3. Effect of plum BY96M777 extracts on the growth of *Escherichia coli* O157:H7 and *Salmonella* Enteritidis with two different assays: (A) absorbance assay and (B) spread plate assay. [a,b]Initial microbial concentrations (CFU/mL): [a]10^3, [b]10^5. [c] Plum concentrations in mg CGA/mL solution. [d]Plum concentrations in mg CGA/plate. Data indicates mean ± SD of three replicates with three repetitions for each replicate.

References

Abdel-Aal, E.-S. M., & Hucl, P. (1999). A rapid method for quantifying total anthocyanins in blue aleurone and purple pericarp wheats. *Cereal Chemistry, 76*, 350–354.

Ahn, S. Y. (1973). Studies on the identification of anthocyanins in plums. *Journal of the Korean Agricultural Chemical Society, 16*, 53.

Baranowski, J. D., Davidson, P. M., Nagel, C. W., & Branen, A. L. (1980). Inhibition of *Saccharomyces cerevisiae* by naturally occurring hydroxycinnamates. *Journal of Food Science, 45*, 592–594.

Beuchat, L. R., & Golden, D. A. (1989). Antimicrobials occurring naturally in foods. *Food Technology, 43*, 134–142.

Bowles, B. L., & Juneja, V. K. (1998). Inhibition of foodborne bacterial pathogens by naturally occurring food additives. *Journal of Food Safety, 18*, 101–112.

Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *Lebensmittel Wissenschaft Technologie, 28*, 25–30.

Cevallos-Casals, B. A., & Cisneros-Zevallos, L. (2003). Stoichiometric and kinetic studies of phenolic antioxidants from Andean purple corn and red-fleshed sweetpotato. *Journal of Agricultural and Food Chemistry, 51*, 3313–3319.

Cevallos-Casals, B. A., & Cisneros-Zevallos, L. (2004). Stability of anthocyanin-based aqueous extracts of Andean purple corn and red-fleshed sweetpotato compared to synthetic and natural colorants. *Food Chemistry, 86*, 69–77.

Davidson, P. M., & Branen, A. L. (1981). Antimicrobial activity of non-halogenated phenolic compounds. *Journal of Food Protection, 44*, 623–632.

Davidson, P. M., & Parish, M. E. (1989). Methods for testing the efficacy of food antimicrobials. *Food Technology, 43*, 148–155.

Draetta, I. S., Iaderoza, M., Baldini, V. L. S., & Francis, F. J. (1985). Antocianinas de ameixa (*Prunus salicina* L.). *Ciencia y Tecnología de Alimentos, 5*, 31.

Duhard, V., Garnier, J.-C., & Megard, D. (1997). Comparison of the stability of selected anthocyanin colorants in drink model systems. *Agro Food Industry Hi-Tech, 8*, 28–34.

Duthie, G. G., Duthie, S. J., & Kyle, J. A. M. (2000). Plant polyphenols in cancer and heart disease: implications as nutritional antioxidants. *Nutrition Research Reviews, 13*, 79–106.

Espín, J. C., Soler-Rivas, C., Wichers, H. J., & García-Viguera, C. (2000). Anthocyanin-based natural colorants: a new source of antiradical activity for foodstuff. *Journal of Agricultural and Food Chemistry, 48*, 1588–1592.

Francis, F. J. (1989). Food colorants: anthocyanins. *Critical Reviews in Food Science and Nutrition, 28*, 273–314.

Fuleki, T., & Francis, F. J. (1968). Quantitative methods for anthocyanins. 1. Extraction and determination of total anthocyanin in cranberries. *Journal of Food Science, 33*, 72–77.

Gil, M. I., Tomás-Barberán, F. A., Hess-Pierce, B., & Kader, A. A. (2002). Antioxidant capacities, phenolic compounds, carotenoids, and vitamin C contents of nectarine, peach, and plum cultivars from California. *Journal of Agricultural and Food Chemistry, 50*, 4976–4982.

Grodzinska-Zachwieja, Z., & Kahl, W. (1966). Bacteriostatic action of chicory (*Cichorium intybus* L.) II. The action of chlorogenic and isochlorogenic acid. *Acta Biologica Cracoviensia Serie Botanique, 9*, 87–95.

Harborne, J. B., & Williams, C. A. (2000). Advances in flavonoid research since 1992. *Phytochemistry, 55*, 481–504.

Hsia, C. L., Luh, B. S., & Chichester, C. O. (1965). Chemistry of anthocyanin in freestone peaches. *Journal of Food Science, 30*, 5.

Igarashi, K., Takanashi, K., Makino, M., & Yasui, T. (1989). *Journal of Japanese Society of Food Science and Technology, 36*, 852.

Ishikura, N. (1975). A survey of anthocyanins in some angiosperms. *Botanical Magazine, 88*, 41–45.

Itoo, S., Matsuo, T., Noguchi, K., & Kodama, K. (1982). The qualities of subtropical fruits. III. Anthocyanin pigment of Japanese plum (*Prunus salicina* Lindl.) cv. Karari. *Kagoshima Daigaku Nogakubu Gakujutsu Hokoku, 32*, 35.

Kim, D.-O., Chun, O. K., Kim, Y. J., Moon, H.-Y., & Lee, C. Y. (2003). Quantification of polyphenolics and their antioxidant capacity in fresh plums. *Journal of Agricultural and Food Chemistry, 51*, 6509–6515.

Leifertova, I., Hejtmankova, N., Hlava, H., Kudrnacova, J., & Santavy, F. (1975). Antifungal and antibacterial effects of phenolic substances: a study of the relationship between the biological activity and the constitution of the investigated compounds. *Acta Universitatis Palackiae Olomucensis Facultatis Medicae, 74*, 83–101.

Los, J., Wilska, J. J., & Pawlak, M. (2000). Polyphenolic compounds of plums (*Prunus domestica*). *Polish Journal of Food Nutrition Sciences, 9/50*, 35–38.

Malien-Aubert, C., Dangles, O., & Amiot, M. J. (2001). Color stability of commercial anthocyanin-based extracts in relation to the phenolic composition. Protective effects by intra- and intermolecular copigmentation. *Journal of Agricultural and Food Chemistry, 49*, 170–176.

Mazza, G., & Miniati, E. (1993). Introduction. In *Anthocyanins in fruits, vegetables, and grains* (pp. 1–28). Boca Raton, FL: CRC Press [Chapter 1].

Moline, J., Bukharovich, I. F., Wolff, M. S., & Phillips, R. (2000). Dietary flavonoids and hypertension: is there a link?. *Medical Hypotheses, 55*, 306–309.

Naidu, A. S. (2000). *Natural food antimicrobial systems*. Boca Raton, FL: CRC Press.

Okuda, T. (1997). Phenolic antioxidants. In *Food and free radicals* (pp. 31–48). New York, NY: Plenum Press.

Payne, K., Rico-Munoz, E., & Davidson, P. (1989). The antimicrobial activity of phenolic compounds against *Listeria monocytogenes* and their effectiveness in a model milk system. *Journal of Food Protection, 53*, 151–153.

Prindle, R. F., & Wright, E. S. (1977). Phenolic compounds. In *Disinfection, sterilization, and preservation* (pp. 219–251). Philadelphia: Lea and Febiger.

Prior, R. L., Cao, G. H., Martin, A., Sofic, E., Mcewen, J., Obrien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G., & Mainland, C. M. (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of *vaccinium* species. *Journal of Agricultural and Food Chemistry, 46*, 2686–2693.

Reyes, L. F., Miller, J. C., Jr., & Cisneros-Zevallos, L. (2004). Environmental conditions influence the content and yield on anthocyanins and total phenolics in purple and red-flesh potatoes during tuber development. *American Journal of Potato Research, 81*, 187–193.

Rodríguez-Saona, L. E., Giusti, M. M., & Wrolstad, R. E. (1998). Anthocyanin pigment composition of red-fleshed potatoes. *Journal of Food Science, 63*, 458–465.

Shi, H., & Niki, E. (1998). Stoichiometric and kinetic studies on *Ginkgo biloba* extract and related antioxidants. *Lipids, 33*, 365–370.

Shim, K. B., Park, C. H., Lee, B. H., & Shetty, K. (1999). Selection of higher level of antioxidants producing rosemary (*Rosmarinus officialis* L.) clone by inoculation of *Pseudomonas* sp. *Journal of the Korean Society of International Agriculture, 11*, 325–330.

Sigma Plot 2.01 for Windows. (1994). Jandel Scientifi. Corte Madera, CA.

Sofos, J. N., Beuchat, L. R., Davidson, P. M., & Johnson, E. A. (1998). Naturally occurring antimicrobials in food. *Regulatory Toxicology and Pharmacology, 28*, 71–72.

Tomás-Barberán, F. A., Gil, M. I., Cremin, P., Waterhouse, A. L., Hess-Pierce, B., & Kader, A. A. (2001). HPLC-DAD-ESIMS analysis of phenolic compounds in nectarines, peaches, and plums. *Journal of Agricultural and Food Chemistry, 49*, 4748–4760.

Tsuda, T., Horio, F., & Osawa, T. (1998). Dietary cyanidin 3-*O*-glucoside increases ex vivo oxidation resistance of serum in rats. *Lipids, 33*, 583–588.

Tsuda, T., Ohshima, K., Kawakishi, S., & Osawa, T. (1994). Antioxidative pigments isolated from the seeds of *Phaseolus vulgaris* L. *Journal of Agricultural and Food Chemistry, 42*, 248–251.

Valle, E. (1957). On anti-fungal factors in potato leaves. *Acta Chemica Scandinavica, 11*, 395.

Van Blaricom, L. O., & Senn, T. L. (1967). Anthocyanin pigments in freestone peaches in the southeast. *Proceedings of the American Society of Horticultural Sciences, 90*, 541.

Wang, H., Cao, G. H., & Prior, R. L. (1997). Oxygen radical absorbing capacity of anthocyanins. *Journal of Agricultural and Food Chemistry, 45*, 304–309.

Wang, H., Nair, M., Strasburg, G., Chang, Y., Booren, A., Gray, J., et al. (1999). Antioxidant and antiinflammatory activities of anthocyanins and their aglycon, cyanidin from tart cherries. *Journal of Natural Products, 62*, 294–296.

Yoshinaga, M., Tanaka, M., & Nakatani, M. (2000). Changes in anthocyanin content and composition of developing storage root of purple-fleshed sweet potato (*Ipomoea batatas* (L.) Lam). *Breeding Science, 50*, 59–64.