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ORIGINAL PAPER

Use of Banana Peel Extract To Stabilise Antioxidant Capacity and Sensory Properties of Orange Juice During Pasteurisation and Refrigerated Storage

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Abstract Banana peel extract (BPE) was added to freshly squeezed orange juices (FSJ) and orange juices from concentrate (JFC), in order to evaluate if it stabilises their antioxidant activity, sensory attributes and physicochemical characteristics after heat treatment and during refrigerated storage. Mild pasteurisation increased shelf life in refrigeration for both types of orange juice, although JFC was more stable than FSJ. Antioxidant activity, determined as $ABTS^{\bullet+}$ scavenging capacity, tends to decrease with refrigeration time. However, when BPE was added, pasteurised juices tend to have greater capacity to scavenge $ABTS^{\bullet+}$ over time. No relevant effects were observed on the capacity to inhibit lipid peroxidation. Panellists found it extremely difficult to detect differences between juices with BPE and conventional ones. Moreover, panellists found the juices with BPE were more acceptable than conventional ones, although some modifications became more evident over time. The sensory quality of the JFC remained more stable during storage than that of FSJ. Juice colour changed slightly after heat treatment, but these changes tended to disappear over time. Adding BPE increased the total soluble solid content in all FSJ and in unpasteurised JFC. Adding BPE or pasteurising did not produce significant changes in pH in either type of juice. An increase of pH and acidity was detected in all the FSJ (except in acidity of juices without BPE) with time of refrigeration.

Keywords Mild pasteurisation · Refrigeration · Value addition · Banana peel · Sensory analysis · Antioxidant capacity

Introduction

Adding natural antioxidants to foods can help protect them from oxidation, increasing their shelf life. Sultana et al. (2007) pointed out that the antioxidant potential of corn cob extracts could stabilise corn oil subjected to heat treatment. Reddy et al. (2005) described how adding different plant extracts to biscuits improved their sensory characteristics and antioxidant activity during storage, when compared to biscuits with the synthetic antioxidant butylated hydroxyanisole. The antioxidant capacity of commercial chicken soup increased when it was enriched with polyphenolic extracts from artichoke, lettuce and cauliflower biowastes (Llorach et al. 2005). Hwang et al. (2009) pointed out that adding wine lees, at a concentration of 50 g/kg, improved the rheological characteristics of ice cream and also provided it with antioxidant properties. Adding grape seed extract prior to cooking significantly improved the oxidative stability of turkey breast meat during heat treatment and storage (Mielnik et al. 2006). Grape antioxidant dietary fibre obtained from pomace effectively inhibited lipid oxidation in raw and cooked chicken hamburgers (Sáyago-Ayerdi et al. 2009) and minced fish muscle during frozen storage (Sánchez-Alonso et al. 2008), without affecting their quality.

Fruit juices constitute excellent food matrices for the production of functional foods. Some recent studies have shown that the beneficial properties of fruit juices can be increased by

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adding antioxidant sources (Corbo et al. 2014; Sánchez-Bel et al. 2015). The quality of orange juice is mainly related to its vitamin C content, colour and flavour. The sensory and nutritional properties of orange juice, and consequently its shelf life, can deteriorate due to many factors, such as initial product quality, processing conditions and packaging properties (Bai et al. 2013). The major changes that occur during storage are the development of off-flavours and browning (Berlinet et al. 2006). Vitamin C is degraded by oxidative and non-oxidative pathways, which results in a decrease in antioxidant capacity, as well as nutritional and/or organoleptic losses (Berlinet et al. 2006; Bacigalupi et al. 2013).

Banana (*Musa acuminata* Colla AAA) peel is being investigated as a natural alternative to synthetic food additives (Ross and Kasum 2002; Ayala-Zavala et al. 2011; Agourram et al. 2013; Pereira and Maraschin 2015; Ortiz et al. 2017). Recently, Biswas et al. (2015) studied the influence of novel bioactive compounds from selected fruit biowastes and plant materials, including apple and cooking banana (*Musa* sp.) peel, on the quality and storability of cooked poultry meat wafer. All biowastes showed a good capacity to scavenge free radicals; therefore, they could be considered as functional ingredients. Moreover, the sensorial analysis for all treated samples was considered more acceptable by the taste panel members even at the end of the storage.

However, adding antioxidants derived from biowaste to food entails some difficulties. For instance, during industrial processing or storage, the sensory quality of food with biowaste added may be affected by modification of antioxidant compounds or microbial deterioration. Therefore, it is necessary to establish the lowest amount of biowaste that has a practical application; in a previous paper (Ortiz et al. 2017), our research group determined that between 3.8 and 5 mg of banana peel extract (BPE) per millilitre of orange juice achieved the maximum antioxidant activity without undesirable sensory and physicochemical changes. In this paper, the addition of BPE to freshly squeezed orange juice (FSJ) and orange juice from concentrate (JFC) was evaluated in order to preserve the quality (antioxidant activity, sensory attributes and physicochemical characteristics) of these orange juices during heat treatment (mild pasteurisation) and refrigerated storage.

Materials and Methods

Obtaining the Extract from Banana Peel

Banana (*M. acuminata* Colla AAA, cv. 'Grande Naine') bunches were obtained from the research fields of the Instituto Canario de Investigaciones Agrarias (Tenerife, Spain). The second hand from the proximal end of each bunch (n = 21) was selected, artificially ripened and stored at 18 °C and 80–90% relative humidity until full-ripeness or stage 6 in the von Loesecke banana colour scale was reached. The ripeness stage of fruits was characterised in the middle finger of the outer whorl of each banana hand (González-Montelongo et al. 2010a). After ripening, peels were manually separated (peel/banana ratio w/w, 38 ± 4%), cut into small pieces (0.5 × 1 mm) and freeze dried at 50 mPa and −40 °C (Christ alpha 1-4 LSC freeze-dryer, Osterode, Germany). The dried banana peel was ground to a fine powder (6.3% >500 μm; 93.2% between 20 and 500 μm; 0.5% <20 μm) and stored at −20 °C until the extractions were carried out.

To obtain the BPE, freeze-dried peel powder and methanol (Scharlau Chemie, Barcelona, Spain) (peel/solvent ratio w/v, 1:7) were homogenised with a Politron PT-6000 (Kinematica AG, Lucerne, Switzerland) high-speed blender at 12,000×g for 1 min and centrifuged at 5000×g for 20 min in a Jouan CR-312 centrifuge (Thermo Electron Corporation, Madrid, Spain). This procedure was repeated three times (González-Montelongo et al. 2010b). The extracts were evaporated to dryness in a Heto VR-1 vacuum evaporator (Allerod, Denmark) at 37 °C for 24 h, obtaining a viscous brown residue (dry extract). The extract yield was 44 ± 12 g extract/100 g banana peel on a dry matter basis (DW). The extraction process was performed as many times as required to obtain the amount of extract needed to add to the juices. Finally, the banana peel dry extract was dissolved in orange juice until the concentration to be assayed was obtained. A concentration of 3.8 mg BPE/ml orange juice was selected, which increases the antioxidant activity of the orange juices without generating undesirable modifications (Ortiz et al. 2017).

Obtaining the Orange Juices

The FSJ was obtained from oranges (*Citrus sinensis* L. Osbeck, cv. 'Washington Navel') provided by the Cooperativa de Tejina (Tenerife, Spain). The maturity stage of the oranges (n = 8) was characterised by the colour of the peel (measured in three points along the equatorial axis; lightness L^* 79 ± 4, hue angle $h°$ 89 ± 6 and chromaticity C^* 76 ± 4) and the edible part (measured in three different points; L^* 46 ± 2, $h°$ 99 ± 2 and C^* 28 ± 4), total soluble solids (TSS) 11.4 ± 0.1 °Brix, pH 3.21 ± 0.1 and titratable acidity 1.25 ± 0.05 g citric acid/ml juice. The oranges were hand squeezed (Philips Cucina, Madrid, Spain) always by the same person and by exerting the same pressure, in order to obtain juice from only the edible part of the fruit without reaching the albedo. The yield of the extraction process was approximately 0.4 l juice/kg oranges (with 79 ± 5 mg pulp/ml juice).

The JFC was prepared from Nova America S.A. orange juice concentrate (Santa Cruz do Rio Pardo, Brazil) (TSS, 66 ± 1 °Brix; citric acid, 4.2 ± 0.2%; pH, 3.8 ± 0.1; TSS/acidity ratio, 16 ± 1; pulp, 10 ± 1%) provided by EIASA (Tenerife, Spain). Orange juice was reconstituted with water

and ascorbic acid (Sigma, Madrid, Spain) was added according to the formula used by EIASA. Both FSJ and JFC were homogenised and packed in sterile amber glass bottles (121 °C for 30 min) of 250 ml, leaving a minimum headspace volume.

Pasteurisation Treatment and Refrigerated Storage

The behaviour of the orange juice after pasteurisation and refrigerated storage time was studied in FSJ and JFC. BPE was added to 25 l of FSJ (obtained from 60 kg of oranges) and 25 l of JFC. The addition of plant extracts rich in antioxidants is justified in a high value-added product; a mild thermal treatment was applied in order to preserve the hygienic-sanitary quality of the functionalised juice, decreasing the thermal degradation of the antioxidants: 62 ± 1 °C for 30 min in temperature-controlled Grant Instruments Y38 water baths (Cambridge, UK). The pasteurisation temperature was checked in a control bottle by using a Hanna Instruments MiniTherm HI-8751 digital thermometer (Eibar, Spain). After pasteurisation, the juice was rapidly cooled by immersion in water at 4 °C. Juice with no extract added (conventional juice, unpasteurised and pasteurised) was used as a control. Then, both pasteurised and unpasteurised orange juices (controls and juices with extract added) were immediately stored at 5 °C. Although the shelf life observed for each kind of orange juice was variable [between 7 (for unpasteurised FSJ) and 45 days (for pasteurised JFC), which were estimated on the basis of the modification of sensory attributes in-nose and in-mouth as a consequence of microbiological alterations or oxidation], they were all long enough to evaluate changes that occurred in the functionalised orange juice due to heat treatment and/or refrigerated storage.

Determination of the Quality Parameters

All analyses were done in triplicate in independent replicates.

Antioxidant Activity

In order to evaluate the capacity of orange FSJ and JFC to scavenge free radicals, two methods were used based on the formation of stable free radicals such as 2,2-diphenyl-1-picrylhydrazyl DPPH and 2,2′-azino-bis-(3-ethylbenzothiazoline)-6-sulfonic acid ABTS. The capacity to scavenge the DPPH (Sigma) radical was monitored according to a slightly modified version of the method used by Brand-Williams et al. (1995) at 515 nm after 15 min. The capacity to scavenge the ABTS radical was determined by a method (Arnao et al. 2001) based on enzymatic generation of the radical by reaction of the ABTS (Sigma) with horseradish peroxidase [type VI, RZ (A403 nm/A275 nm) = 2.8, Sigma] in sodium phosphate buffer, pH 7.5, in the presence of hydrogen peroxide (Sigma). The assay temperature was controlled at 25 °C and the inhibition by the juice antioxidants was measured at 730 nm after 6 min. In both methods, the results were expressed as gram trolox (Aldrich, Madrid, Spain) equivalents (TE) per 100 ml of juice (González-Montelongo et al. 2010a).

The capacity to inhibit lipid peroxidation was evaluated using the β-carotene bleaching method, which is based on the capacity of antioxidants to decrease the loss of β-carotene (Aldrich) in a β-carotene/linoleic acid (Sigma) emulsion (Miller 1971). To induce auto-oxidation, the temperature was increased (50 °C) and oxygenated deionised water was used, which was generated by bubbling air into water for 60 min. In these conditions, β-carotene molecules lose their conjugated double bonds, causing a loss in orange colour intensity that was measured at 470 nm after incubation for 210 min. The antioxidant activity was expressed as milligram TE per 100 ml of juice (González-Montelongo et al. 2010a).

Sensory Analysis

Sensory analyses of the orange juice were carried out in a standardised test room in the Instituto Canario de Calidad Agroalimentaria (Tenerife, Spain). The sensory panel was made up of 12 experts in sensory analysis (wine and honey). Each juice sample (40 ml) was served to the panellists in wine-testing glasses, at a serving temperature of 13 ± 2 °C and coded with a random number composed of three digits.

Prior to carrying out the sensory evaluation, the panellists were trained on the sensory characteristics of the conventional product (juice with no BPE added) and on the methodology of the tests. In addition, the criteria used to evaluate the quality of the juices and the recognition of perceived sensations were discussed. Moreover, different reference standards meant to reproduce the visual characteristics (colour, turbidity and browning) of the orange juice were evaluated during training. The colour range was based on oranges in different ripening stages. The turbidity reference ranges (one for FSJ and another for JFC) were obtained by adding different amounts of orange pulp (between 25 and 360 mg) to the liquid resulting (final volume 25 ml) from juice centrifugation at 5000×*g* for 10 min. Both types of juices were maintained at 70 °C for variable times (1–7 days) to provoke different browning ranges. All ranges were characterised by colour and, in the case of turbidity, by their transmittance at $\lambda = 600$ nm.

Descriptive tests were used to evaluate the different orange juices considered; the panellists provided a simple description of the samples that were detected as different, focusing on what they thought were the sensory differences between conventional juice and juice with BPE. The sensory characteristics described were visual appearance (colour, turbidity and browning), odour or in-nose sensation (characteristic aroma and off-odour) and overall flavour or in-mouth sensation (characteristic flavour and off-flavour) of the juices. Rather

than using scores, the panellists wrote down what they understood as the specific differences in the samples and how extreme those differences were; they also discussed how easy/difficult it was to detect the differences. They also indicated their opinion of each sensory characteristic, defining each as positive, negative or unimportant.

Physicochemical Analysis

Colour was measured with a Minolta Chroma meter CR-300 (Minolta Corp., Ramsey, NJ, USA) colour difference meter, using attributes L^*, $h°$ and C^*. TSS was determined using an Atago ATC-1 (Tokyo, Japan) hand refractometer and pH was measured by a WTW (St. Woburn, MA, USA) pH meter. After determining the pH, titratable acidity (g citric acid/ml juice) was measured with a 0.1 N sodium hydroxide standard solution (Merck, Darmstadt, Germany) up to pH 8.1.

Statistical Analysis

Data analysis was carried out using Statgraphics-Plus 5.1 software (Statistical Graphics, Rockville, MD, USA). The statistical analysis was carried out for three independent replicates. Grubbs' test was applied to detect outliers in the data set and analysis of variance was used to evaluate how extract concentration affected the quality of the juice. Fisher's least-significant-difference test, at the 5% significance level, was applied to experimental results to assess intra-pair significant differences.

Results and Discussion

In a recently published paper (Ortiz et al. 2017), our research group established the dose (3.8 mg/ml) of BPE that can be added to orange juices to achieve some antioxidant activity without any risk of undesirable sensory and physicochemical changes compared to juice with no BPE added. In this paper, the addition of BPE to FSJ and JFC was evaluated in order to stabilise the antioxidant activity, sensory attributes and physicochemical characteristics of these orange juices during mild pasteurisation and refrigerated storage.

Antioxidant Activity

A natural loss or improvement of antioxidant activity due to formation of pro-oxidant compounds or compounds with antioxidant properties can occur (Polydera et al. 2005) during processing or storage of orange juice. Unpasteurised FSJ had a very short shelf life (7 days) in refrigeration. When these orange juices were heat treated with a non-industrial pasteurisation process, the shelf life increased to approximately 30 days. The capacity to scavenge DPPH radicals in unpasteurised FSJ with BPE was 22% higher ($P < 0.050$) than that of conventional unpasteurised FSJ, after 7 days of storage (Fig. 1a). After 15 days of refrigeration, unpasteurised orange FSJ with and without BPE had a similar capacity to scavenge DPPH radicals. On the other hand, this capacity remained virtually constant in pasteurised FSJ over time regardless of whether or not BPE was added (Fig. 1b). Sánchez-Moreno et al. (2005) noted that the capacity to scavenge DPPH of orange FSJ was not modified by pasteurisation (70 °C/30 s), which is reasonably in accordance with the results obtained in this work. In general, neither adding BPE nor pasteurisation seemed to affect the capacity of FSJ to scavenge ABTS radicals (Fig. 1c, d). However, it should be emphasised that antioxidant activity after 30 days of storage was 21% lower ($P < 0.050$) in conventional juices than in those with BPE added. Therefore, after 30 days of storage, the capacity to scavenge ABTS radicals was 49 and 33% lower than that initially observed for pasteurised FSJ without and with BPE, respectively (Fig. 1d). This agrees with the results reported by Polydera et al. (2005), who found that the capacity of pasteurised (80 °C, 60 s) orange FSJ to scavenge ABTS radicals decreased during storage at 5 °C.

No significant changes in the capacity to scavenge DPPH radicals in unpasteurised orange JFC with and without BPE were observed during the refrigerated storage time (Fig. 2a). Adding BPE to pasteurised orange JFC slightly increased ($P < 0.050$) its capacity to scavenge DPPH radicals after 21 and 30 days of refrigerated storage (Fig. 2b). However, a similar capacity to scavenge DPPH radicals was observed in JFC with and without BPE added. On the other hand, unpasteurised orange JFC with BPE added tended to have greater capacity to scavenge ABTS radicals than conventional juices after refrigerated storage, with significant differences the 15th day of refrigeration (Fig. 2c); however, the opposite effect occurred ($P < 0.050$) after 30 days in refrigeration. A similar behaviour was found in pasteurised orange JFC with BPE. These juices increased ($P < 0.050$) their capacity to scavenge ABTS radicals after 7 and 15 days of cold storage. However, after a refrigerated storage time equal or greater than 21 days, these differences disappeared and the antioxidant activity (ABTS radicals) remained similar to that of conventional juice (Fig. 2d). During refrigerated storage, the capacity to scavenge ABTS radicals of unpasteurised and pasteurised orange JFC decreased more when BPE was added than when it was not added (Fig. 2c, d). Adding BPE did not produce any significant changes in the capacity to inhibit lipid peroxidation in both pasteurised and unpasteurised orange FSJ and JFC.

Sensory Evaluation

Between 7 and 15 days, dramatic modifications of sensory attributes in-nose and in-mouth emerged, in unpasteurised FSJ, as a consequence of microbiological alterations. These unacceptable alterations marked its shelf life. In the descriptive test, panellists

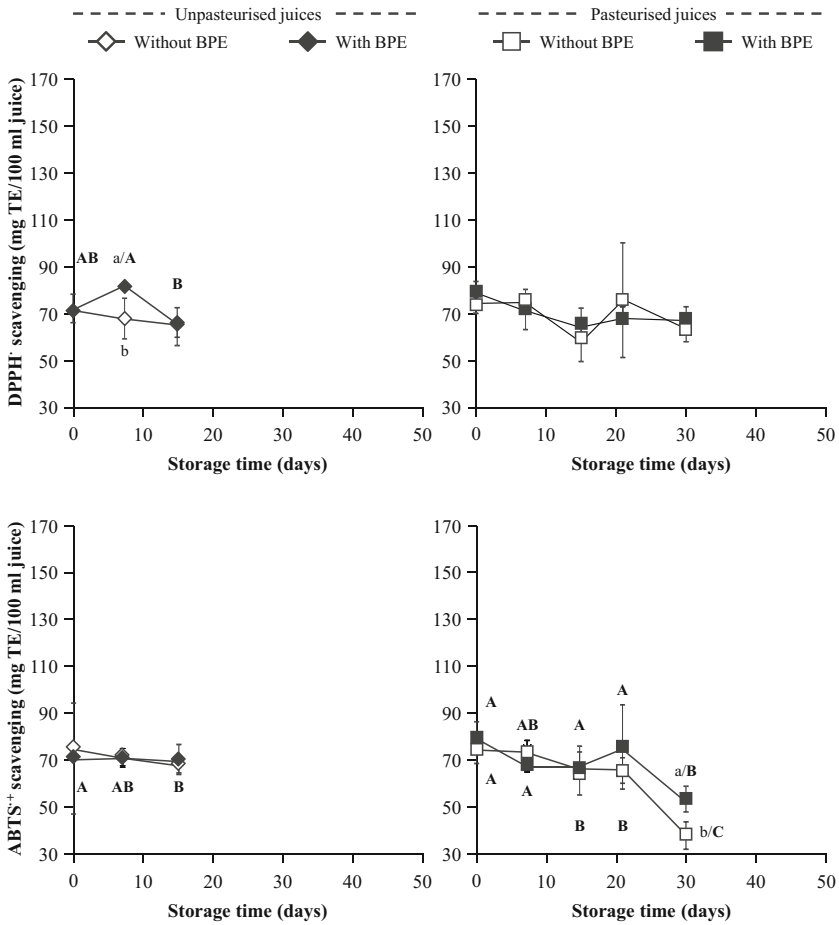

Fig. 1 Evolution of the capacity to scavenge radicals in pasteurised and unpasteurised freshly squeezed orange juices (FSJ), without and with (3.8 mg/ml orange juice) banana peel extract (BPE) added, during storage at 5 °C. DPPH•, 2,2-diphenyl-1-picrylhydrazyl; ABTS•+, 2,2′-azino-bis-(3-ethylbenzothiazoline)-6-sulfonic acid; TE, trolox equivalents. Three independent replicates of each treatment were analysed. Different lowercase (*a*, *b*) and bold capital (*A*–*C*) letters denote significant differences ($P < 0.050$) between juices without and with banana peel added and between during storage time, respectively. *No letters* denote no significant differences between factors

stated that adding BPE to orange FSJ modified its appearance, very slightly with in-mouth sensations and more markedly with its in-nose sensations. However, these modifications were described as unimportant. Adding BPE produced positive changes in the visual aspect of the FSJ, making its colour brighter and more uniform. FSJ with BPE had a pleasant flavour, less bitter and sour and softer than conventional FSJ. During the entire period that they were stored at 5 °C, the panellists highlighted that adding BPE made the FSJ oxidise more slowly than conventional juices. This was particularly true after 1 month of storage, when panellists detected an itching sensation in-mouth because of the presence of carbon dioxide in the conventional juice. This sensation was never described in FSJ with BPE. On the other hand, the panellists described less positively the in-nose sensations, mostly because they detected herbaceous notes. However, this aspect was mitigated by the in-nose perception of lower levels of oxidation in FSJ with BPE, which was evaluated very positively by the panellists.

The sensory quality of the JFC remained more stable during storage than that of FSJ. The panellists stressed that it was extremely difficult to detect differences between JFC with BPE added and conventional juice. The appearance of JFC remained practically unchanged. Moreover, during storage, JFC with BPE showed less browning than those without the extract. The BPE also made the orange JFC appear livelier, with a slightly darker tone that was evaluated positively by the panellists. Many panellists pointed out the presence of more foam (formed during homogenisation of the juice before pouring) in conventional orange JFC compared to those with extract added. This could be due to the fact that during banana peel extraction, part of the fat contained in the peel (Emaga et al. 2007) may be dragged along and this fat could be involved in the process of bubble destabilisation, eliminating the foam formed during juice homogenisation. In a positive way, the aroma of the JFC became more intense. Herbaceous notes (typical of the extract) were also detected, although they were less pronounced than in FSJ. This aspect was less important in pasteurised JFC because of its distinctive "dry" odour. Regarding in-mouth sensations, BPE contributed to the body and complexity of the JFC, making it more expressive, pleasant and fresh. The extract also made the JFC oxidise more slowly and reduced acidity, aspects that appeared in conventional juice throughout its storage. The high quality of pasteurised JFC with BPE after 45 days of storage must be highlighted, as it was assessed much more positively than the other juices (which were described as oxidised, flavourless or plain).

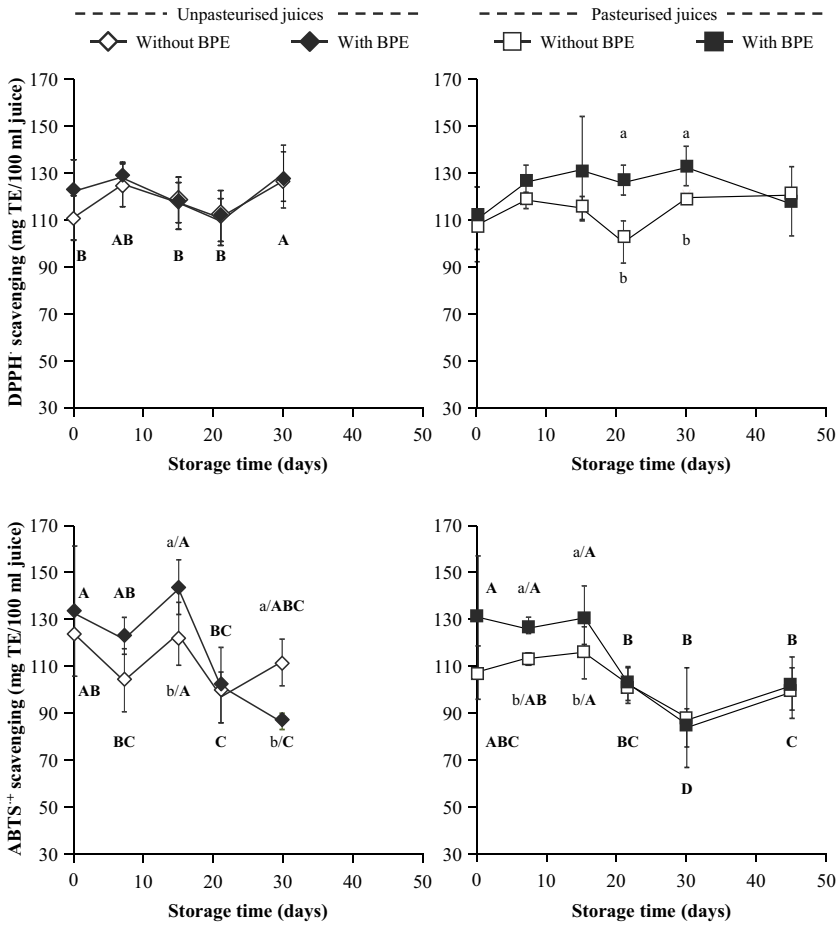

Fig. 2 Evolution of the capacity to scavenge radicals in pasteurised and unpasteurised orange juices from concentrate (JFC), without and with (3.8 mg/ml orange juice) banana peel extract (BPE) added, during storage at 5 °C. DPPH•, 2,2-diphenyl-1-picrylhydrazyl; ABTS•+, 2,2′-azino-bis-(3-ethylbenzothiazoline)-6-sulfonic acid; TE, trolox equivalents. Three independent replicates of each treatment were analysed. Different lowercase (*a*, *b*) and bold capital (*A–D*) letters denote significant differences ($P < 0.050$) between juices without and with banana peel added and between during storage time, respectively. *No letters* denote no significant differences between factors

Physicochemical Characterisation

The principal changes in the colour of unpasteurised and pasteurised FSJ occurred initially, but over time these changes tended to disappear (Table 1). In general, adding BPE to orange FSJ did not produce significant changes in colour (lightness, hue and chromaticity), when compared to conventional juices. Furthermore, pasteurisation did not cause variation in the lightness of the FSJ throughout the entire storage period, although it caused a decrease in the hue compared to unpasteurised FSJ. However, after 7 days of storage, this difference disappeared, and the hue remained constant during the rest of the storage period. Moreover, this heat treatment initially caused a considerable increase in the chromaticity of FSJ with BPE added. During storage, the chromaticity of FSJ with BPE decreased in pasteurised juice and increased in unpasteurised juice; thus, after 7 days of storage, they reached a similar chromaticity. Changes in the orange juice colour after thermal pasteurisation, including increased chromaticity, have been attributed to modifications in the carotenoid pigment profile (Wibowo et al. 2015). Sánchez-Moreno et al. (2005) found that the process of pasteurisation did not significantly change either the lightness or the chromaticity of orange FSJ; however, the hue decreased in pasteurised FSJ compared with that in unpasteurised FSJ. Recently, Chung et al. (2016) demonstrated that the addition of polyphenols to a model beverage improved the stabilisation of its natural colour and of its nutraceutical content.

Pasteurised JFC without or with BPE did not show changes in lightness during storage. However, adding this extract to unpasteurised JFC caused an initial decrease in lightness with respect to the juice without extract; during the storage of unpasteurised JFC, lightness decreased slightly in juice containing BPE after 45 days, while a remarkable decrease was detected in conventional juice after 45 days. Adding BPE did not produce significant changes in hue or chromaticity of the orange JFC. After 30 days of refrigerated storage, the hue of unpasteurised conventional juices increased slightly, while the chromaticity decreased. On the other hand, the chromaticity fell slightly after 30 days in JFC with BPE while the hue remained constant.

After adding BPE, the TSS content increased significantly in unpasteurised and pasteurised FSJ and in unpasteurised JFC (Table 2). This difference remained constant for pasteurised FSJ during all the refrigerated storage.

JFC had higher pH values and lower acidity than FSJ (Table 2). Adding BPE or pasteurising did not produce significant changes in pH or titratable acidity, in either type of

Table 1 Colour parameters in freshly squeezed orange juice (FSJ) and orange juice from concentrate (JFC), without and with (3.8 mg/ml orange juice) banana peel extract (BPE), during storage at 5 °C

Storage time (days)	FSJ			JFC		
	*L**	*h*°	*C**	*L**	*h*°	*C**
Unpasteurised juices without BPE						
0	42.1 ± 0.9	105.0 ± 0.3 b	18.6 ± 0.2 *B*/**C**	46.4 ± 0.8 a/**A**	109.6 ± 0.2 *B*/**B**	23.6 ± 0.6 *A*/**A**
7	41.0 ± 0.9	105.0 ± 0.2	23.8 ± 0.6 **B**	43.8 ± 3.5 **A**	111.0 ± 1.2 **B**	18.9 ± 2.0 **AB**
15	42.3 ± 0.3	105.6 ± 0.6	25.7 ± 1.5 **A**	46.5 ± 1.0 **A**	109.8 ± 0.2 **B**	23.3 ± 1.0 *A*/**A**
21	–	–	–	46.5 ± 1.1 **A**	109.7 ± 0.7 **B**	22.5 ± 1.4 **A**
30	–	–	–	37.0 ± 5.7 **B**	116.2 ± 4.4 **A**	13.8 ± 0.6 **B**
Unpasteurised juices with BPE						
0	41.9 ± 1.2	106.0 ± 0.2 a/*A*/**A**	17.3 ± 0.9 *B*/**B**	42.2 ± 1.5 b/**AB**	111.6 ± 1.5 **AB**	19.5 ± 2.7 **AB**
7	40.8 ± 1.0	105.1 ± 0.3 **B**	23.5 ± 1.0 **A**	44.2 ± 0.3 **A**	108.0 ± 2.0 **C**	21.4 ± 0.6 **A**
15	41.8 ± 0.9	106.0 ± 0.2 **A**	24.2 ± 0.5 **A**	45.5 ± 0.9 **A**	109.8 ± 0.4 **BC**	22.4 ± 1.0 **A**
21	–	–	–	44.6 ± 1.5 **A**	110.5 ± 0.6 **ABC**	21.6 ± 0.7 **A**
30	–	–	–	40.1 ± 3.8 **B**	113.1 ± 2.1 **A**	16.7 ± 3.1 **B**
Pasteurised juices without BPE						
0	44.9 ± 4.1	101.2 ± 4.0	26.0 ± 7.5 *A*	44.9 ± 0.8	110.9 ± 0.3 *A*	21.2 ± 0.8 **B**
7	42.3 ± 1.3	105.0 ± 0.5	22.6 ± 0.9	43.6 ± 0.7	111.2 ± 1.0 a	19.2 ± 1.2
15	42.5 ± 1.2	104.9 ± 1.0	24.6 ± 1.3	45.2 ± 1.3	110.3 ± 0.4	21.9 ± 0.4 **B**
21	42.7 ± 0.3	104.7 ± 0.1	24.4 ± 1.2	45.0 ± 2.0	111.6 ± 1.7	20.4 ± 2.5
30	42.1 ± 1.2	104.1 ± 0.5 b	23.7 ± 0.7	43.0 ± 2.4	111.9 ± 1.7	19.3 ± 3.2
45	–	–	–	45.8 ± 1.0	110.1 ± 0.3	21.7 ± 0.3
Pasteurised juices with BPE						
0	43.9 ± 3.6	100.9 ± 2.4 *B*/**B**	26.2 ± 4.1 *A*/**A**	43.0 ± 2.6	111.2 ± 1.1 **B**	19.8 ± 2.8 **AB**
7	40.9 ± 0.5	105.4 ± 0.3 **A**	22.6 ± 1.3 **B**	44.7 ± 1.6	109.4 ± 0.4 b/**B**	21.0 ± 1.0 **A**
15	40.6 ± 0.5	105.2 ± 0.6 **A**	23.4 ± 1.7 **B**	45.2 ± 0.6	109.9 ± 0.3 **B**	22.2 ± 0.8 **A**
21	41.3 ± 1.2	105.3 ± 0.6 **A**	22.6 ± 1.5 **B**	44.9 ± 0.8	110.1 ± 0.6 **B**	22.1 ± 0.6 **A**
30	41.3 ± 0.2	105.2 ± 0.3 a/**A**	23.2 ± 0.6 **B**	39.7 ± 3.5	113.9 ± 2.2 **A**	16.5 ± 3.1 **B**
45	–	–	–	43.5 ± 2.4	111.1 ± 2.4 **B**	20.6 ± 3.5 **AB**

Values are the mean ± standard deviation of three determinations. Within each row, different lowercase (a–b), italic capital (*A*–*B*) and bold capital (**A**–**C**) letters denote significant differences ($P < 0.050$) between juices without and with BPE, between unpasteurised and pasteurised juices and between storage time, respectively. *No letters* denote no significant differences between factors

*L** lightness, *h*° hue angle, *C** chromaticity

juice (FSJ or JFC). Slight differences in the evolution of pH and titratable acidity over time were noted; however, in all the cases, pH was always lower than 4, and therefore these differences have no relevance from a technological point of view. Cortés et al. (2008a) noted that pasteurising (90 °C/20 s) orange juice did not alter the pH. Different results were found by Cortés et al. (2008b), who observed a significant increase of pH in both pasteurised and unpasteurised juices during the storage at 2 °C, because of their microbiological deterioration.

Conclusions

BPE is a promising natural additive that when added to FSJ and JFC stabilises the quality of the juices during mild pasteurisation and refrigerated storage. In general, a significant increase of the antioxidant activity of the orange juices was not observed by adding 3.8 mg BPE/ml juice, possibly due to antagonistic interactions between the antioxidants from banana peel and orange juice (Ortiz et al. 2017). However, after 30 days of storage (end of their shelf life), the capacity of pasteurised FSJ to scavenge ABTS radicals was 21% lower in juices without BPE than in those with BPE. In addition, when BPE was added, pasteurised JFC tend to have greater capacity to scavenge ABTS radicals during almost 21 days of refrigerated storage.

Regarding sensory attributes, it was difficult for the panellists to detect differences between FSJ and JFC with and without BPE and conventional juices; however, some differences became more evident over time. In general, these

Table 2 Physicochemical parameters in freshly squeezed orange juices (FSJ) and orange juices from concentrate (JFC), without and with (3.8 mg/ml orange juice) banana peel extract (BPE), during storage at 5 °C

Storage time (days)	FSJ			JFC		
	TSS (°Brix)	pH	Titratable acidity (g citric acid/100 ml)	TSS (°Brix)	pH	Titratable acidity (g citric acid/100 ml)
Unpasteurised juices without BPE						
0	11.4 ± 0.1a	3.21 ± 0.01 **C**	1.25 ± 0.05	10.7 ± 0.1b	3.90 ± 0.02 **A**	0.88 ± 0.03
7	11.5 ± 0.2	3.27 ± 0.01 **B**	1.31 ± 0.04	10.9 ± 0.1	3.67 ± 0.01 **E**	0.85 ± 0.07
15	11.4 ± 0.1	3.47 ± 0.01 **A**	1.35 ± 0.01	11.0 ± 0.1	3.79 ± 0.01 **B**	0.88 ± 0.01
21	–	–	–	10.9 ± 0.1	3.73 ± 0.01 **C**	0.91 ± 0.04
30	–	–	–	10.8 ± 0.1	3.70 ± 0.01 **D**	0.94 ± 0.02
Unpasteurised juices with BPE						
0	11.6 ± 0.1 b	3.20 ± 0.01 **C**	1.31 ± 0.02 **B**	11.0 ± 0.2 a/**C**	3.91 ± 0.02 **A**	0.90 ± 0.02 **C**
7	11.5 ± 0.1	3.31 ± 0.03 **B**	1.29 ± 0.01 **B**	11.0 ± 0.1 **AB**	3.69 ± 0.03 **D**	0.87 ± 0.06 **BC**
15	11.7 ± 0.2	3.48 ± 0.01 **A**	1.40 ± 0.04 **A**	11.1 ± 0.1 **A**	3.79 ± 0.01 **B**	0.91 ± 0.03 **BC**
21	–	–	–	11.1 ± 0.1 **AB**	3.73 ± 0.01 **C**	0.95 ± 0.01 **AB**
30	–	–	–	10.9 ± 0.1 **BC**	3.72 ± 0.02 **C**	1.00 ± 0.07 **A**
Pasteurised juices without BPE						
0	11.1 ± 0.1 a/**B**	3.20 ± 0.01 **E**	1.34 ± 0.13	10.7 ± 0.1 **B**	3.85 ± 0.01 **A**	0.91 ± 0.03
7	11.1 ± 0.1 a/**C**	3.32 ± 0.01 **D**	1.28 ± 0.04	10.7 ± 0.2 **AB**	3.68 ± 0.01 **F**	0.72 ± 0.04
15	11.3 ± 0.1 a/**A**	3.47 ± 0.01 **A**	1.27 ± 0.01 b	10.9 ± 0.1 **A**	3.77 ± 0.01 **B**	0.84 ± 0.08
21	10.9 ± 0.2 a/**D**	3.42 ± 0.01 **B**	1.29 ± 0.03	10.6 ± 0.1 **A**	3.71 ± 0.01 **D**	0.89 ± 0.01
30	11.1 ± 0.1 a/**C**	3.35 ± 0.01 **C**	1.33 ± 0.08	10.7 ± 0.1 **C**	3.69 ± 0.01 **E**	0.93 ± 0.01
45	–	–	–	10.9 ± 0.1 **A**	3.75 ± 0.01 **C**	0.93 ± 0.24
Pasteurised juices with BPE						
0	11.5 ± 0.1 b	3.22 ± 0.01 **E**	1.28 ± 0.01 **D**	10.9 ± 0.1**ABC**	3.87 ± 0.01 **A**	0.89 ± 0.03
7	11.4 ± 0.1 b	3.31 ± 0.01 **D**	1.30 ± 0.02 **DC**	11.0 ± 0.1**ABC**	3.70 ± 0.01 **E**	0.81 ± 0.06
15	11.7 ± 0.1 b	3.48 ± 0.01 **A**	1.36 ± 0.02 a/**B**	11.0 ± 0.1**AB**	3.79 ± 0.01 **B**	0.89 ± 0.15
21	11.2 ± 0.1 b	3.43 ± 0.01 **B**	1.33 ± 0.02 **BC**	11.0 ± 0.1**C**	3.73 ± 0.01 **D**	0.88 ± 0.01
30	11.4 ± 0.1 b	3.37 ± 0.01 **C**	1.41 ± 0.03 **A**	10.7 ± 0.1 **BC**	3.70 ± 0.01 **E**	0.96 ± 0.02
45	–	–	–	11.0 ± 0.1 **A**	3.77 ± 0.01 **C**	0.98 ± 0.06

Values are the mean ± standard deviation of three determinations. Within each row, different lowercase (a–b) and bold capital (**A**–**F**) letters denote significant differences ($P < 0.050$) between juices without and with BPE and between storage time, respectively. *No letters* denote no significant differences between factors

TSS total soluble solids

differences were positive; therefore, FSJ with BPE was described as having a brighter and more uniform colour, more pleasant and persistent flavour and being less bitter and sour. Throughout its shelf life, JFC with BPE showed less browning than those without BPE, appearing with a livelier colour, was more expressive in-mouth, more pleasant and fresher tasting. Moreover, during the entire period that they were stored at 5 °C, the panellists highlighted that adding BPE made both types of juices oxidise (evaluated as an itching sensation in-mouth because of the presence of carbon dioxide) more slowly than conventional juices. Some of these sensorial perceptions were corroborated by the measurement of the physicochemical characteristics of the juices; therefore, TSS content increased by adding BPE in unpasteurised and pasteurised FSJ and in unpasteurised JFC.

Further investigations are needed to confirm these promising sensory results and it is crucial to carry out consumer sensory testing.

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References

Agourram, A., Ghirardello, D., Rantsiou, K., Zeppa, G., Belviso, S., Romane, A., et al. (2013). Phenolic content, antioxidant potential, and antimicrobial activities of fruit and vegetable by product extracts. *International Journal of Food Properties, 16*, 1092–1104.

Arnao, M. B., Cano, A., & Acosta, M. (2001). The hydrophilic and lipophilic contribution to total antioxidant activity. *Food Chemistry, 73*(2), 239–244.

Ayala-Zavala, J. F., Vega-Vega, V., Rosas-Domínguez, C., Palafox-Carlos, H., Villa-Rodríguez, J. A., Siddiqui, M. W., et al. (2011). Agro-industrial potential of exotic fruit by-products as a source of food additives. *Food Research International, 44*, 1866–1874.

Bacigalupi, C., Lemaistre, M. H., Boutroy, N., Bunel, C., Peyron, S., Guillard, V., et al. (2013). Changes in nutritional and sensory properties of orange juice packed in PET bottles: an experimental and modelling approach. *Food Chemistry, 141*, 3827–3836.

Bai, J., Manthey, J. A., Ford, B. L., Luzio, G., Cameron, R. G., Narciso, J., et al. (2013). Effect of extraction, pasteurization and cold storage on flavonoids and other secondary metabolites in fresh orange juice. *Journal of the Science of Food and Agriculture, 93*, 2771–2781.

Berlinet, C., Brat, P., Brillouet, J. M., & Ducruet, V. (2006). Ascorbic acid, aroma compounds and browning of orange juices related to PET packaging materials and pH. *Journal of the Science of Food and Agriculture, 86*, 2206–2212.

Biswas, A. K., Beura, C. K., Yadav, A. S., Pandey, N. K., Mendiratta, S. K., & Kataria, J. M. (2015). Influence of novel bioactive compounds from selected fruit by-products and plant materials on the quality and storability of microwave-assisted cooked poultry meat wafer during ambient temperature storage. *LWT - Food Science and Technology, 62*(1), 727–733.

Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of free radical method to evaluate antioxidant activity. *Lebensmittel Wissenschaft und Technologie, 28*(1), 25–30.

Chung, C., Rojanasasithara, T., Mutilangi, W., & McClements, D. J. (2016). Stabilization of natural colors and nutraceuticals: inhibition of anthocyanin degradation in model beverages using polyphenols. *Food Chemistry, 212*, 596–603.

Corbo, M. R., Bevilacqua, A., Petruzzi, L., Casanova, F. P., & Sinigaglia, M. (2014). Functional beverages: the emerging side of functional foods commercial trends, research, and health implications. *Comprehensive Reviews in Food Science and Food Safety, 13*, 1192–1206.

Cortés, C., Esteve, M. J., & Frígola, A. (2008a). Color of orange juice treated by high intensity pulsed electric fields during refrigerated storage and comparison with pasteurised juice. *Food Control, 19*(2), 151–158.

Cortés, C., Esteve, M. J., & Frígola, A. (2008b). Effect of refrigerated storage on ascorbic acid content of orange juice treated by pulsed electric fields and thermal pasteurisation. *European Food Research and Technology, 227*(2), 629–635.

Emaga, T. H., Andrianaivo, R. H., Wathelet, B., Tchango, J. T., & Paquot, M. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chemistry, 103*(2), 590–600.

González-Montelongo, R., Lobo, M. G., & González, M. (2010a). Antioxidant activity in banana peel extracts: testing extraction conditions and related bioactive compounds. *Food Chemistry, 119*(3), 1030–1039.

González-Montelongo, R., Lobo, M. G., & González, M. (2010b). The effect of extraction temperature, time and number of steps on the antioxidant capacity of methanolic banana peel extracts. *Separation and Purification Technology, 71*(3), 347–355.

Hwang, J. Y., Shyu, Y. S., & Hsu, C. K. (2009). Grape wine lees improves the rheological and adds antioxidant properties to ice cream. *LWT - Food Science and Technology, 42*(1), 312–318.

Llorach, R., Tomás-Barberán, F. A., & Ferreres, F. (2005). Functionalisation of commercial chicken soup with enriched polyphenol extract from vegetable by-products. *European Food Research and Technology, 220*(1), 31–36.

Mielnik, M. B., Olsen, E., Vogt, G., Adeline, D., & Skrede, G. (2006). Grape seed extract as antioxidant in cooked, cold stored turkey meat. *LWT - Food Science and Technology, 39*(3), 191–198.

Miller, H. E. (1971). A simplified method for the evaluation of antioxidants. *Journal of the American Oil Chemists' Society, 48*(2), 91.

Ortiz, L., Dorta, E., Lobo, M. G., González-Mendoza, L. A., Díaz, C., & González, M. (2017). Use of banana (*Musa acuminata* Colla AAA) peel extract as an antioxidant source in orange juices. *Plant Foods for Human Nutrition, 72*, 60–66.

Pereira, A., & Maraschin, M. (2015). Banana (*Musa* spp) from peel to pulp: ethnopharmacology, source of bioactive compounds and its relevance for human health. *Journal of Ethnopharmacology, 160*, 149–163.

Polydera, A. C., Stoforos, N. G., & Taoukis, P. S. (2005). Effect of high hydrostatic pressure treatment on post processing antioxidant activity of fresh navel orange juice. *Food Chemistry, 91*(3), 495–503.

Reddy, V., Urooj, A., & Kumar, A. (2005). Evaluation of antioxidant activity of some plant extracts and their application in biscuits. *Food Chemistry, 90*(1–2), 317–321.

Ross, J. A., & Kasum, C. M. (2002). Dietary flavonoids: bioavailability, metabolic effects and safety. *Annual Review of Nutrition, 22*, 19–34.

Sánchez-Alonso, I., Jiménez-Escrig, A., Saura-Calixto, F., & Borderías, A. J. (2008). Antioxidant protection of white grape pomace on restructured fish products during frozen storage. *LWT - Food Science and Technology, 41*(1), 42–50.

Sánchez-Bel, P., Romojaro, A., Egea, I., & Pretel, M. T. (2015). Wild edible plants as potential antioxidant or nutritional supplements for beverages minimally processed. *LWT - Food Science and Technology, 62*(1–2), 830–837.

Sánchez-Moreno, C., Plaza, L., Elez-Martínez, P., de Ancos, B., Martín-Belloso, O., & Cano, M. P. (2005). Impact of high pressure and pulsed electric fields on bioactive compounds and antioxidant activity of orange juice in comparison with traditional thermal processing. *Journal of Agricultural and Food Chemistry, 53*(11), 4403–4409.

Sáyago-Ayerdi, S. G., Brenes, A., & Goñi, I. (2009). Effect of grape antioxidant dietary fiber on the lipid oxidation of raw and cooked chicken hamburgers. *LWT - Food Science and Technology, 42*(5), 971–976.

Sultana, B., Anwar, F., & Przybylski, R. (2007). Antioxidant potential of corncob extracts for stabilization of corn oil subjected to microwave heating. *Food Chemistry, 104*(3), 997–1005.

Wibowo, S., Vervoort, L., Tomic, J., Santiago, J. S., Lemmens, L., Panozzo, A., et al. (2015). Colour and carotenoid changes of pasteurised orange juice during storage. *Food Chemistry, 171*, 330–340.