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Stability of anthocyanin-based aqueous extracts of Andean purple corn and red-fleshed sweet potato compared to synthetic and natural colorants

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Abstract

Anthocyanin-based aqueous Andean red sweet potato and purple corn extracts were evaluated under different pH, temperature, and light conditions, and compared to commercial colorants (purple carrot, red grape, red 40, and red 3). Red sweet potato and purple carrot colorants, rich in acylated anthocyanins, showed higher stability than purple corn and red grape colorants, rich in non-acylated anthocyanins. After storage at 20 °C for 138 days, the order of stability in the pH range 0.9–4 was: red sweet potato $\geqslant$ purple carrot > purple corn > red grape. After this storage time, red sweet potato pH 4 extracts maintained a red-violet hue. Half-lives for pH 3 extracts at 98 °C were 4.6, 4.6, 2.4, and 2.0 h for red sweet potato, purple carrot, red grape, and purple corn, respectively. The hues for purple corn pH 3 extracts were similar to those of red 40. Parameters measured included degradation index, polymeric colour, colour retention and spectral data.

Keywords: Color stability; pH; Temperature; Light; Red sweet potato; Purple corn; Purple carrot; Red grape; Red 40

1. Introduction

Natural plant colorants have been in high demand by the food industry for replacing synthetic dyes such as FD&C red 40 and the banned FD&C red 2 for the past decade (Francis, 1989; Fabre et al., 1993). This need has come from legislative action and consumer concern against synthetic food additives (Francis, 1989; Hong & Wrolstad, 1990; Shi, Bassa, Gabriel, & Francis, 1992). However, replacing synthetic dyes with natural colorants offers a challenge due to the higher stability of synthetic dyes with respect to light, oxygen, temperature, and pH, among other factors.

Anthocyanins have a high potential for use as natural colorants due to their attractive orange, red, purple, and blue colours; however, they have stability problems (Markakis, 1982; Francis, 1989). The colour and stability of anthocyanin pigments are dependent on several factors, including structure and concentration of the pigment, pH, temperature, light intensity and quality, presence of copigments, metallic ions, enzymes, oxygen, ascorbic acid, sugars and their degradation products and sulfur dioxide, among others (Mazza & Miniati, 1993; Francis, 1989). In acidic media four anthocyanin structures exist in equilibrium: flavylium cation, quinonoidal base, carbinol pseudobase and chalcone. The relative amounts of these structures at equilibrium vary with pH and anthocyanin structure (Mazza & Miniati, 1993).

Regarding molecular structure, some anthocyanins are more stable than others. For example, malvidin glycosides, the main anthocyanins in grapes, are among the most colour-stable, due to dimethoxylation of the molecule (Bridle & Timberlake, 1997). Also, acylation with hydroxylated aromatic organic acids confers higher stability, with few exceptions (Bassa & Francis, 1987; Francis, 1989).

Stability of anthocyanins can also increase with inter molecular copigmentation (Francis, 1989; Malien-Aubert, Dangles, & Amiot, 2001). Aqueous fruit, vegetable,

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and grain extracts, with high anthocyanin content, contain mixtures of different compounds that may serve as copigments for intermolecular association with anthocyanins. However, not all compounds enhance copigmentation; for example, sugars and their degradation products tend to accelerate the degradation of anthocyanins. The rate of anthocyanin degradation is associated with the rate at which the sugar is degraded to furfural-type compounds derived from the Maillard reaction (Duhard, Garnier, & Megard, 1997).

Highly stable colorant systems may already be present in nature; however, they need to be identified and characterized for their phytochemical composition and stability attributes. The Andean region offers great diversity of crops with high potential as colorant sources, including a red-fleshed sweet potato and a purple corn, which have a long history of folklore use. Red sweet potato has the majority of its anthocyanins acylated, while purple corn does not (Bassa & Francis, 1987; Goda et al., 1996; de Pascual-Teresa, Santos-Buelga, & Rivas-Gonzalo, 2002). In addition, both crops have low sugar contents, making possible the concentration of highly pigmented aqueous extracts low in soluble solids. Currently, there are some aqueous colorants in the market made from purple corn and red sweet potato; however, their stability with respect to pH, temperature, and light, has not been fully characterized and compared to that of commercial natural and synthetic colorants. Identifying stable aqueous colorant extracts (e.g. fruit and vegetable juices) is attractive because their GRAS (Generally Recognized As Safe) status makes them easily commercialized.

The overall goal of this study was to characterize the stability of Andean purple corn and red-fleshed sweet potato anthocyanin-based aqueous extracts compared to synthetic red 40 and red 3 colorants as well as purple carrot and red grape commercial colorants. Our approach involved determining: (1) the pH effect on chromaticity (including the alkaline region) and (2) the effects of acylation, pH, temperature, and light on anthocyanin stability through time.

2. Materials and methods

2.1. Materials

Purple corn (Amazonas Imports, Inc., Sun Valley, CA, USA) and freeze-dried red sweet potato (Viru, Peru) were imported from Peru. Antho-Red Grape concentrate (03880, LOT HH861), FD&C red 3 and FD&C red 40 were kindly contributed by Warner Jenkinson (St. Louis, Missouri, USA). Purple carrot concentrate (code: 99343279/00) was generously supplied by Artemis International, Inc. (Fort Wayne, Indiana, USA). Hydrochloric acid was purchased from EM Science (a division of EM Industries Inc., Gibbstown, NJ, USA), McIlvaine buffer from Lab Chem Inc. (Pittsburgh, PA, USA), sodium hydroxide from Fisher Scientific (Fair Lawn, New Jersey, USA), potassium phosphate monobasic from Baker Analyzed Inc. (Phillipsburg, New Jersey, USA), guaiacol and sodium azide from ICN Biomedicals Inc. (Aurora, Ohio, USA), 3% hydrogen peroxide from Kroger Grocery Store (College Station, Texas, USA), and potassium metabisulphite and Polyvinylpolypyrrolidone (PVPP) from Sigma Chemical Co. (St. Louis, Missouri, USA).

2.2. Colorant preparation and characterization

Red sweet potato slices were steam-blanched at 105 °C for 10 min while purple corn cob powder was diluted in nanopure water and water-blanched at 100 °C for 10 min inside a glass vial. Samples were immediately quenched in an ice-water bath and homogenized with nanopure water in an Ultra-Turrax homogenizer (IKA Works, Inc., Wilmington, NC, USA). Tube contents were filtered and centrifuged for 15 min at 29,000*g*. Each sample extract was prepared at 11 different pHs (0.9, 2, 3, 4, 5, 6, 7, 8, 9, 10.7, 11.7) with McIlvaine buffer (sodium phosphate dibasic $< 2\%$, citric acid $< 2\%$, and thymol $< 0.1\%$). Each sample was prepared initially at pH 0.9 with an absorbance reading or tinctorial strength of 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.

The effect of pH on chromaticity was determined in extracts at pH 3, 5, and 7 which were prepared at a ~10-fold higher tinctorial strength ($A_{\lambda_{max}} \times$ dilution factor). The concentration effect on chromaticity was determined at 5 different tinctorial strengths, ranging from 0.6 to 26 for red 40, red sweet potato, and purple corn extracts. 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 colourimeter (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 on 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 $^*b$.

2.3. Evaluation of peroxidase (POX) activity

Crop samples of 1–2 g were mixed with 20 ml cold 0.05 M potassium phosphate buffer (pH 6.4) and 0.4 g

PVPP inside a plastic tube and homogenized to uniform consistency at ~0 °C. The obtained solutions were filtered and centrifuged at 29,000*g* for 15 min. A 0.1 ml aliquot solution was mixed with 2.55 ml of buffer inside a cuvette, after which 0.1 ml 0.25% H_2O_2 and 0.25 ml 0.1 M guaiacol were added to initiate the reaction of POX. Absorbance (A) readings at 420 nm were taken every 2 s at 24 °C and reaction rate was calculated from the linear portion of the curve. One unit of POX activity was defined as the increase in A_{420nm} in 1 min per g of dry sample. Analyses were done in triplicate.

2.4. Colorant stability studies

The effect of pH on colorant stability was performed through time (after 1 h and 1.7, 5, 9, and 138 days) at 20 °C with samples inside capped vials covered with aluminium foil and sealed with parafilm. The effect of temperature on colorant stability was done with samples inside capped glass vials covered with aluminium foil sealed with parafilm and immersed in a water bath at 99 °C (±1 °C) for 0, 30, 60, 90, and 120 min. Light effect on colorant stability was performed with samples inside capped glass vials sealed with parafilm and exposed to white fluorescent light (Phillips FCW40) with an intensity of 277 μmol photons s^{-1} m^{-2} (20 °C) for 1 h and 1.7, 5, and 9 days. Controls for light and temperature assays were samples inside capped vials covered with aluminium foil, sealed with parafilm, and stored at 20 °C.

The colorant half-life ($t_{1/2}$) was determined for samples exposed to light and temperature only. Calculation of $t_{1/2}$ was done with four to five data points, using a fitted linear equation based on zero or first order kinetics. The equilibration time was not accounted for when calculating $t_{1/2.}$

2.5. Colour density, polymeric colour, and degradation index

Anthocyanin colour density and polymeric content were determined using the bisulfite bleaching method (Wrolstad, 1976). Solutions were bleached with potassium metabisulphite (using water as a control) and absorbance readings were taken at 420 nm and λ_{max}. Total colour density, a measure of the colour strength of the solution, is the sum of $A_{\lambda_{max}} + A_{420\,nm}$. Polymeric colour, an indicator of polymerized pigments, including tannins, and brown compounds, is the sum of $A_{\lambda_{max}} + A_{420\,nm}$ of the bleached sample, assuming that only monomeric anthocyanins get bleached (Somers, 1971). Polymeric colour was expressed as a % of total colour density. Degradation index (DI) was obtained as the ratio between A_{420nm} and $A_{\lambda_{max}}$ (Wrolstad, 1976).

3. Results and discussion

3.1. Colorant extract preparation

Red sweet potato and purple corn samples were blanched to eliminate enzymatic anthocyanin degradation. POX activity was evaluated due to its high heat resistance, guaranteeing destruction of degrading enzymes, including polyphenoloxidase (PPO) (Richardson & Hyslop, 1985; Williams, Lim, Chen, Pangborn, & Whitaker, 1986), which is considered the major enzyme responsible for anthocyanin degradation in fruits and vegetables (Kader, Rovel, Girardin, & Metche, 1997). POX activity in red sweet potato (136 units/g dry basis) was higher than that found in purple corn cob (27 units/g dry basis). Steam blanching sweet potatoes for 2 and 10 min reduced POX activity by 99% and 100%, respectively, while water blanching purple corn cob for 4 and 10 min reduced POX activity by 99% and 100%, respectively. Thus, a 10 min blanching was used in colorant extract preparations to ensure inactivation of degrading enzymes.

The obtained red sweet potato extracts showed high absorbance readings at 330 nm (391% of λ_{max}), characteristic of acylated anthocyanins, while purple corn extracts showed a lower absorbance at this wavelength (62% of λ_{max}), suggesting a large presence of non-acylated anthocyanins. The major anthocyanins in red sweet potato have been identified as acylated cyanidin and peonidin glucoside derivatives (Goda et al., 1996), while de Pascual-Teresa et al. (2002) found cyanidin 3-glucoside to be the main anthocyanin present in purple corn, with contributions of pelargonidin-3-glucoside, peonidin-3-glucoside, and their respective malonyl derivatives. In general, it is known that acylation may confer stability to anthocyanins (Bassa & Francis, 1987; Francis, 1989). However, some acylated derivatives could also be unstable, such as those present in low amounts in purple corn (Duhard et al., 1997).

In the following stability studies we compared colorants rich in acylated anthocyanins (red sweet potato and purple carrot) to colorants rich in non-acylated anthocyanins (purple corn and red grape) to determine the stability conferred by acylation.

3.2. Chromaticity

Colorants tested were prepared at similar tinctorial strengths at pH 3 and then adjusted to pHs 5 and 7. Chroma decreased from pH 3 to 5 for both extracts, indicating a less saturated colour form due to the presence of colourless carbinol (Table 1). A higher chroma at pH 7 for red sweet potato compared to purple corn was due to the presence of a purple-blue quinonoidal base with higher absorbance. Generally, this form is less

Table 1
Chromaticity parameters of red sweet potato and purple corn colorants compared to FD&C red 40 and FD&C red 3

Colorant	pH	L	Hue	Chroma	Tinctorial strength	λ_{max}
Red 40	3	72	39	70	9.0	502
Red 3	3	71	25	73	7.2	488
Red sweet	3	72	−7	59	7.2	530
potato	5	80	−23	32	–	540
	7	67	−46	43	–	562
Purple corn	3	74	20	47	9.0	514
	5	87	1	14	–	524
	7	65	4	24	–	554

stable and the absorbance decreases dramatically after a few minutes (Brouillard, 1982).

Hue decreased with increasing pH for red sweet potato (Table 1). However, for purple corn, hue decreased from pH 3 to 5 and slightly increased from pH 5 to 7. At pH 7, purple corn appeared dark purple-red. Hue for red sweet potato extracts at pH 3 was lower than those of red 3 and red 40, while hue for purple corn extracts at similar pH approximated that of synthetic colorants, especially red 3. The lower hue of red sweet potato compared to purple corn, at all pHs, is most likely due to a bluing effect conferred by acylation (Duhard et al., 1997). The effect of pH on L^* showed similar trend to that of chroma values.

Research has shown that hue increases with colorant concentration (Rodríguez-Saona, Giusti, & Wrolstad, 1998). When aqueous extracts at pH 3 were prepared, at different tinctorial strengths, L^* decreased and both hue and chroma increased with concentration (Fig. 1). By controlling concentration it will be possible to match the hues of synthetic colorants, such as red 40; however, their tinctorial strengths could be different. For example, to obtain a hue in the range of 20–30°, at the studied conditions, red 40 would have to be prepared at a tinctorial strength range of ~0.9–3, while purple corn would need to be at a range of ~0.9–10. For red sweet potato extracts, a hue of 20° could be achieved, using a tinctorial strength of ~16.

3.3. pH stability

3.3.1. General

To determine stability at different pHs, colorants were prepared at similar tinctorial strengths (~0.8) at pH 0.9 and then adjusted to other pHs. Alkaline conditions were studied to consider foods with pHs in this range, such as dairy and tortilla products. Pictures of all colorants are shown in Fig. 2 and their absorbance spectra in Fig. 3. Colour retention at λ_{max} (Table 2), DI (Fig. 4) and polymeric colour (Table 3) were used to understand colorant degradation at different pHs and through time. DI accounts for three components of degradation, including an increase in absorbance due to

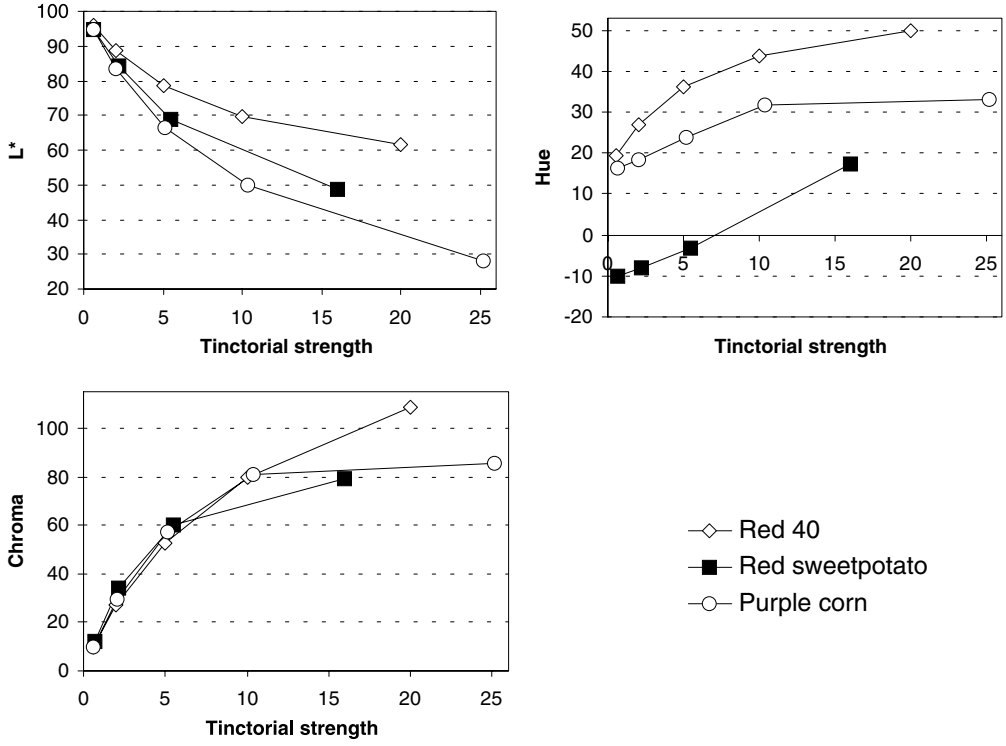

Fig. 1. Concentration effect on chromaticity parameters of pH 3 extracts.

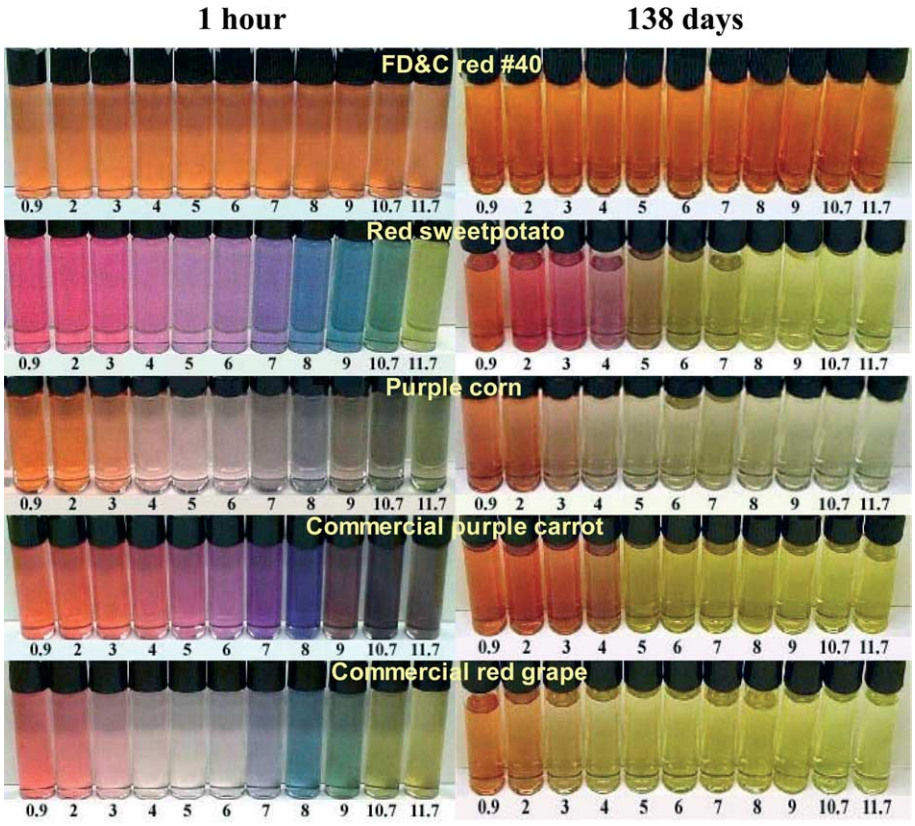

Fig. 2. Pictures of all colorants at different pHs initially and after 138 days at 20 °C, protected from light and oxygen.

browning, a decrease in absorbance due to formation of colourless carbinol bases, and the effect of bathochromic shifts due to anthocyanin structure evolving into less stable forms. The DI absorption ratios are useful for following anthocyanin degradation in a given system, however, they should not be used to compare systems with different pigment composition (Francis, 1982). Results indicated that DI, for all colorants, increased > pH 3 (Fig. 4), and during storage, the DI increased with time at pH > 4 (data not shown). A detailed study of the stability of extracts with pH is discussed in the following sections divided in two pH ranges (pH 1–6 and pH 7–12).

3.3.2. pH range 1–6

Absorbance readings for all samples decreased with increased pH up to pH 6 (Fig. 3). This decrease in absorbance was more dramatic in purple corn and commercial red grape extracts, rich in non-acylated anthocyanins, which showed colourless structures at pH 4–6. At these pHs, the red flavylium cation hydrated to yield the colourless carbinol (Mazza & Miniati, 1993). The discolouration effect was slightly lower for purple corn extracts, which could be due to protection of the few acylated anthocyanins present. Regarding the observed colours, red sweet potato and red grape were pink-red up to pH 4 and 2, respectively, while purple carrot and purple corn were orange-red up to pH 4 and 3, respectively (Fig. 2).

Red sweet potato extracts, at pH 0.9–3, showed hyperchromic shifts with time related to chemical changes in the molecule (Inami, Tamura, Kikazuki, & Nakatani, 1996) due to interactions with the buffer used.

In general, red sweet potato and purple carrot colorants, rich in acylated anthocyanins, showed higher stability at pH 0.9–4 after 138 days at 20 °C than purple corn and red grape colorants, rich in non-acylated anthocyanins (red sweet potato ⩾ purple carrot > purple corn > red grape) (Table 2). The hue for red sweet potato colorant at pH 4 still showed an attractive red-violet colour after this storage period.

3.3.3. pH range 7–12

Bathochromic shifts were observed for all colorants at pH > 5 (Fig. 3). All samples showed high absorption between 570 and 630 nm in the pH range 7–9, due to the presence of unstable blue quinonoidal structures. A higher absorbance was observed for red sweet potato and purple carrot colorants, most likely due to their acylated anthocyanins. Simultaneously, an increased absorption in the chalcone and browning regions (380–420 nm) was observed for all samples.

After 41 h, all quinonoidal structures decreased their absorbances significantly. The colour of these unstable

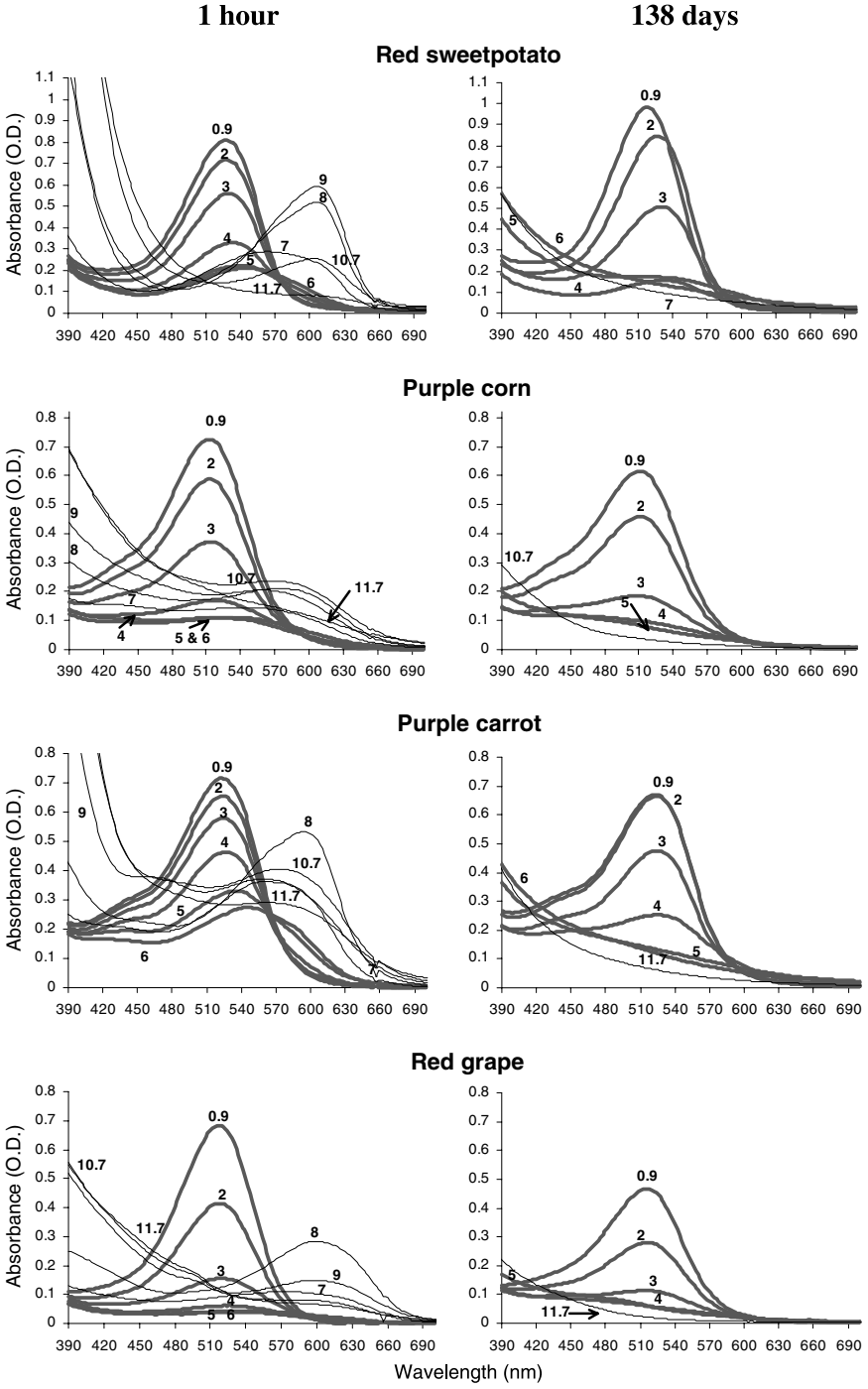

Fig. 3. Spectrum charts for extracts at different pHs, initially and after 138 days at 20 °C, protected from light and oxygen.

quinonoidal bases increasingly shifted towards brown and yellow with time. After 138 days, yellow colourless structures predominated for all extracts at pHs >4.

In general, below pH 2, anthocyanins were primarily in the form of the red flavylium cation. When pH increased >2, there were rapid proton losses favouring red or blue quinonoidal forms. Through time, the flavylium cation became hydrated to yield the colourless carbinol or pseudobase, which equilibrated to the open chalcone form, also colourless (Mazza & Miniati, 1993). The orange-red colour resembling that of red 40 was only observed up to pH 3 for red sweet potato, purple corn, and commercial purple carrot. Red sweet potato and purple carrot initially showed attractive colours at all pHs; however, the high colour intensity in the alkaline region decreased with time. After 138 days, these extracts at pH

Table 2
Percent colour retention at λ_{max} of extracts after 138 days at 20 °C, protected from light and oxygen

Colorant	pH			
	0.9	2	3	4
Red sweet potato	96	99	90	55
Purple corn	79	75	50	[a]
Purple carrot	87	99	82	55
Red grape	65	67	[a]	[a]
Red 40	102	102	101	101

[a] Initial absorption at λ_{max} of these samples was very low.

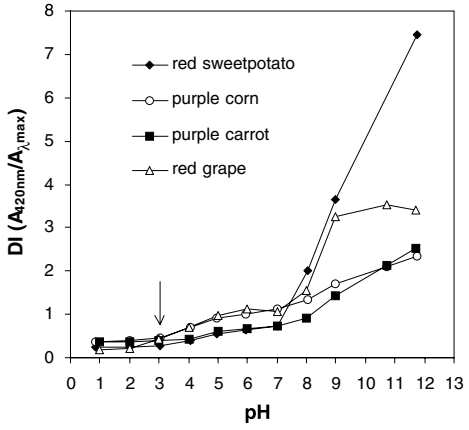

Fig. 4. The effect of pH on the degradation index of colorants after 1 h equilibration time. The arrow indicates the pH above which DI increased.

0.9–2 had similar hues and chromas to red 40 (data not shown).

3.4. Temperature stability

The effect of exposing extracts at pH 1 and 3 to 98 °C for 2 h was studied, determining % colour retention at λ_{max} (Fig. 5) and % polymeric colour (Table 3). This temperature was chosen to reflect a severe heat treatment during thermal food processing operations (e.g. blanching, pasteurization, cooking). Extracts at pH 1 and 3 were selected, due to their higher stability as determined previously. At pH 1 there was an increase in absorbance of red sweet potato (Fig. 5), as was observed in the previous section. Even though red sweet potato retained colour the most after 120 min, the degradation rate from 30 to 120 min was similar to that of commercial purple carrot. Purple corn was very susceptible to 98 °C, showing high degradation. Half-lives for commercial purple carrot, red sweet potato, and purple corn, at pH 1, were 3.0, 2.8, and 1.8 h, respectively.

At pH 3, the same order of stability was observed as with pH 1, except that there was no initial increase in the absorbance for red sweet potato. Commercial red grape had slightly higher stability than purple corn. Colour retention for all extracts, at pH 3, was higher than that at pH 1. This could be explained by a lower initial absorbance of pH 3 extracts, reflecting a lower content of flavylium cations than pH 1 extracts. Flavylium cations decrease their absorbance more easily than already colourless forms. Half-lives for commercial purple carrot, red sweet potato, commercial red grape, and purple corn at pH 3 were 4.6, 4.6, 2.4, and 2.0 h, respectively.

Polymeric colour was calculated to determine the level of polymerization after heat treatment (Table 3). Initial polymeric colour was 11.4%, 14.9%, 18.1%, and 21.9% for purple corn, red sweet potato, commercial purple carrot, and commercial red grape colorants, respectively. Higher initial polymeric colour of commercial colorants could be due to more severe processing conditions and/or previous longer storage. Generally, fresh produce has most of its anthocyanins in the monomeric form and upon processing they start polymerizing. Polymeric material increased after the heat treatment, especially for purple corn, which increased from 11.4 to 80%. Purple corn was also the sample that retained its colour at λ_{max} the least. Red sweet potato and commercial purple carrot maintained an unchanged polymeric component after the 2 h treatment.

3.5. Light stability

At pH 1, all samples, except purple corn exposed to light, experienced an increase in absorbance (Fig. 6). The red sweet potato colorant, after 2 days of light exposure, had a 12% higher $A_{\lambda_{max}}$ than its control. It is possible that, in the presence of light, this absorbance increase is achieved faster due to an enhanced stabilization of the

Table 3
Colour density and polymeric colour of pH 3 extracts before and after exposure to heat and light

	Initial		Final			
	Color density	Polymeric colour (%)	98 °C[a]		Light[b]	
			Colour density	Polymeric colour (%)	Colour density	Polymeric colour (%)
Red sweet potato	0.66	14.9	0.49	16.8	0.24	42.4
Purple corn	0.54	11.4	0.30	79.0	0.07	82.4
Purple carrot	0.74	18.1	0.71	18.9	–	–
Red grape	0.21	21.9	0.13	29.0	–	–

[a] Exposed to 98 °C for 2 h.
[b] Exposed to fluorescent light for 9 days.

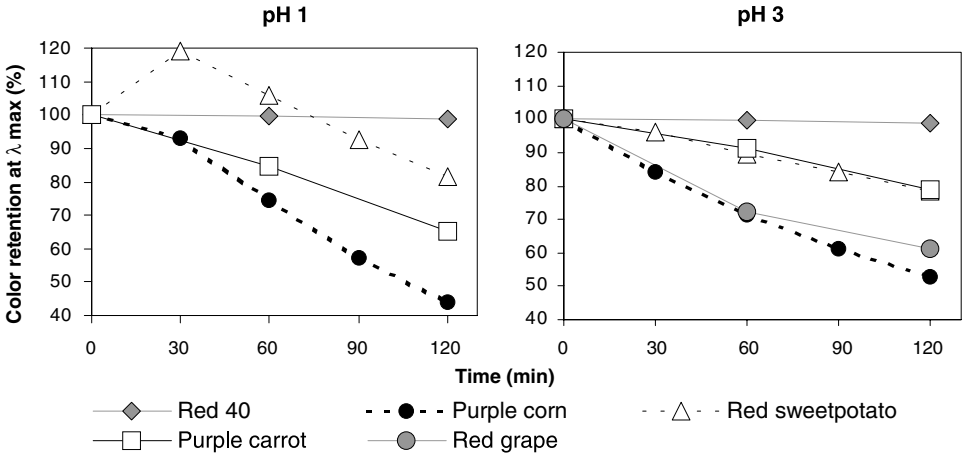

Fig. 5. The effect of 98 °C on percent colour retention of natural and synthetic colorants at pH 1 and 3. Controls remained stable, thus were omitted from the figure.

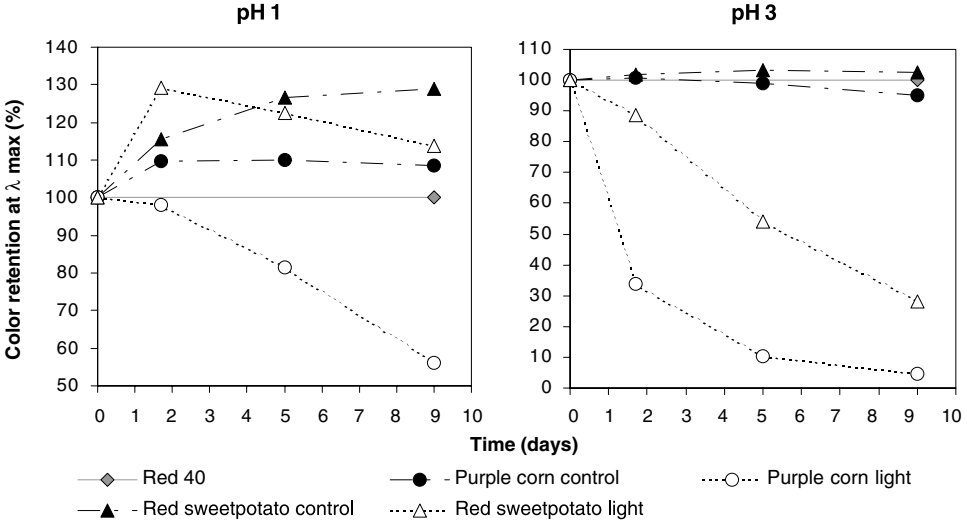

Fig. 6. The effect of fluorescent light on percent colour retention of natural and synthetic colorants at pH 1 and 3.

anthocyanin molecule in the pH 1 buffer due to excitation of the flavylium cation.

During light exposure, red sweet potato colorants were degraded slower than purple corn, suggesting a protective effect of acylation on the anthocyanin molecule. Van Buren, Bertino, and Robinson (1968) reported that acylated diglucosides present in wine were the most stable, followed by nonacylated diglucosides and monoglucosides, in decreasing order, when exposed to light.

Purple corn had higher polymeric colour than red sweet potato after light exposure (Table 3). Polymeric colour at pH 3 after 9 days, increased for purple corn from 11.4% to 82.4% compared to an increase from 14.9% to 42.4% for red sweet potato colorants. Red sweet potato extracts had higher $t_{1/2}$ (pH 1, 28 days; pH 3, 6.1 days) than purple corn extracts (pH 1, 10.3 days; pH 3, 1.3 days).

In general, the heat treatment was more severe in reducing $t_{1/2}$ than light and colorants with mostly acylated anthocyanins had higher $t_{1/2}$ than those extracts with mostly non-acylated anthocyanins. Purple corn and red sweet potato pH 3 extracts were more resistant to 98 °C but less resistant to light, than pH 1 extracts. An explanation for this may be found by understanding the different degradation kinetic pathways caused by heat and light, as well as the effect of absorption increase of pH 1 extracts.

In conclusion, anthocyanin-based aqueous extracts of red sweet potato were highly or moderately resistant to the pH, temperature and light factors tested. In addition, red sweet potato extracts maintained a red-violet hue for extended periods of time, showing comparable stability to a commercial purple carrot colorant. Even though purple corn extracts showed lower colour sta-

bility, the hues of purple corn extracts at pH 3 can match those of red 40 if prepared at different tinctorial strengths. Overall, colorants rich in acylated anthocyanins, such as red sweet potato and purple carrot, showed higher stability than colorants rich in non-acylated anthocyanins, such as purple corn and red grape. New sources, high in anthocyanin pigments, should be sought and tested for their stability. Andean red sweet potato and purple corn represent inexpensive crops with high pigment yield that could be sources of anthocyanins for the food colorant market.

References

Bassa, I. A., & Francis, F. J. (1987). Stability of anthocyanins from sweet potatoes in a model beverage. A research note. *Journal of Food Science, 52*, 1753–1754.

Bridle, P., & Timberlake, C. F. (1997). Anthocyanins as natural food colours – selected aspects. *Food Chemistry, 58*, 103–109.

Brouillard, R. (1982). Chemical structure of anthocyanins. In P. Markakis (Ed.), *Anthocyanins as food colors* (pp. 1–40). New York: Academic Press (Chapter 1).

de Pascual-Teresa, S., Santos-Buelga, C., & Rivas-Gonzalo, J. C. (2002). LC-MS analysis of anthocyanins from purple corn cob. *Journal of the Science of Food and Agriculture, 82*, 1003–1006.

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

Fabre, C. E., Santerre, A. L., Loret, M. O., Baberian, R., Pareilleux, A., Goma, G., & Blanc, P. J. (1993). Production and food applications of the red pigments of *Monascus* rubber. *Journal of Food Science, 58*, 1099–1111.

Francis, F. J. (1982). Analysis of anthocyanins. In P. Markakis (Ed.), *Anthocyanins as food colors* (pp. 181–207). New York: Academic Press (Chapter 7).

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

Goda, Y., Shimizu, T., Kato, Y., Nakamura, M., Maitani, T., Yamada, T., Terahara, N., & Yamaguchi, M. (1996). Two acylated anthocyanins from purple sweet potato. *Phytochemistry, 44*, 183–186.

Hong, V., & Wrolstad, R. (1990). Characterization of anthocyanin-containing colorants and fruit juices by HPLC/photodiode array detection. *Journal of Agricultural and Food Chemistry, 38*, 698–708.

Inami, O., Tamura, I., Kikazuki, H., & Nakatani, N. (1996). Stability of anthocyanins in *Sambucus canadensis* and *Sambucus nigra*. *Journal of Agricultural and Food Chemistry, 44*, 3090–3096.

Kader, F., Rovel, B., Girardin, M., & Metche, M. (1997). Mechanism of browning in fresh highbush blueberry fruit (*Vaccinium corymbosum* L.). Role of blueberry polyphenol oxidase, chlorogenic acid and anthocyanins. *Journal of the Science of Food and Agriculture, 74*, 31–34.

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.

Markakis, P. (1982). Anthocyanins as food additives. In *Anthocyanins as food colours* (pp. 245–253). New York: Academic Press (Chapter 9).

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

Richardson, T., & Hyslop, D. B. (1985). Enzymes. In O. R. Fennema (Ed.), *Food chemistry* (2nd ed., pp. 371–476). New York: Marcel Dekker (revised and expanded).

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, Z., Bassa, I. A., Gabriel, S. L., & Francis, F. J. (1992). Anthocyanin pigments of sweet potatoes – *Ipomoea batatas*. *Journal of Food Science, 57*, 755–757, 770.

Somers, T. C. (1971). The polymeric nature of wine pigments. *Phytochemistry, 10*, 2175–2186.

Van Buren, J. P., Bertino, J. J., & Robinson, W. B. (1968). The stability of wine anthocyanins on exposure to heat and light. *American Journal of Enology and Viticulture, 19*, 147.

Williams, D. C., Lim, M. H., Chen, A. O., Pangborn, R. M., & Whitaker, J. R. (1986). Blanching of vegetables – which indicator enzyme to choose. *Food Technology, 40*, 130–140.

Wrolstad, R. E. (1976, reprinted 1993). Color and pigment analyses in fruit products. Agricultural Experiment Station, Oregon State University, Corvallis, Oregon. Station Bulletin, 624, 1–17.