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ORIGINAL PAPER

Stability and Degradation Kinetics of Bioactive Compounds and Colour in Strawberry Jam during Storage

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Abstract The effect of storage time and temperature on degradation of bioactive compounds such as ascorbic acid, anthocyanins, total phenols, colour and total antioxidant capacity of strawberry jam were investigated. The results indicated that lightness (L) value decreased significantly ($p<0.05$) over 28 days of storage at 4 and 15 °C, with lower values measured at higher temperatures. Anthocyanins, ascorbic acid and colour degradation followed first-order kinetics where the rate constant increased with an increase in the temperature. The reaction rate constant (k) increased from 0.95×10^{-2} day^{-1} to 1.71×10^{-2} day^{-1} at 4 and 15 °C for anthocyanins. Similarly, k increased from 2.08×10^{-2} day^{-1} to 4.54×10^{-2} day^{-1} at 4 and 15 °C for ascorbic acid. In general, total antioxidant activity for strawberry jam samples stored for 28 days at 4 and 15 °C exhibited lower values as compared to control (day 0). The results showed greater stability of nutritional parameters at 4 °C compared to 15 °C.

Keywords Strawberry jam · Kinetics · Ascorbic acid · Anthocyanins · Colour

Introduction

The plant-derived edible and non-edible products contain a wide range of phenolic compounds such as phenolic acids, flavonoids, anthocyanins, tannins, etc. that possess antioxidant activities (Liyana-Pathirana et al. 2006). Strawberry (*Fragaria* × *ananassa* Duch.) is a non-climatic fruit with numerous health benefits (Pinto et al. 2007). The presence of various health-promoting bioactive compounds such as anthocyanins, polyphenols and vitamin C reflects the importance of strawberry and its products. Dietary intake of anthocyanins and ascorbic acid in reducing the risk of many chronic diseases such as cancer, coronary heart disease and immune system decline has been well documented (Kaur and Kapoor 2001). Fruits are a particularly good source of phenolic compounds which have been shown to have protective effects against cardiovascular disease, diabetes and stroke (Heinonen et al. 1998; Scalbert and Williams 2000). A variety of factors have been shown to affect the antioxidant capacity of fruits including thermal processing (Dewanto et al. 2002; Quitão-Teixeira et al. 2008), unit operations such as slicing, peeling and storage regime (Piga et al. 2003a). Strawberries are consumed mainly as fresh fruit. In addition, many other strawberry products such as juice, nectar, puree and juice concentrate as well as jam are consumed widely.

Jam is intermediate moisture food and common processing steps are the concentration of fruit juice, storage in tank farms, redilution and preparation of strawberry jam by heating under vacuum, bottling, closing under vacuum and cooling (Silbereisen et al. 1996). Conventional processing of jams involves heating at high temperatures. The temperature during processing is often about 90 °C, and the jam is held at this temperature for 3–5 min to achieve proper heating of the entire fruit (Wicklund et al. 2005). The sensitivity to oxidative degradation enhanced by heat results in splitting of the anthocyanin molecule into biologically inactive forms, making them vulnerable to losses during food handling. The colour of strawberry

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products (jams, juices) is due to the presence of water-soluble anthocyanin pigment (pelargonidin-3-glucoside), which is unstable and susceptible to degradation during processing and storage (Zabetakis et al. 2000). Factors affecting the colour of strawberry products include storage temperature, pH, ascorbic acid, hydrogen peroxide, structure and concentration of anthocyanins, and cultivars (García-Viguera et al. 1998, 1999; Garzon and Wrolstad 2002; Özkan et al. 2002; Wicklund et al. 2005). The impact of processing and storage techniques on different components in berries varies significantly. Whereas vitamin C (AA and DHAA) is very susceptible to degradation when subjected to physical stress, other phenolic compounds and antioxidant activities in berry products are reported to be unchanged or even to increase during processing or storage (Kalt 2005; Amakura et al. 2000; Zafrilla et al. 2001; Mazza and Miniati 1994; Mikkelsen and Poll 2002).

Since colour is a critical quality parameter in food purchases, colour measurement has gained much attention from food scientists and industry (Quevedo et al. 2008; Du and Sun 2005). To investigate colour quality in a systematic way, it is necessary to objectively measure colour as well as pigment concentration (Ngo et al. 2007). An attractive red colour is one of the most important quality characteristics for the strawberry jam processing industry and may have an important influence on consumers' acceptance of jams and it is therefore very important that the jam is prepared and stored in a manner that maximises its colour stability. The underlying cause of the colour loss has been attributed to the degradation of anthocyanin pigments and the formation of browning compounds such as Maillard reaction products. Withy et al. (1993) reported that monomeric pigment concentrations decrease during storage, therefore stability of anthocyanins is markedly influenced by temperature (Markakis 1982). It was also demonstrated that vitamin C content decreases significantly during jam making and storage (Suutarinen et al. 2002). García-Viguera et al. (1999) studied the effect of cultivar and storage temperature (>20 °C) and storage period on quality of strawberry jam. However, studies show greater degradation of anthocyanins in raspberry jam stored at higher temperature. The reported optimum storage temperature for jam is 4 °C (Ochoa et al. 1999).

Kinetic models are often used for an objective, fast and economic assessment of food safety. Kinetic modelling may also be employed to predict the influence of processing on critical quality parameters. Kinetic models have been developed to evaluate degradation of quality parameters including colour, browning, ascorbic acid during thermal processing, high pressure processing, sonication, ozonation and pulsed electric field processing (Rodrigo et al. 2001; Polydera et al. 2005; Tiwari et al. 2008a, b). Anthocyanins and ascorbic acid degradation under isothermal heating are reported to follow first-order kinetics for juice and concentrate of sour cherry (Cemeroğlu et al. 1994), strawberries (Garzon and Wrolstad 2002) and blackberries (Wang and Xu 2007). These models can also be employed to predict the influence of processing on critical quality parameters. Hence, the objective of this study was to investigate the degradation kinetics of bioactive compounds and colour of strawberry jam during storage at two different temperatures.

Materials and Methods

Chemicals

2, 2-Diphenyl-1-picrylhydrazyl (DPPH), pyrogallol, Folin–Ciocalteau reagent (2 N), sodium carbonate, gallic acid, L-ascorbic acid, 2, 6-dichloroindophenol (DCIP) and pectin were obtained from Sigma Aldrich (Dublin, Ireland). Sodium hydrogencarbonate, metaphosphoric acid, methanol (HPLC grade), citric acid and ammonium sulphate were purchased from BDH (Poole, BH15, ITD, UK).

Formulation of Strawberry Jams

Procedure of jam making was adapted from Suutarinen et al. (2002) with some modifications. Strawberries (*Fragaria* × *ananassa* Duch. cv. Camarillo) were obtained from a local fruit importer (Keeling Ltd., Dublin, Ireland). After washing and dicing, the fruits (854.6 g) were blended in a mechanical blender (10–15 s) and the sugar (354 g) was placed in a saucepan, brought to a boil and held for 3 min, with constant stirring. Following this, further sugar (353 g) was added and heating continued until the mixture reached a temperature of 105 °C. Pectin (11.4 g) (GENU pectin 150 USA-SAG type) and citric acid (10.8 g) were added and the mixture was allowed to boil for another minute. After cooling to 88 °C, the jams were placed in glass jars and allowed to set overnight. In addition, total soluble solids were measured to ensure they gave a Brix index of approximately 55° Bx using a refractometer (2WA, Abbe, Japan). Samples were stored at 4 °C or 15 °C in a chiller and in an incubator (Genlab, L755055, Cheshire, UK), respectively. Sample analyses were carried out after 0, 7, 14, 21 and 28 days of storage. All treatments were carried out in triplicate.

Extraction of Antioxidants

Total Antioxidants and Phenols

Methanol (25 ml) was added to 4–5 g of fruit/jam and samples were homogenised for 1 min at 24,000 rpm using

an Ultra-Turrax T-25 tissue homogenizer (Janke & Kunkel, IKA®-Labortechnik, Germany). Following mechanical agitation (V400 Multitube Vortexer, Alpha Laboratories, The Netherlands) for 20 min at 1,050 rpm and room temperature, the samples were centrifuged (MSE Mistral 3000i, Sanyo Gallenkamp, Leicestershire, UK) for 15 min at 2,000 ×*g* and 4 °C. Samples (10 ml) of the supernatant were filtered through 0.22-μm PTFE syringe filters (Phenomenex, UK) and stored at −20 °C in foil-covered plastic test tubes for subsequent analysis.

Anthocyanins

Five grams of sample was homogenised in 25 ml of methanolic HCl (0.01 M) at 24,000 rpm using the Ultra-Turrax T25 tissue homogeniser for 70 s. Following this, samples were centrifuged at 2,000 ×*g* for 15 min at 4 °C.

Phenols

The total phenols (TP) in the jam samples were determined using Folin–Ciocalteau reagent according to the method of Singleton and Rossi (1965). Then, 100 μl of methanolic extract, 100 μl of MeOH, 100 μl Folin–Ciocalteau reagent (FC) and 700 μl of Na_2CO_3 were added to 1.5-ml microcentrifuge tubes and the samples were vortexed briefly. The tubes were then left in the dark for 20 min at room temperature. Following this, the samples were centrifuged (Eppendorf, Centrifuge 5417R, Germany) at 13,000 rpm for 3 min. The absorbance of the sample was read at 735 nm using aqueous gallic acid (10–400 mg/l) as a standard. Results were expressed as micrograms of gallic acid equivalent per gram of fresh sample.

Determination of Total Antioxidant Capacity

Total antioxidant capacity of the jams (extracts) was measured using the DPPH reagent as described by Puupponen-Pimia et al. (2003). Then, 2.8 ml of a methanolic solution of DPPH (45 μg/ml) was thoroughly mixed with 200 μl of methanolic test sample and placed in the sample cell of spectrophotometer (UV-1700 Pharma Spec, Shimadzu, Milton Keynes, UK). The absorbance of the mixture was measured after 30 min at 515 nm. The initial absorbance of the DPPH solution was also recorded and the decline in the radical concentration indicated the radical scavenging activity of the test sample. A methanolic solution of pyrogallol (125 μg/ml) was used as a reference corresponding to 100% radical scavenging activity and the total antioxidant capacity (TAC) of the methanolic extracts was expressed as a percent of the antioxidant capacity of pyrogallol as described in Eq. (1) below;

$$TAC(\%) = \frac{A_{0(\text{sample})} - A_{30(\text{sample})}}{A_{0(\text{pyrogallol})} - A_{30(\text{pyrogallol})}} \quad (1)$$

Where:

$A_{0/30\ (\text{sample})}$ absorbance of DPPH at 515 nm prior the addition of sample and 30 min after addition of sample

$A_{0/30\ (\text{pyrogallol})}$ absorbance of DPPH at 515 nm prior to addition of pyrogallol and 30 min after addition of pyrogallol

Determination of Ascorbic Acid

Ascorbic acid levels were determined by the method of the AOAC (1990). To 4–5 g of jam sample, 60 ml of saturated ammonium sulphate was added. The sample was then homogenised (2 min at 24,000 rpm) using an Ultra-Turrax T-25 tissue homogeniser. The extracts were filtered through a Whatman no. 4 filter paper or equivalent and 30 ml of the filtrate was collected to which 15 ml of metaphosphoric acid was added. The mixture was then titrated against the calibrated DCIP solution until a pale pink colour persisted for at least 15 s. Results were expressed as micrograms per gram fresh weight (of jam).

Determination of Anthocyanins (ANT)

Anthocyanin content of the extracts was determined by the spectrophotometric method of Wrolstad et al. (1982). Results were expressed as micrograms per gram fresh weight and anthocyanin content was calculated according to Eq. (2) below;

$$\text{Anthocyanin Pigment} = A \times \text{MW} \times \text{DF} \times 10^3/(\varepsilon \times \text{L}) \quad (2)$$

Where:

A the difference in absorbance (A) between pH 1.0 and 4.5 samples

MW molecular weight for pelarglodin-3-glucoside= 433 g/mol

DF dilution factor

ε extinction coefficient for pelarglodin-3-glucoside = 22,400

L path length=1.0 cm

Measurement of Instrumental Colour

The colour of the samples was measured using a Hunter-Lab colour meter (Hunter Lab DP-9000 colour difference meter, Hunter Associates Laboratory, VA, USA) fitted with

a 2.5-cm-diameter aperture. The instrument was calibrated using the black and white tiles provided. The instrument (65°/0° geometry, D25 optical sensor, 10° observer) was calibrated using white (L 92.8; a −0.8, b 0.1) and black reference tiles. Colour was expressed in Hunter Lab units L, a and b. In addition, chroma and total colour difference (TCD) were calculated using the following equations, where L_0, a_0, b_0 are the control values for strawberry jam. TCD indicates the magnitude of colour difference between stored and control samples. Differences in perceivable colour can be analytically classified as very distinct (TCD > 3), distinct (1.5 < TCD < 3) and small difference (TCD < 1.5) (DrLange 1999; Tiwari et al. 2008a).

Total colour difference

$$= \left[(L-L_0)^2+(a-a_0)^2+(b-b_0)^2\right]^{1/2} \quad (3)$$

$$\text{Chroma} = \left(a^2+b^2\right)^{1/2} \quad (4)$$

Statistics

Analysis of variance (ANOVA) and separation of means was carried out using the Proc GLM procedure (SAS V.9.1, SAS Institute, NC, USA). Treatment means were separated using Tukeys' test and considered significantly different at $p<0.05$. All trials were conducted in triplicate. The degradation of ascorbic acid, anthocyanins and colour loss in strawberry jam were calculated by using the standard equation for zero and first-order reactions and degradation rate constants were determined by fitting Eqs. (5) and (6) to experimental data.

$$C = C_0 + k_0 t \quad (5)$$

$$C = C_0 e^{k_1 t} \quad (6)$$

where C is the studied parameter (L, a, b, ANT, AA, TCD) at any given reaction time, C_0 are initial values of untreated samples and k_0, k_1 are rate constants. Data fitting was considered significant at a probability level of 95%. ANOVA was carried out to determine any significant differences ($p<0.05$) during storage.

Results and Discussion

Effect of Storage Time and Temperature on Colour Parameters of Strawberry Jam

Table 1 shows the colour attributes of strawberry jam during storage period of 28 days. Table 1 indicates that L value decreased significantly ($p<0.05$) from 18.3 to 17.5 at 4 °C and to 17.0 at 15 °C during storage period compared to control. Higher temperature had a pronounced effect on lightness of strawberry jam. Significant decrease in L value was observed after 7 days of storage at 4 °C, whereas jams stored at 15 °C also exhibited lower values ($p<0.05$). It is quite evident that samples stored at higher temperature (15 °C) had lower L values during storage period of 28 days. Similar results were reported by García-Viguera et al. (1999). Martí et al. (2002) also reported a significant decrease in L value during storage period of 150 days at 25 °C, resulting in darker colour during the storage period of pomegranate juice. Results also demonstrated that yellowness of jams were fairly consistent up to 28 days of storage at both temperatures with the exception on day 28 at 4 °C, where values decreased significantly ($p<0.05$) as compared to control sample. Redness of strawberry jam was found to decrease significantly on day 7 at both temperatures. It is also clear that storage of jam at any

Table 1 Changes in quality parameters of strawberry jam during storage

Storage time (days)	L*	a*	b*	Anthocyanins[r]	Ascorbic acid[s]
Temperature 4 °C					
0	18.3±0.41[a]	28.6±0.31[a]	8.7±0.14[a]	164.8±6.32[a]	429.0±27.2[a]
7	17.5±0.25[b]	22.3±0.17[b]	8.6±0.16[ab]	142.9±2.06[ab]	385.7±17.6[b]
14	17.4±0.17[b]	21.4±0.14[b]	8.4 ±0.03[ab]	134.0±4.77[ab]	243.0±14.3[c]
21	17.4±0.24[bc]	20.9±0.16[b]	8.4 ±0.05[ab]	125.5±2.79[b]	233.8±23.7[dc]
28	17.0±0.12[c]	20.5±0.09[b]	8.3±0.85[b]	114.9±7.67[c]	215.5±12.6[d]
Temperature 15 °C					
0	18.3±0.41[a]	28.6±0.31[a]	8.7±0.14[a]	164.8±6.32[a]	429.0±27.2[a]
7	17.0±0.21[b]	21.8±0.19[b]	8.6±0.10[a]	120.0±1.32[b]	302.0±15.2[b]
14	17.0±0.12[b]	21.6±0.43[b]	8.5±0.16[a]	115.2±2.21[bc]	200.0±19.5[c]
21	16.6±0.09[b]	20.9±0.53[b]	8.1±0.12[a]	114.5±3.02[c]	134.4±21.2[d]
28	16.5±0.11[b]	20.8±0.44[b]	8.1±0.19[a]	103.7±4.07[d]	128.6±16.5[d]

[abcd] Values followed by same letter within a column are not significantly different ($p<0.05$)

[r] Expressed as μg/g fresh weight

[s] Expressed as μg/g fresh weight

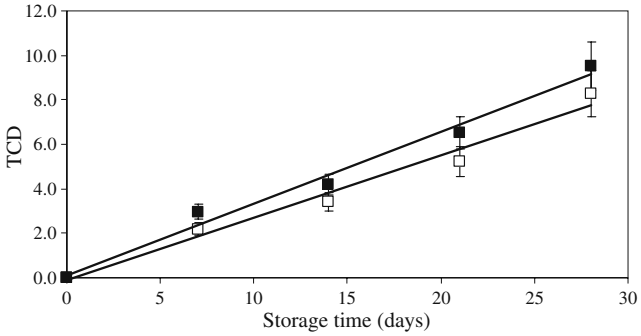

Fig. 1 Changes in total colour difference in strawberry jam stored at (□) 4 and (■) 15 °C, respectively

temperature generally results in a shift towards lower Hunter *a* values; this shift is greater in the case of jams stored at 15 °C compared to 4 °C storage temperature. Similar results were reported by Suutarinen et al. (2002). They found that colour coordinates (*L*, *a*, *b*) of jam berries and media after 2 weeks of jam making degraded significantly ($p<0.05$). García-Viguera et al. (1999) reported that only *a* values showed a decrease in response to an increase in storage temperature, giving jams a less red hue. Figure 1 indicates total colour difference (TCD) increased linearly ($p<0.05$) for jam during storage. TCD values for this study were found to be very distinct after storage period of 9 and 11 days at storage temperature of 4 and 15 °C, respectively. Chroma, one of the important colour attributes of jam, was found to decrease exponentially ($p<0.05$) during storage following first-order degradation (Fig. 2) with a coefficient of determination (R^2) of 0.96 and 0.91 for samples stored at 4 and 15 °C, respectively (Table 2).

These results demonstrate the significant effect of storage temperature and time on the colour degradation of the samples studied. Strawberry jam colour is a mix of red and yellow. Changes in strawberry juice is associated with anthocyanin degradation since anthocyanins are responsible for appealing, bright red colour of strawberry jam. Parallel to decrease in *a* values, anthocyanin content of samples decreased

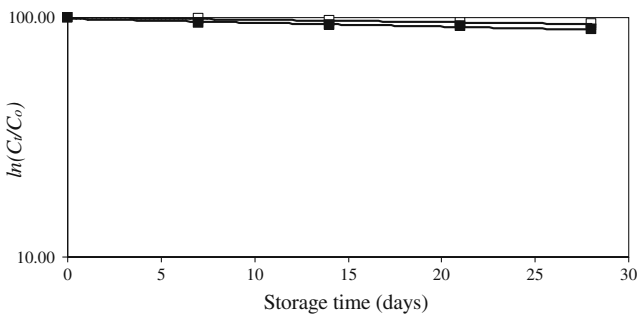

Fig. 2 Effect of storage time on colour intensity (chroma) of strawberry jam stored at (□) 4 °C and (■) 15 °C, respectively

Table 2 Effect of storage temperature on rate constant ($days^{-1}$) for quality parameters of strawberry jam

Parameter	Storage temperature (°C)	$K\times10^{-2}$ ($days^{-1}$)	R^2
Anthocyanin	4.0	0.95±0.23	0.95
	15.0	1.71±0.11	0.91
Ascorbic acid	4.0	2.08±0.23	0.94
	15.0	4.54±0.43	0.95
TCD	4	27.55±1.05	0.97
	15	32.84±1.43	0.98
Chroma	4	0.21±0.01	0.95
	15	0.45±0.02	0.91

throughout the storage. High correlation was found between *a* value and anthocyanin content of jams during storage, with the correlation coefficients ($r=0.92$, $p=0.023$) at 4 °C and ($r=0.98$, $p=0.002$) at 15 °C.

Ascorbic Acid and Anthocyanin Degradation

In the present study, levels of anthocyanin in strawberry jams ranged from 114.9 to 164.8 µg of anthocyanins/g fruit in jam and 103.7–164.8 µg/g among all the samples analysed at 4 and 15 °C, respectively (Table 1); these values are in the range of those reported elsewhere by other authors (García-Viguera et al. 1999). Ascorbic acid content of strawberry jam was 128.6–429.0 µg/g (Table 1) and values were within the range as reported in the literature (Suutarinen et al. 2002). Ascorbic acid and anthocyanin content was found to decrease with increase in storage time and temperature. A decrease of 10.0% and 29.6% was observed for ascorbic acid after 7 days of storage at 4 and 15 °C of storage temperature, whereas 49.7% and 70.0% decrease was observed after 28 days of storage period. Conversely, total anthocyanins were found to be decreased by 13.2% and 27.1% after 7 days of storage at 4 and 15 °C of storage temperature and 30.2% and 37.1% decrease after

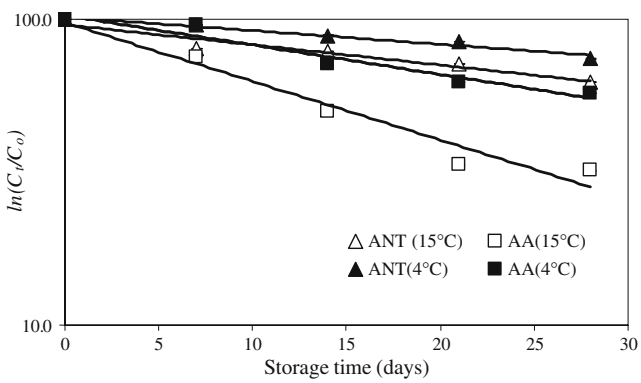

Fig. 3 Effect of storage time (days) on anthocyanins (*ANT*) and Ascorbic acid (*AA*) content of strawberry jam at varying temperature

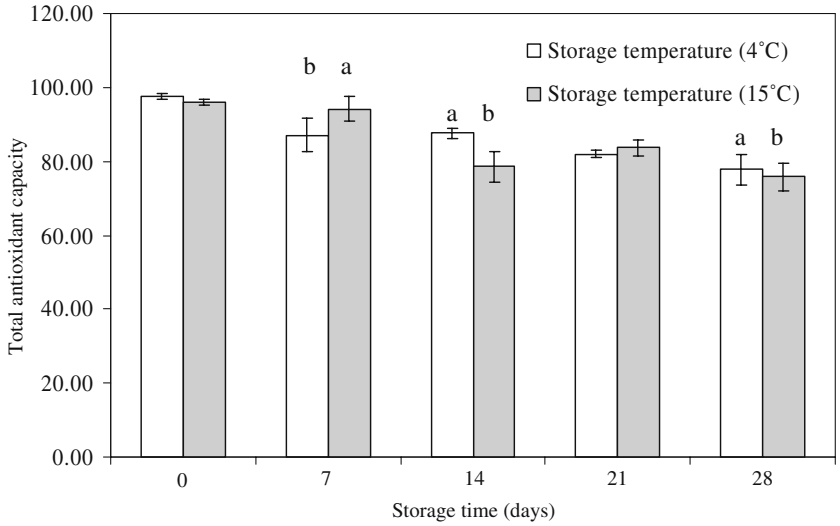

Fig. 4 Changes in total antioxidant capacity (%) of strawberry jam during storage. *Bars* represent mean ± standard deviation; *a*, *b* indicates significance ($p<0.05$)

28 days at 4 and 15 °C, respectively. These results indicate that ascorbic acid and anthocyanin loss is greater at 15 °C compared to 4 °C storage temperature. The degradation of anthocyanins and ascorbic acid in all strawberry jam samples at 4 and 15 °C were fitted to a first-order kinetic model (Fig. 3), confirming the results of previous studies reporting the same model during storage (Garzon and Wrolstad 2002; Skrede et al. 1992). Ascorbic acid and anthocyanin content was found to follow first-order degradation with $R^2>0.91$ (Table 2). Degradation rate constant for AA was 2.08×10^{-2} day^{-1} and 4.54×10^{-2} day^{-1} at 4 and 15 °C, respectively. This indicates that degradation rate constant is dependent on storage temperature. Similarly, higher degradation rate constant was observed for anthocyanin at 15 °C (1.71×10^{-2} day^{-1}) compared to 4 °C (0.95×10^{-2} day^{-1}). Ochoa et al. (1999) reported minor changes in total anthocyanin content in raspberry pulp stored at 4 °C compared to 20 and 37 °C. Similar results were reported for jam samples, where vitamin C content decreased significantly during preparation of jam and storage (Suutarinen et al. 2002). Anthocyanins and vitamin C are reported to be heat-labile compounds and are unstable at high temperature during processing or storage (Piga et al. 2003b). The stability of anthocyanins or vitamin C is also influenced by other fruit components, particularly the interaction of vitamin C with anthocyanin which has been reported in strawberry juice and model systems (Sondheimer and Kertesz 1953). Ngo et al. (2007) reported that total anthocyanins in strawberries canned in 20°Bx syrup declined 69% over 60 days at room temperature storage. Processing berries into purees resulted in a 43% loss in total monomeric anthocyanins, compared to original levels found in fresh fruit (Brownmiller et al. 2008). Similar losses in raspberry purees were reported by Ochoa et al. 1999. However, it has been reported that catechin and PPO readily react, resulting in reactive

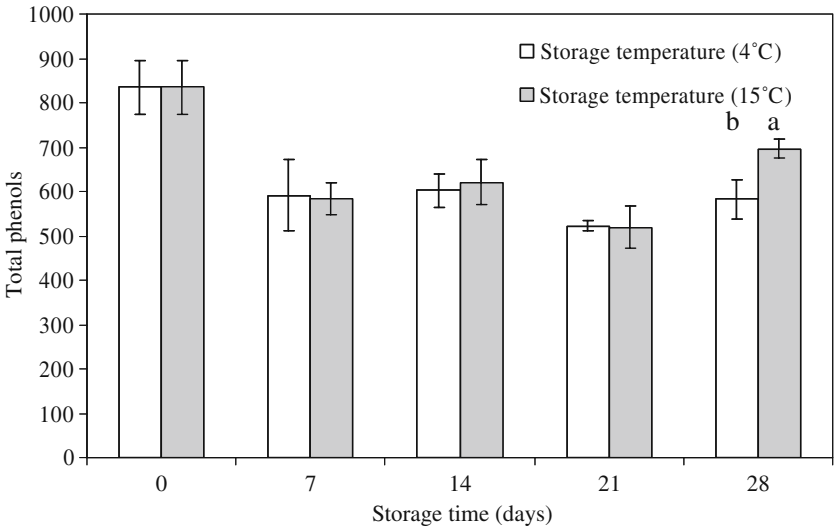

Fig. 5 Changes in phenol content (mg GAE/100 g) of strawberry jam during storage. *Bars* represent mean ± standard deviation; *a*, *b* indicates significance ($p<0.05$)

quinones which degrade anthocyanins, thereby altering colour (Wesche-Ebeling and Montgomery 1990) or influence of heat treatment leads to dissociation of the complexes and a release of the flavylium cation that is hydrated to the colourless and labile hemiacetal base, causing a decrease of total anthocyanin content (Dangles and Brouillard 1992).

Effect of Storage Time and Temperature on Total Antioxidant Activity and Phenolic Content of Strawberry Jam

The experimental results obtained as a function of storage treatment (days) are shown in Fig. 4. Radical scavenging activity of methanolic extracts of strawberry jam was expressed as total antioxidant capacity (TAC) in this study and compared with a synthetic antioxidant, pyrogallol. Using the DPPH assay, the results of the antioxidant capacity of strawberry jam samples stored at 4 and 15 °C showed a decrease over 28 days storage period. Antioxidant capacity of strawberry jam decreased to 78.6% as compared to initial value of 96.8% at 4 °C ($p<0.05$) over 28 days storage period. A similar trend was observed at 15 °C, where levels decreased to 77.5% at the end of storage as compared to control value ($p<0.05$). Amakura et al. (2000) reported that radical scavenging activity of bayberry, blackcurrant, blackberry, blueberry, raspberry, red currant and strawberry jam decreased by 50–60% of its initial value. In our study, antioxidant capacity of strawberry jams was much higher. Some authors have also reported that reduction of total antioxidant capacity of orange juices based on the radical scavenging of free radicals (hydroxyl and 1, 1-diphenyl-2-picrylhydrazly radicals) was attributed to the degradation of vitamin C by thermal treatments (Lo Scalzo et al. 2004).

The changes in the total phenolic content during storage of strawberry jam are shown in Fig. 5. Total phenols (TP) in strawberry jam ranged from 837.1 to 528.8 μg/g FW and 837.1–545.5 μg/g at 4 and 15 °C, respectively, among all samples analysed. Storage time and temperature had a significant effect ($p<0.05$) on total phenolic content. During storage of jam at 4 °C, TP levels were generally decreased ($p<0.05$). We observed losses of 24.2%, 26.3%, 36.8% and 31.6% on day 7, 14, 21 and 28, respectively, as compared to control sample at 4 °C. In contrast, strawberry jam lost 28.6%, 22.5%, 34.8% and 17.6% of TP over the storage period at 15 °C ($p<0.05$). Differences in phenolic stability occurred between storage temperatures, being slightly higher at higher temperatures. During fruit processing, cell structures are disrupted and the fruits become more prone to non-enzymatic oxidation which could be one of the main reasons for the loss in phenolic compounds. Total phenolic content was significantly correlated with total antioxidant activity ($r=0.84$, $p=0.045$) at 4 °C and ($r=0.98$, $p=0.003$).

Conclusions

The kinetics of ascorbic acid and anthocyanin degradation and colour changes of strawberry jam during storage were investigated. The first-order kinetic model was the best fit for the ascorbic acid, anthocyanins degradation and colour loss. Results indicated that low temperature storage (4 °C) is ideal for strawberry jam as degradation of ascorbic acid and anthocyanin is significantly lower compared to higher temperature (15 °C). This was also apparent from this study that the most sensitive parameter for the measurement of colour degradation in strawberry jam in response to temperature treatment during storage was chroma and total colour difference. Colour change (a) and anthocyanin content was highly correlated, whereas a good correlation was also observed between total antioxidant activity and phenolic. In general, total phenols and total antioxidant activity of jams were relatively lower at higher temperatures. Thus, the effects of storage conditions on the nutritional properties of strawberry jam should be considered prior to selection of storage conditions. Further studies on the stabilisation of strawberry anthocyanins are needed if strawberries would be processed into jams.

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