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Food Chemistry

Title:

Effect of temperature on stability of anthocyanins, ascorbic acid and color in strawberry and raspberry jams

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Abstract:

Strawberry (cv. Senga Sengana) and raspberry (cv. Veten) were processed into jams at 60, 85 or 93 °C and stored at 4 or 23 °C for 8 and 16 weeks. High processing temperature reduced ascorbic acid, total monomeric anthocyanins (TMA) and total phenolics (TP) in strawberries (p<0.05), but not in raspberries. Processing temperature had minor effect on bioactive compounds in the jams during storage (<10% explained variance), but influenced color (L*, Hue, Chroma), especially L* of the strawberry jams (73.3%). Storage period explained most of the variance in ascorbic acid (>90%), TMA (>42%) and TP (>69%). Storage temperature affected stability of anthocyanins, but had minor effect on ascorbic acid, which declined rapidly independent of storage temperature. Storage temperature also explained most of the variance (>40%) in Chroma of the jams and L* of raspberry jams (53%). Bioactive compounds and color were more stable in raspberry jams than in strawberry jams.

Keywords: Strawberry, raspberry, processing, jam, storage, anthocyanin, ascorbic acid, color

Chemical compounds studied in this article:

Pelargonidin-3-glucoside (PubChem CID: 443648); Cyanidin-3-glucoside (PubChem CID: 197081); Cyanidin-3-sophoroside (PubChem CID: 44256720); Cyanidin-3-rutinoside (PubChem CID: 441674); L- ascorbic acid (PubChem CID: 54670067).

1. Introduction

Strawberry and raspberry are popular commodities worldwide. The berries have attractive taste and appearance and are rich sources of bioactive compounds. Sugars, organic acids and volatile compounds are responsible for the characteristic flavor and odor of the berries while polyphenols, ascorbic acid and dietary fiber are suggested to cause the observed health benefits of berries (Giampieri et al., 2012; Rao & Snyder, 2010).

The main groups of polyphenols in strawberries and raspberries are anthocyanins, ellagitannins and proanthocyanidins (Aaby, Mazur, Nes, & Skrede, 2012; Buendia et al., 2010; Zafrilla, Ferreres, & Tomás-Barberán, 2001). There are differences in the composition and concentration of different phenolic compounds between the two types of berries. While the major anthocyanin in strawberry is pelargonidin-3-glucoside (Pg-3-gluc) (Aaby et al., 2012; Buendia et al., 2010), raspberries predominantly contain cyanidin glycosides (Boyles & Wrolstad, 1993; Mazur et al., 2014a). The difference in anthocyanin composition causes a lighter and more yellow/orange hue of strawberries compared with a darker and more bluish hue of raspberries (Giusti & Wrolstad, 2001).

The levels of ascorbic acid, total amounts of phenolics and antioxidant capacity also vary between the two types of berries (Skrede, Martinsen, Wold, Birkeland, & Aaby, 2012). Ascorbic acid is valuable as a source of vitamin C, and as an antioxidant it also influences stability of bioactive compounds like anthocyanins and other polyphenols in berries and berry products (Nikkhah, Khaiamy, Heidary, & Azar, 2010; Skrede, Wrolstad, Lea, & Enersen, 1992).

Berries are often processed into jams, jellies, purees and juices. Processing mostly involves heating to inactivate microorganisms and endogenous degrading enzymes like polyphenol oxidase (Holzwarth, Korhummel, Kammerer, & Carle, 2012). The heat treatment may, however, also degrade bioactive compounds by non-enzymatic reactions (Ngo, Wrolstad, & Zhao, 2007; Patras, Brunton, O'Donnell, & Tiwari, 2010) and processing is shown to cause slight decrease in concentrations of polyphenols and ascorbic acid in strawberries (Klopotek, Otto, & Bohm, 2005) and raspberries (Garcia-Viguera et al., 1998; Mazur et al., 2014a; Oancea & Calin, 2016). The decrease in content of bioactive compounds are more extensive at higher processing temperatures (Holzwarth, Korhummel, Siekmann, Carle, & Kammerer, 2013).

Storage of berry products affects flavonoids and ascorbic acid negatively, especially at high storage temperatures and prolonged storage period (Aaby, Wrolstad, Ekeberg, & Skrede, 2007; Mazur et al., 2014b; Patras, Brunton, Tiwari, & Butler, 2011). Color is an important quality criterion of berry jams, and several studies have reported extensive color changes during processing and storage of jams (Bursać Kovačević et al., 2015; Holzwarth et al., 2012; Mazur et al., 2014b; Pineli, Moretti, Chiarello, & Melo, 2015).

While strawberries have been widely studied, the effects of processing of raspberries are not extensively investigated, and as far as we know, the effect of temperature during raspberry jam production has not been determined. Results from previous studies indicate that ascorbic acid, anthocyanins and color are more stable in raspberry jam than in strawberry jam, but this has not been evaluated in the same study. The industry would benefit from more comparative knowledge of the importance of different processing and storage conditions on quality of strawberry and raspberry products.

Based on previous studies, our hypotheses were that processing temperature affects bioactive compounds and color of strawberries and raspberries both directly throughout processing and during subsequent storage of jams, and that bioactive compounds and color are more stable in raspberries than in strawberries. The study thus aimed at determining the effects of processing temperature, storage temperature and length of storage period on the stability of bioactive compounds and color parameters of strawberries, raspberries and their jams, and to compare the results for the two types of berries.

2. Materials and methods

2. 1. Chemicals

Methanol, acetonitrile, phosphoric acid, acetic acid, HCl, potassium phosphate, L-ascorbic acid and sodium carbonate, all analytical or HPLC grade, were obtained from Merck KGAa (Darmstadt, Germany). Metaphosphoric acid, gallic acid, Folin-Ciocalteau's reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH•), potassium sorbate and sodium benzoate were obtained from Sigma-Aldrich (St. Louis, MO, USA) and Trolox from Fluka Chemie GmbH (Buchs, Switzerland). Pelargonidin-3-glucoside (Pg-3-gluc), cyanidin-3-glucoside (Cy-3-gluc), cyanidin-3-sophoroside (Cy-3-soph) and cyanidin-3-rutinoside (Cy-3-rut) were purchased from Polyphenols AS (Sandnes, Norway). Pectin (LM 102) was obtained from CPKelco (Denmark).

2.2. Berry material

Commercially ripe strawberries (*Fragaria* x *ananassa*, cv. Senga Sengana) and raspberries (*Rubus idaeus*, cv. Veten) were obtained singel-frozen from Valldal Grønt (Valldal, Norway). The berries were stored at –20 °C until processing.

2.3 Jam processing

The method for jam processing was based on input from the jam industry in Norway, and was similar to a procedure previously described (Mazur et al., 2014a). Jams were processed at three temperatures; 60, 85 or 93 °C (± 3°C). The berries were thawed at room temperature for two hours, homogenized and processed in a jam pilot plant (Flowtech, Skanderborg, Denmark) consisting of a heating vessel with steam jacket, and a vessel for holding the jams before filling into jars. Berries (6 kg) and water (0.7 L) were heated to 10 °C before sugar (6.9 kg) was added. The mixture was heated to final temperatures of 60, 85 or 93 °C, and held at those temperatures for 5 min. Pectin (90 g) dissolved in hot water (1.05 L) was added at vigorous stirring, along with preservatives (benzoate and sorbate, 0.3 and 0.4 g/kg, respectively) and citric acid (140 mL of a 25% solution). The jams were filled into glass jars (200 g) at 60 – 65 °C. The production was performed in duplicate (production number 1 and 2) at each temperature. Four jars of jams from each production were used for analysis of fresh jams. The remaining jars were stored in the dark at 4 or 23 °C and analyzed after storage for 8 and 16 weeks. The processing procedure was the same for strawberries and raspberries.

With this recipe, the jams contained about 40% berries (weight/weight). The chemical composition of the jams, except for pH, °Brix and color were calculated and expressed as mg per 100 g of berries in jams.

133

134 *2.4. Soluble solids and pH*

135 Soluble solids in berries and jams were measured by refractive index on a Mettler
136 Toledo RE40 digital refractometer (Mettler-Toledo AG, Greifensee, Switzerland),
137 and given as °Brix (g sucrose per 100 g of sample). pH was measured with a
138 Methron 744 pH-meter (Methron AG, Herisau, Switzerland).

139

140 *2.5 Ascorbic Acid*

141 L-ascorbic acid was determined using a method previously described (Sànchez-
142 Mata, Camara-Hurtado, Diez-Marques, & Torija-Isasa, 1999). Berries or jams (15 g)
143 were homogenized in 4.5% metaphosphoric acid (20 mL) for 1 min with a Polytron
144 PT3100 homogenizer (Kinematica AG, Lucerne, Switzerland). The homogenate was
145 made to 50 mL with 4.5% metaphosphoric acid and centrifuged at 12 100 x *g* for 20
146 min at 15 °C (Beckman J2-21M, Palo Alto, California). The supernatant was filtered
147 through a fluted filter (Schleicher & Schuell, 597 ½, Φ125 mm), and purified on
148 SepPak alumina A cartridge (Waters, Milford, USA) activated with 5 mL acidified
149 methanol (0.01 M HCl) and 5 mL acidified water (0.01 HCl). The eluate was filtered
150 through a 0.45 µm Millex-HA filter (Millipore, Billerica, MA, USA) before injection (5
151 µl) on HPLC.

152 The HPLC used was an HP 1100 (Agilent Technologies, Waldbronn, Germany) with
153 Chemstation software, auto injector and diode array detector. The column was a
154 Supelco LC 18 DB column (25 cm x 4.6 mm) with 5 µm packing material and a
155 guard column with the same material, both from Supelco Park (Bellefonte, PA,

156 USA). Separation was performed isocratic with mobile phase of methanol, 0.05 M
157 KH_2PO_4 (pH 2.6) and water in the ratio 26/60/14 volume/volume/volume (v/v/v).
158 Flow rate was 1 mL/min, and the absorbance was recorded at 245 nm. The amount
159 of L-ascorbic acid was calculated from an external linear standard curve with four
160 concentrations (0-0.5 mg/mL), expressed as mg ascorbic acid per 100 g of berries
161 or berries in jams.

162

163 2.6. Total Monomeric Anthocyanins (TMA)

164 Analysis of total monomeric anthocyanins (TMA) was performed using the pH
165 differential method as previously described (Wrolstad, Durst, & Lee, 2005), using an
166 HP 8542A spectrophotometer (Agilent Technologies). Acidified methanol extracts
167 (0.2 mL) were diluted in buffers (0.8 mL) at pH 1 (potassium chloride, 0.025 M) and
168 pH 4.5 (sodium acetate, 0.4 M). Absorptions were detected at 700 nm, in addition to
169 510 nm for strawberry and 520 nm for raspberry, after 50 min reaction time at room
170 temperature. TMA in strawberry was calculated as equivalents of Pg-3-gluc with
171 molar extinction coefficient (ε) 22 400 and molecular weight (MW) = 433.2 g/mol.
172 Raspberry anthocyanins were quantified as equivalents of Cy-3-gluc with ε 29 600
173 and MW = 445.2 g/mol. The results were reported as mg anthocyanin per 100 g of
174 berries or berries in jams.

175

176 *2.7. Extraction of phenolic compounds*

177 Phenolic compounds were extracted from berries and jams as previously described
178 (Boyles & Wrolstad, 1993). Exactly weighed sample (ca. 3 g) was added 15 mL
179 acidified methanol. The mixture was gently homogenized with magnetic agitation

(RCT basic, IKA Werke GMBH & Co, KG Staufen, Germany) at 4 °C overnight. The solution was placed at room temperature before filtering through a fluted filter and washed with acidified methanol until a total volume of 25 mL. Extractions were performed in duplicate. Acidified methanol extract was used for analyzes of individual anthocyanins, total monomeric anthocyanins and total phenolics. For the DPPH analysis, the phenolic compounds were extracted with pure methanol.

2.7.1. Purification of extract for analysis of individual anthocyanins

Acidified methanol extract (5 mL) was evaporated at 37 °C under nitrogen flow (Pierce, Reacti-Therm III, Heating/Stirring Module, Rockford, IL,), and then dissolved in water (5 mL). Aliquots of 2 mL were purified by solid phase-extraction on a C18 SepPak cartridge (Waters, Milford, MA, USA) which was activated with acidified methanol (5 mL) and acidified water (5 mL) before use. The sample was eluted from the cartridge with acidified methanol (4 mL). The eluate was evaporated to dryness, dissolved in phosphoric acid/acetic acid/acetonitrile/water (1/10/5/84, v/v/v/v; mobile phase A) (1 mL), and filtered through a 0.45 µm Millex-HA filter prior to injection on HPLC.

2.8. Analysis of individual anthocyanins by HPLC

Individual anthocyanins were analyzed using an HP 1050 HPLC (Agilent Technologies) with Chemstation software, auto injector and diode-array detector. The purified extract (20 µL) was injected and separated on a Luna C-18 column (250 mm x 4.6 mm i.d. 5 µm particle size) with a 5 µm C-18 (ODS) guard column (4.0 mm L x 3.0 mm i.d.), both from Phenomenex (Torrance, CA, USA) (Skrede,

Wrolstad, & Durst, 2000). The mobile phases consisted of A; phosphoric acid/acetic acid/acetonitrile/water (1/10/5/84, v/v/v/v) and B; acetonitrile. Anthocyanins were eluted using a gradient from 2% to 12% B in 15 min, up to 22% B from 15 to 20 min, and held at 22% B for 5 min. Flow rate was 1 mL/min. The anthocyanins were quantified by external standards of Pg-3-gluc (λ= 510 nm) for strawberry and Cy-3-soph, Cy-3-gluc and Cy-3-rut (λ= 520 nm) for raspberry. The linear standard curves were made with four concentrations (7.6 – 40 µg/mL). All extracts were analyzed in duplicate. The concentration of anthocyanin was expressed as mg per 100 g of berries or berries in jams.

2.9. Total Phenolics (TP)

Total phenolics (TP) were determined as previously described (Aaby et al., 2007). Gallic acid standard or acidified methanol extracts (200 µL) were mixed with Folin-Ciocalteau's reagent (1000 µL, diluted 1:10 with water) and 7.5% Na_2CO_3 (800 µL) and incubated for 30 min at room temperature. The sample was mixed before measuring absorbance at 765 nm in an HP 8542A spectrophotometer. In the blanks, extracts were replaced by water. TP was calculated as gallic acid equivalent (GAE) using a standard calibration curve for gallic acid (5 – 40 µg/mL) and given as mg GAE per 100 g of berries or berries in jams.

2.10. Anti-radical power (ARP)

Antioxidant capacity was determined as the scavenging effect of the sample extract towards the stable free radical 2,2-diphenyl-1-picrylhydroxyl (DPPH•) as previously

described (Skrede et al., 2012). Methanolic extracts (0.1 mL) were added to 3.9 mL DPPH• solution (25 mg/mL) and the absorbance (515 nm) was immediately recorded by an HP 8542A spectrophotometer. The sample was kept in dark at room temperature for 120 min before the next measurement (515 nm), to determine the decrease in absorbance. Each sample was prepared in duplicates for each of at least three concentrations. The amount of sample required to decrease the initial DPPH• concentration by 50% (EC_{50}) was calculated by linear regression of remaining DPPH• (percentage) versus sample concentration. The anti-radical power (ARP) was given as the reciprocal of EC_{50} in units of μmol Trolox equivalents (TE) per gram of sample and was expressed as μmol TE per g of berries or berries in jams.

2.11. Color measurement

Color measurements of berries and jams were performed with a Hunter Lab, LabScan XE (Hunter Associates Laboratory, Reston, VA, USA) based on the CIE L*a*b* system with illuminant D65 and 10° observer. L* indicates lightness, where white = 100 and black = zero. °Hue (color shade) was calculated as arc tan (b*/a*), and Chroma (color intensity – a vector from grey to saturated color) as square root of ($a^{*2}+b^{*2}$) (Wrolstad, Durst, & Lee, 2005).

The samples were homogenized (Braun kitchen machine, Melsungen, Germany) and filled into a glass cup equipped with a rubber ring giving the sample thickness. A white disk was placed on top of the sample. Measurements were performed in duplicate for each sample cup, and the cup was filled twice with each sample.

2.12. Statistical analysis

The results reported for berries were based on duplicate extractions (n = 2). The results reported for jams were based on duplicate extractions or samples of jams from two productions at each processing temperature (n = 2 x 2). Data were presented as mean ± standard deviation. One-way analysis of variance (ANOVA) was performed to evaluate significant differences between the samples. Differences between average responses were evaluated by Tukey's pairwise comparisons test. The differences were regarded as significant when $p<0.05$. ANOVA, a general linear model, was used to determine effects of the experimental factors and their interactions. The production number (1 and 2) and all interactions involving the production number were considered random effects, while the remaining factors; processing temperature (P_{Temp}; 60, 85 and 93 °C), storage period (S_{Time}; 0, 8, and 16 weeks), and storage temperature (S_{Temp}; 4 and 23 °C) were fixed. Explained variances of the factors and their interactions were the sum-of-squares as percentage of total sum-of-squares. Statistical analysis was performed using Minitab® Statistical Software (version 16, Minitab Ltd., State College, PA, USA).

3. Results

3.1. Effects of jam processing

Soluble solids, pH, ascorbic acid, total monomeric anthocyanins (TMA), individual anthocyanins, antioxidant properties (TP and ARP), and color attributes (L*, °Hue and Chroma) of berries and freshly made jams processed at 60, 85, and 93 °C are given in Table 1 (strawberry) and Table 2 (raspberry), respectively. As all parameters

except soluble solids, pH and color were calculated based on berries in jams, the impact of processing temperature on berry constituents can be directly compared.

Sugar was added during processing and contents of soluble solids were thus considerably higher in jams than in berries. Citric acid was included in both raspberry and strawberry jams, but lowered pH only in the strawberry jams.

3.1.1. Ascorbic acid, anthocyanins and antioxidant properties

Processing at 93 °C significantly decreased concentration of ascorbic acid in strawberries by 37% (p<0.05), whereas processing at 60 and 85°C had no significant effect on ascorbic acid content (Table 1). For raspberry, processing into jams had no significant effect on levels of ascorbic acid (Table 2).

TMA in strawberry jams were not significantly different from TMA in the berries (p>0.05) (Table 1). TMA in strawberry jams processed at 85 and 93 °C was, however, significantly lower than after processing at 60 °C; the loss being about 20% (p<0.05). Processing into jam had no significant effect on Pg-3-gluc (p>0.05), but there was a tendency towards a gradual decrease in concentration with increasing processing temperature. Production of raspberry jams had no significant effect on TMA at any temperatures (Table 2). Both Cy-3-(2^{G}-glucrut) and Cy-3-soph increased during processing, but significantly only at 85 °C (p<0.05). Cy-3-gluc and Cy-3-rut decreased significantly when processed at 93 °C.

The antioxidant parameters total phenolics (TP) and antiradical power (ARP) of the jams were not significantly different from the values in the berries (p>0.05) (Tables 1 and 2).

297

298 *3.1.2. Color*

299 When processing strawberries into jams, the color turned darker (lower L*), more
300 yellowish (higher °Hue) and less intense in chromaticity (lower Chroma), with the
301 most pronounced and significant changes in L* and Chroma at the higher processing
302 temperatures (p<0.05) (Table 1). Raspberries became darker (lower L*) and less
303 intense in chromaticity (lower Chroma) when processed into jams (Table 2). There
304 were no significant differences in color of raspberry jams processed at different
305 temperatures (p>0.05). The raspberry jams were darker, and Chroma was lower,
306 compared with the strawberry jams.

307

308 *3.2. Effects of processing temperature, storage temperature and storage period*

309 The effects of processing temperature, storage temperature and storage period, on
310 bioactive compounds and color of strawberry and raspberry jams are given in Tables
311 3 and 4, respectively. Chemical composition and color of the jams at production and
312 after storage are presented in Tables 5 and 6, respectively.

313

314 *3.2.1. Ascorbic acid*

315 Processing temperature (P_{Temp}) and its interaction with storage period (P_{Temp} x S_{Time})
316 had significant effects on ascorbic acid in strawberry jams but explained only 5.0%
317 (p≤0.01) and 4.8% (p≤0.01) of the variation, respectively (Table 3). The
318 concentration of ascorbic acid in the strawberry jams decreased significantly (54 –
319 68%) during the first 8 weeks of storage (p<0.05) (Table 5). Storage period (S_{Time}),

explained 87.2% of the variance ($p \leq 0.001$), while storage temperature (S_{Temp}) showed no significant effect on ascorbic acid degradation ($p > 0.05$). After 8 weeks of storage at 4 and 23 °C there were no significant differences between ascorbic acid levels in the jams ($p > 0.05$). After storage for 16 weeks at 4 and 23 °C, 37% and 25% of ascorbic acid remained in the strawberry jams, with no significant effects of processing temperatures.

For raspberry jams, there were no significant effects of processing temperature (P_{Temp}) on ascorbic acid contents (Table 4). The variance was mainly explained by storage period (S_{Time}, 97.1%). Ascorbic acid contents decreased significantly during the first 8 weeks of storage ($p < 0.05$) (Table 6). The degradation of ascorbic acid continued upon storage, and the concentration was approximately 10 mg/100 g in all jams (26-42% retention) after 16 weeks.

3.2.2. Anthocyanins

Processing temperature (P_{Temp}) explained only 4.3% of the variation in TMA in strawberry jams (Table 3). The substantial part of the variance was explained by storage period (S_{Time}, 42.6%), closely followed by storage temperature (S_{Temp}, 34.7%). The interaction between S_{Time} and S_{Temp} explained 12.8% of variation of TMA in strawberry jams.

When stored at 4 °C, only strawberry jams processed at 60 °C had significant losses of TMA after 8 weeks ($p < 0.05$) (Table 5). These jams had higher initial TMA levels compared with jams processed at the higher temperatures. After 8 weeks at 4 °C, however, the positive effect of the low processing temperature was no longer detectable. When stored at 23 °C for 8 weeks, there were significant decreases in

TMA contents in strawberry jams processed at all three temperatures. The levels further decreased by more than 50% when storage was extended to 16 weeks. There were no significant effects of processing temperature on TMA levels when the jams were stored at 23 °C. At the end of the high temperature storage period all strawberry jams had similar TMA levels (11 – 14 mg/100 g). Storage at 4 °C gave significantly higher retention of both Pg-3-gluc and Cy-3-gluc compared with storage at 23 °C.

In raspberry jam, processing temperature (P_{Temp}) had no significant effect on TMA during storage (Table 4). Storage period (S_{Time}) was the main factor influencing stability of TMA by explaining 54.3% of the variance. Storage temperature (S_{Temp}) explained 10.0% of the variance in TMA, while the interaction between S_{Time} and S_{Temp} explained 21.3%, suggesting that the effect of storage temperature depended on storage period. For the individual anthocyanins, processing temperature (P_{Temp}) was responsible for 3.8 - 6.0% of the variance. Storage conditions had the highest influence on the individual anthocyanins, and storage period (S_{Time}) explained 64 - 76% of the variance.

Raspberry jams stored at 4 °C showed no significant decrease in TMA during 16 weeks of storage (p>0.05) (Table 6). In jams stored at 23 °C, there was significant decrease in TMA after 8 weeks, and further storage until 16 weeks caused additional loss. After 16 weeks of storage, the retention of TMA was 79 – 85% and 37 – 40% in the raspberry jams stored at 4 and 23 °C, respectively. The contents of individual anthocyanins were also significantly lower in jams stored at 23 °C compared with storage at 4 °C.

368 *3.2.3. Antioxidant properties (TP and ARP)*

369 Processing temperature (P_{Temp}) explained 15.3% of the variance in TP in strawberry
370 jams, while storage period (S_{Time}) explained 69% (Table 3). There was no significant
371 variance explanation from storage temperature (S_{Temp}). The variance of ARP was not
372 significantly explained by any of the experimental factors. No significant changes in
373 TP were observed after 8 weeks of storage (Table 5). After 16 weeks, there were
374 significantly lowered levels of TP in all jams, except for jam processed at 85 °C and
375 stored at 23 °C. There was no change in ARP during storage of strawberry jams.

376 In raspberry jams, the processing temperature explained 2.5% of the variance in TP,
377 while no significant explanation was seen for ARP (Table 4). Storage period
378 explained most of the variance in both TP and ARP. Eight weeks of storage did not
379 affect the levels of TP, but the levels were significantly decreased in all jams after 16
380 weeks of storage (p<0.05) (Table 6). The levels of ARP tended to decrease in all
381 jams during storage (p>0.05).

382

383 *3.2.4. Color*

384 Processing temperature (P_{Temp}, 73.3%) was the main factor explaining variance in
385 lightness (L*) of strawberry jams, followed by storage period (S_{Time}, 12.2%) (Table 3).
386 Storage temperature (S_{Temp}) had no significant effect (p>0.05). The darker color of
387 the jams processed at the higher temperatures were maintained during storage
388 (Table 5). Variances in °Hue were also mainly explained by processing temperature
389 (P_{Temp}, 31.2%). Storage temperature, storage period and their interaction contributed
390 to the explanation with 15.5, 8.2 and 29.7%, respectively. There was a significant
391 increase in °Hue only in the jams processed at 60 °C and stored at 23 °C for 16

weeks (Table 5). Variance in Chroma was partly explained by processing temperature (P_{Temp}, 23.5%) and storage period (S_{Time}, 23.8%), and especially by storage temperature (S_{Temp}, 40.3%) (Table 3). Storage at 4 °C for 8 weeks had no significant effect on Chroma (p>0.05) (Table 5). Chroma decreased in all strawberry jams stored at 23 °C for 8 weeks, while no further changes were seen during the next 8 weeks.

In raspberry jams, processing temperature (P_{Temp}) explained 21.3% and storage temperature (S_{Temp}) 52.7% of the variance in L* (Table 4). °Hue and Chroma were less influenced by processing temperature, with 6.9% and 8.1% explained variance, respectively. The most important experimental factor explaining these color parameters were storage temperature (39.0% and 41.3%) and storage period (38.0% and 35.7%). There was a tendency towards darker jams (lower L*) when stored at room temperature. However, there were no significant differences in L* among the samples (p>0.05) (Table 6). The only significant decrease in °Hue during storage was for raspberry jams made at 85 °C and stored at 23 °C for 16 weeks. Storage at 23 °C caused significantly lower Chroma, i.e. a duller color, compared with storage at 4 °C. Chroma decreased significantly in jams processed at 60 and 85 °C during the first 8 weeks of storage at 23 °C. After 8 weeks, Chroma values were stable.

4. Discussion

Color and bioactive compounds, such as vitamin C and anthocyanins, are important for the attractiveness of berries and their products. The levels of bioactive compounds and sensory properties of the product as it reaches the consumer are

dependent on raw material, i.e. berries used, and processing and storage conditions. In the present study, the effects of temperature during processing (60, 85 and 93 °C) and storage (4 and 23 °C), and the differences between strawberry and raspberry as raw materials were investigated. The faith of bioactive compounds in berries, especially strawberries, during processing to jams and purees have been investigated in several studies (Aaby et al., 2007; Bursać Kovačević et al., 2015; Holzwarth et al., 2012; Mazur et al., 2014b; Pineli et al., 2015). However, in most previous studies only one processing temperature has been applied.

4.1. Ascorbic acid, anthocyanins and antioxidant capacity

The degradation of ascorbic acid when processing strawberries at 85 °C was comparable to previous findings with similar processing temperatures, i.e. 12% loss of ascorbic acid when processing strawberries into puree at 85 °C (Klopotek et al., 2005) and 18% loss after making puree at 75 – 80 °C (Aaby et al., 2007). The present study showed less degradation of ascorbic acid with low processing temperature (60 °C) and more degradation with high temperature (93 °C), as compared with the conventionally used temperature of 85 °C. Chemical degradation of L-ascorbic acid involves oxidation to dehydro ascorbic acid (DHAA), followed by hydrolysis to 2,3-diketogulonic acid and further oxidation, dehydration and polymerization reactions. Since these reactions, and especially the hydrolysis of DHAA, are accelerated by increasing temperature (Gregory III, 2008), it is not surprising that more ascorbic acid was retained during processing at the lower temperatures. Total monomeric anthocyanins (TMA) in strawberries were also better preserved during processing at 60 °C compared with higher processing

temperatures, although there were no significant differences between TMA in berries and jams. Similarly, no significant decreases of monomeric anthocyanins in strawberries were found when processing into purees at 60, 75 and 90 °C (Holzwarth et al., 2012).

. Prolonged storage was the main detrimental factor for ascorbic acid in the jams, which is in accordance with previous studies showing that ascorbic acid is rapidly degraded regardless of storage temperature (Aaby et al., 2007; Mazur et al., 2014b). Anthocyanins, on the other hand, was better preserved when stored at low temperature, as have been reported in several studies (Aaby et al., 2007; García-Viguera, Zafrilla, & Tomás-Barberán, 1999a; Mazur et al., 2014b; Ngo et al., 2007). While more anthocyanins were present in newly made strawberry jams processed at 60 °C compared with jams processed at higher temperatures, a more rapid decline of anthocyanins was observed during storage of these jams. This may indicate that anthocyanin-degrading enzymes in the jams were insufficiently inactivated at 60 °C. In a study with strawberry purees, polyphenol oxidase (PPO) was completely inactivated at 75 °C and 90 °C, while residual activity was observed when the purees were heated at 60 °C (Holzwarth et al., 2012). PPO in strawberries has been shown to be very heat stable and even to regenerate during storage (Aaby, Grimsbo, Hovda, & Rode, 2018; Gössinger et al., 2009; Holzwarth et al., 2012).

In our study, neither ascorbic acid nor TMA in raspberries were affected by processing. Furthermore, the anthocyanins were more stable in raspberry jams than in strawberry jams when stored at 23 °C. The quite high stability of ascorbic acid and anthocyanins in raspberries during processing is in accordance with previous studies of raspberry jam processing (Garcia-Viguera et al., 1998; Kim & Padilla-Zakour, 2004; Mazur et al., 2014a). One reason for the higher stability of TMA in raspberries

could be that the individual raspberry anthocyanins are more stable than those in strawberries. Raspberries contain di- and triglycosidic anthocyanins, which have been shown to be more stable than anthocyanins with monoglycosidic substitution (Boyles & Wrolstad, 1993). However, both species contain Cy-3-gluc, and Cy-3-gluc was more stable in raspberry jams than in strawberry jams, indicating that not only differences in anthocyanin composition were responsible for the higher stability of anthocyanins in raspberry jams. Another reason could be that raspberries contained higher anthocyanin concentrations than strawberries. Previously, the smallest losses of anthocyanins in raspberry jams were found in jams made from berries with the highest concentration of anthocyanins (Mazur et al., 2014a). In another study, increasing anthocyanin concentration by fortification increased the half-life of anthocyanins in strawberry juice from five to 12 days (Garzón & Wrolstad, 2002). Fortification of strawberry and blackcurrant syrup with anthocyanins also increased the stability of anthocyanins (Skrede et al., 1992). Increased stability at higher concentrations might be due to anthocyanin self-association (Castañeda-Ovando, Pacheco-Hernández, Páez-Hernández, Rodríguez, & Galán-Vidal, 2009). The lower pH in raspberry jams than in strawberry jams could also affect the stability of the anthocyanins. Previous studies (Kim & Padilla-Zakour, 2004; Oliveira et al., 2015) reported that increasing pH in strawberry puree resulted in decreased stability of the anthocyanins. Several studies have shown that ascorbic acid destabilizes anthocyanins (Nikkhah et al., 2010; Skrede et al., 1992). As strawberries contain higher concentrations of ascorbic acid than raspberries, this may contribute to the lower stability of anthocyanins in strawberries compared with raspberries. Differences in activity of degrading enzymes might also contribute to different stability of anthocyanins in raspberries and strawberries.

The antioxidant properties (TP and ARP) of strawberry and raspberry were not significantly affected by processing and only to a small degree by storage, which is in accordance with previous studies on strawberry purees (Holzwarth et al., 2012), raspberry jam (Kim & Padilla-Zakour, 2004) and strawberry jam (Rababah et al., 2011; Wicklund et al., 2005). The decreases observed in ascorbic acid and anthocyanins during storage of the jams were not reflected in concurrent changes in TP and ARP. The explanation is probably that other polyphenols than anthocyanins, e.g. ellagitannins and proanthocyanidins, likewise contribute to antioxidant capacity of strawberries and raspberries (Aaby et al., 2007; Beekwilder et al., 2005), and that degradation products formed during storage, e.g. ellagic acid released from ellagitannins by hydrolysis, could have higher antioxidant capacity than the native phenolic compounds found in the berries.

4.2. Color

Strawberries and raspberries became darker when processed into jams. The decrease in L* when berries were processed into jams were most likely related to changes in consistency. The gel structure of the jams may give less reflection of light and thus a darker color (Hunter & Harold, 1987). The changes in Chroma upon jam processing, demonstrated that visible color is not directly related to pigment concentration. With the current recipe, both types of jam contained 40% of the anthocyanins in intact berries, while reductions in Chroma were only 20-30%. This could be due to the lack of linear sensitivity in the human eye (Hunter & Harold, 1987). The stability in red color during processing of berries has also been explained

as diffusion of anthocyanins from the berries to the gel during processing (Holzwarth et al., 2013).

The strawberry jams tended to become lighter during storage, but the changes were not significant. This is in accordance with previous results, showing that L*-values in strawberry jams were not significantly affected by temperature or duration of storage (Mazur et al., 2014b). The more yellowish color (°Hue increased) in strawberry jams processed at 60 °C when stored at 23 °C for 16 weeks was in accordance with previous studies (Mazur et al., 2014b; Pineli et al., 2015). Storage at 23 °C caused a duller color (Chroma decreased) in both strawberries and raspberries during the initial storage at 23 °C, but not at 4 °C. Upon prolonged storage, Chroma values were stable as has also been reported previously (Garcia-Viguera et al., 1998; Mazur et al., 2014b; Patras et al., 2011).

Processing temperature had a higher impact on variance in color parameters in strawberry jams than in raspberry jams during storage, which may be related to the lower stability of anthocyanins in strawberry jams processed at 60 °C. The degradation of monomeric anthocyanins during storage, however, was not to the same extent reflected in the color parameters. This is most likely due to several factors, such as the optical phenomena of saturation in chromaticity of dark samples (Hunter & Harold, 1987; Skrede, 1987). Another factor could be browning products after degradation of anthocyanins, such as polymeric anthocyanins, tannins and melanoidin pigments formed during storage. These compounds have been shown to remain colored and could thus be partly responsible for the color in stored jams (Giusti & Wrolstad, 2001). Furthermore, the formation of bluish compounds similar to those reported in ageing red wine (Mateus, Oliveira, Haettich-Motta, & de Freitas,

2004), may have contributed to the color changes seen during storage in the present study, especially in the raspberry jams.

5. Conclusion

High processing temperature significantly reduced ascorbic acid, anthocyanins and TP in strawberries (p<0.05), but not in raspberries. The benefits from processing strawberries at low temperature (60 °C) disappeared during storage as the bioactive compounds degraded. The main factors explaining variation in bioactive compounds in the jams were storage temperature and especially storage period. The stability of anthocyanins was higher at the lowest storage temperature (4 °C), while ascorbic acid degraded rapidly independent of storage temperature. Anthocyanins were better preserved in raspberry jams than in strawberry jams during storage at room temperature (23 °C), e.g. after 8 weeks of storage, TMA averaged 50% (strawberry) and 61% (raspberry) of the concentration in newly made jams. In contrast to bioactive compounds, processing temperature explained most of the variance in lightness and hue in strawberry jams, while chromaticity was mainly affected by storage temperature and storage period in both raspberry and strawberry jams.

The hypothesis that processing temperature affects bioactive compounds and color of berries directly after jam processing and subsequent storage, was confirmed for strawberries, but not for raspberries. Furthermore, our proposal that bioactive compounds and color were more stable in raspberries than in strawberries was verified. The higher stability of bioactive compounds in raspberries compared with strawberries may be explained by differences in total concentrations of anthocyanins and ascorbic acid, as well as individual anthocyanin composition of the berries.

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567

568 **Conflict of interests**

569 Authors declare no conflict of interests.

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Table1. Soluble solids, pH, ascorbic acid, total monomeric anthocyanins (TMA), individual anthocyanins, total phenolics (TP), antiradical power (ARP), and color (L*, °Hue, Chroma) in strawberries and strawberry jams produced at 60, 85 and 93 °C[a]

	Strawberries	Jam	
		60 °C	85 °C
Soluble solids (°Brix)	10.0 ± 0.0 b	51.0 ± 0.0 a	51.0 ± 0.0 a
pH	3.39 ± 0.00 a	3.26 ± 0.01 b	3.20 ± 0.01 c

Ascorbic acid (mg/100 g) [b]	50.1 ± 2.8 a	48.2 ± 3.0 ab	39.3 ± 0.2 ab
Anthocyanins (mg/100g) [b]			
TMA (mg/100g)	66.1 ± 4.7 ab	70.9 ± 5.8 a	52.5 ± 0.7 b
Pg-3-gluc (mg/100g)	23.9 ± 6.1 a	30.4 ± 0.8 a	27.1 ± 1.6 a
Cy-3-gluc (mg/100g)	1.8 ± 0.0 ab	1.9 ± 0.1 a	1.8 ± 0.0 a
Antioxidant properties:			
TP (mg GAE/100 g) [b]	204 ± 9 ab	260 ± 17 a	197 ± 23 b
ARP (µmol TE/g) [b]	12.6 ± 1.4 a	12.1 ± 0.1 a	11.1 ± 0.9 a
Color attributes:			
L*	25.6 ± 0.2 a	21.8 ± 0.0 a	19.1 ± 2.3 ab
°Hue	32.4 ± 0.0 b	37.9 ± 0.1 a	38.6 ± 0.3 a
Chroma	41.3 ± 0.0 a	38.4 ± 0.0 ab	37.9 ± 2.1 ab

[a]The results are mean from analysis of two samples or extracts of berries (n=2) and two samples or extracts from each of the two productions of jam at each processing temperature (n=4). Different letters in the same row indicate significant differences (p<0.05) based on Tukey's comparison test. [b]Ascorbic acid, total monomer anthocyanins (TMA), pelargonidin-3-glucoside (Pg-3-gluc), cyanidin-3-glucoside (Cy-3-gluc), total phenolics (TP) and antiradical power (ARP) in jams are calculated per 100 g of berries in the jam.

723 Table 2. Soluble solids, pH, ascorbic acid, total monomeric anthocyanins (TMA), individual
724 anthocyanins, total phenolics (TP), antiradical power (ARP) and color (L*, °Hue, Chroma) in
725 raspberries and raspberry jams produced at 60, 85 and 93 °C[a]

	Raspberries	Jam	
		60 °C	85 °C
Soluble solids (°Brix)	10.0 ± 0.0 b	52.0 ± 0.7 a	52.0 ± 0.0 a
pH	2.97 ± 0.00 a	3.04 ± 0.04 a	2.98 ± 0.01 a
Ascorbic acid (mg/100 g) [b]	30.6 ± 1.8 a	30.0 ± 0.4 a	28.0 ± 0.8 a
Anthocyanins (mg/100g)[b]:			
TMA (mg/100g)	93.0 ± 3.9 a	87.2 ± 3.2 a	92.6 ± 5.5 a
Cy-3-soph (mg/100g)	14.8 ± 1.1 b	18.4 ± 0.8 ab	18.5 ± 1.2 a
Cy-3-gluc (mg/100g)	14.7 ± 0.2 a	15.3 ± 0.3 a	16.0 ± 0.6 a
Cy-3-(2^G-glucrut) (mg/100g)	8.4 ± 0.3 b	10.7 ± 1.1 ab	11.4 ± 0.5 a
Cy-3-rut (mg/100g)	9.7 ± 0.1 a	8.4 ± 0.4 ab	8.8 ± 0.5 ab
Antioxidant properties:			
TP (mg GAE/100 g)[b]	258 ± 18 a	273 ± 26 a	266 ± 27 a
ARP (µmol TE/g)[b]	32.4 ± 6.0 a	29.1 ± 2.5 a	27.1 ± 2.0 a
Color attributes:			
L*	19.2 ± 2.7 a	9.1 ± 0.8 b	9.9 ± 2.3 b
°Hue	27.9 ± 0.3 a	24.7 ± 0.8 a	26.2 ± 3.2 a
Chroma	41.6 ± 1.2 a	31.2 ± 1.4 b	32.0 ± 2.8 b

726 [a]The results are mean from analysis of two samples or extracts of berries (n=2) and two samples or extracts
727 from each of the two productions of jam at each processing temperature (n=4). Different letters in the same
728 row indicate significant differences (p<0.05) based on Tukey's comparison test. [b]Ascorbic acid, total monomer
729 anthocyanins (TMA), cyanidin-3-sophoroside (Cy-3-soph), cyanidin-3-glucoside (Cy-3-gluc), cyanidin-3-(2^G-
730 glucosylrutinoside) (Cy-3-(2^G-glucrut), cyanindin-3-rutinoside (Cy-3-rut), total phenolics (TP) and antiradical
731 power (ARP) in jams are calculated per 100 g of berries in the jam.

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734 Table 3. Explained variance (%) and significance[a] of all experimental factors for strawberry jams
735 calculated by ANOVA General Linear Model

	DF[b]	Ascorbic acid	TMA	Pg-3-gluc	Cy-3-gluc	TP	ARP	L*	°Hue
Process temp (P_{Temp})	2	5.0**	4.3 **	1.4**	1.7**	15.3*	12.7	73.3***	31.2**
Storage temp (S_{Temp})	1	0	34.7***	10.3***	12.2***	3.5	5.8	2.1	15.5**
Storage period (S_{Time})	2	87.2***	42.6***	81.5***	78.9***	69.0***	18.1	12.2*	8.2*
P_{Temp} x S_{Temp}	2	0.8	2.2*	0.2	0.8*	2.3	0	1.7	6.4*
P_{Temp} x S_{Time}	4	4.8*	2.8	0.9*	0.3	7.4	22.1	5.7	7.2
S_{Temp} x S_{Time}	2	1.7*	12.8***	5.5***	5.9***	0.4	30.9	3.5	29.7**
Residual (Error)	4	0.5	0.5	0.1	0.2	2.1	10.3	1.4	1.8
R-sq(adj)		98	98	99	99	91	56	94	92

736 [a]Explained variance is the sum-of-squares for one factor as % of total sum-of squares. Significance levels: *$p \leq$
737 0.05; **$p \leq 0.01$; ***$p \leq 0.001$. [b]Degrees of freedom.

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747 Table 4. Explained variance (%) and significance[a] of all experimental factors for raspberry jams
748 calculated by ANOVA General Linear Model

	DF[b]	Ascorbic acid	TMA	Cy-3 soph	Cy-3-gluc	Cy-3-(2^{G}-glucrut)	Cy-3-rut	TP	ARP
Process temp (P_{Time})	2	0	9.1	3.8.0*	4.5**	6.0**	4.1**	2.5**	0.7
Storage temp (S_{Temp})	1	1.0*	10.0*	17.1***	20.1***	8.8***	11.8***	1.6**	6.0
Storage period (S_{Time})	2	97.1***	54.3**	65.5***	63.7***	69.0***	76.1***	93.3***	72.9**
P_{Temp} x S_{Temp}	2	0.2	0.4	0.4	0.4	0.4	0.4	0	2.2
P_{Temp} x S_{Time}	4	1.1	1.4	4.4*	1.1	8.2**	2.8**	0.8	5.7
S_{Temp} x S_{Time}	2	0.21	21.3*	8.2**	9.9***	0.5**	4.5***	1.7**	8.6
Residual (Error)	4	0.4	3.4	0.5	0.3	0.5	0.2	0.1	3.9
R-sq(adj)		98	85	98	99	98	99	99	84

749 [a]Explained variance is the sum-of-squares for one factor as % of total sum-of squares. Significance levels: *$p \leq$
750 0.05; **$p \leq 0.01$; ***$p \leq 0.001$. [b]Degrees of freedom.

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759 Table 5. Ascorbic acid, total monomeric anthocyanins (TMA), total phenolics (TP), antiradical power
760 (ARP), individual anthocyanins, and color (L* °Hue, Chroma) in strawberry jams produced at 60, 85
761 and 93 °C at day 0 and after storage for 8 and 16 weeks at 4 and 23 °C[a]

P_{Temp} (°C)	S_{Time} (weeks)	S_{Temp} (°C)	Ascorbic acid (mg/100 g)	TMA (mg/100 g)	Pg-3-gluc (mg/100 g)	Cy-3-gluc (mg/100 g)	TP (mg GAE/100 g)	ARP (µmol TE/100 g)	L*	°Hue	Chroma
60	0		48.2 ± 3.0 a	70.9 ± 5.8 a	39.4 ± 0.8 a	1.8 ± 0.05 a	260 ± 5 ab	12.1 ± 0.1 a	21.8 ± 0.0 ab	37.9 ± 0.1 bcd	38.4 ± 0.0 ab
	8	4	17.0 ± 0.8 cd	57.5 ± 1.4 b	20.1 ± 1.5 d	1.5 ± 0.1 ab	266 ± 20 a	11.5 ± 0.1 a	19.5 ± 0.1 ab	36.2 ± 0.1 cde	35.6 ± 0.6 abcd
	8	23	15.2 ± 0.4 cd	26.0 ± 2.2 e	9.1 ± 0.8 ef	0.6 ± 0.1 c	214 ± 12 abcd	11.4 ± 0.2 a	20.1 ± 0.1 ab	37.9 ± 0.7 bcd	27.9 ± 0.9 efg
	16	4	12.8 ±0.5 cd	58.4 ± 3.4 b	10.9± 0.9 ef	0.9 ± 0.3 c	156 ± 20 de	11.6 ± 2.5 a	23.6 ± 0.2 a	35.6 ± 0.2 def	40.2 ± 0.9 a
	16	23	10.9 ± 0.7 cd	11.1 ± 0.1 f	1.4 ± 0.4 g	0.0 ± 0.0 d	137 ± 11 e	11.0 ± 1.0 a	23.8 ± 0.3 a	44.2 ± 0.2 a	29.3 ± 0.1 cdefg
85	0		39.3 ± 0.2 b	52.5 ± 0.7 bc	27.1 ± 1.5 ab	1.8 ± 0.0 a	197 ± 22 bcdef	11.1 ± 0.9 a	19.1 ± 2.3 ab	38.6 ± 0.3 bc	38.0 ± 2.3 ab
	8	4	18.1 ± 0.7 c	52.3 ± 2.2 bc	21.0 ± 0.5 cd	1.6 ± 0.2 ab	213 ± 2 abcd	11.8 ± 1.4 a	18.3 ±	37.2 ± 0.4 bcd	35.8 ± 1.4 abc

									0.4 ab			
	8	23	16.5 ± 1.5 cd	30.1 ± 0.6 e	11.0 ± 0.4 ef	0.8 ± 0.1 c	181 ± 40 cde	11.1 ± 1.0 a	17.3 ± 3.0 ab	37.2 ± 0.9 bcd	28.8 ± 2.4 defg
	16	4	18.4 ± 1.2 c	44.4 ± 2.6 cd	12.6 ± 1.4 c	0.8 ± 0.1 c	143 ± 10 e	11.7 ± 1.8 a	20.0 ± 0.7 ab	35.2 ± 1.1 bcd	37.8 ± 2.7 ab
	16	23	10.7 ± 1.5 cd	12.4 ± 0.1 f	1.7 ± 0.0 g	0.0 ± 0.0 d	142 ± 13 e	10.2 ± 1.2 a	20.0 ± 2.9 ab	39.7 ± 1.1 ab	28.9 ± 1.7 cdefg
93	0		31.8 ± 7.3 b	54.9 ± 2.0 b	24.5± 0.6 bc	1.6 ± 0.1 ab	207 ± 5 abcd	11.4 ± 0.3 a	14.5 ± 2.6 b	36.4 ± 1.5 bcd	32.3 ± 2.5 bcde
	8	4	13.6 ± 1.5 cd	52.5 ± 0.9 bc	18.5 ± 0.4 d	1.4 ± 0.0 b	230 ± 16 abc	12.5 ± 0.3 a	15.9 ± 0.7 ab	33.6 ± 0.0 cd	30.7 ± 0.2 cdef
	8	23	13.9 ± 0.7 cd	30.6 ± 0.3 e	9.8 ± 1.3 ef	0.8 ± 0.0 c	216 ± 2 abcd	12.1 ± 0.3 a	16.0 ± 2.2 ab	34.1 ± 1.0 cd	24.2 ± 0.8 g
	16	4	11.2 ± 1.2 cd	40.5 ± 1.7 d	8.4 ± 1.8 f	0.7 ± 0.1 c	156 ± 2 de	11.6 ± 0.4 a	17.0 ± 4.3 ab	32.9 ± 2.1 d	33.6 ± 3.1 abcde
	16	23	8.9 ± 0.3 d	13.5 ± 1.4 f	1.6 ± 0.2 g	0.0 ± 0.0 d	137 ± 4 e	10.6 ± 0.2 a	16.8 ± 4.3 ab	37.1 ± 4.0 bcd	25.7 ± 1.5 fg

[a]The results are mean from analysis of two samples or extracts from each of the two productions of jam at each production temperature (n=4). Different letters in the same column indicate significant differences (P<0.05) based on ANOVA one-way variance analysis followed by Tukey's comparison test.

Table 6. Ascorbic acid, total monomeric anthocyanins (TMA), total phenolics (TP) antiradical power (ARP), individual anthocyanins, and color (L*, °Hue, Chroma) in raspberry jams produced at 60, 85 and 93 °C at day 0 and after storage for 8 and 16 weeks at 4 °C and 23 °C[a]

P_{Temp} (°C)	S_{Time} (weeks)	S_{Temp} (°C)	Ascorbic acid (mg/100 g)	TMA (mg/100 g)	Cy-3-soph (mg/100g)	Cy-3-gluc (mg/100g)	Cy-3-(2^{G}-glucrut) (mg/100g)	Cy-3-rut (mg/100g)	TP (mg GAE/100 g)	ARP (μ TE/10
60	0		30.0 ± 0.4 a	87.2 ± 3.2 a	18.4 ± 0.8 ab	15.3 ± 0.3 ab	10.7 ± 1.1 abc	8.4 ± 0.4 abcd	272 ± 26 a	29.1 ±
	8	4	19.5 ± 0.6 b	85.3 ± 18.0 ab	20.3 ± 1.1 a	16.1 ± 1.0 a	12.2 ± 1.0 a	10.2 ± 0.5 a	245 ± 14 a	19.9 ±
	8	23	15.4 ± 0.3 bcd	57.3 ± 3.0 bcde	13.9 ± 1.2 cde	9.6 ± 0.9 de	8. 9± 1.0 abcd	7.7 ± 1.1 bcd	238 ± 48 a	20.7 ±
	16	4	9.0 ± 0.3 f	68.7 ± 1.0 abcd	10.2 ± 0.6 ef	9.5 ± 0.6 de	4.7 ± 0.3 ef	4.0 ± 0.2 f	129 ± 2 b	19.1 ±
	16	23	7.8 ± 0.2 f	32.7 ± 1.7 e	2.8 ± 1.0 g	1.9 ± 0.4 f	1.9 ± 0.7 f	1.1 ± 0.6 g	137 ± 1 b	21.2 ±
85	0		28.0 ± 0.8 a	92.6 ± 5.5 a	18.5 ± 1.2 ab	15.9 ± 0.6 a	11.4 ± 0.5 ab	8.8 ± 0.6 abc	266 ± 27 a	27.1 ±
	8	4	17.1 ± 1.3 bc	92.9 ± 7.0 a	17.9 ± 0.2 abc	14.9 ± 0.1 ab	10.7 ± 0.3 abc	9.7 ± 0.4 ab	247 ± 7 a	22.1 ±
	8	23	17.2 ± 0.2 bc	56.9 ± 4.8 cde	10.8 ± 0.8 ef	8.6 ± 0.4 e	7.3 ± 0.8 bcde	6.6 ± 0.5 de	235 ± 16 a	20.5 ±
	16	4	11.7 ± 0.3 def	74.2 ± 12.6 abc	11.3 ± 1.5 ef	9.7 ± 0.8 de	5.8 ± 0.5 def	4.7 ± 0.0 ef	138 ± 13 b	22.6 ±
	16	23	10.0 ± 0.7 ef	35.1 ± 4.1 e	4.0 ± 0.2 g	2.3 ± 0.1 f	2.5 ± 0.6 f	1.5 ± 0.2 g	137 ± 23 b	23.1 ±
93	0		29.7 ± 1.0 a	76.2 ± 9.3 abc	16.0 ± 0.0 bcd	13.0 ± 0.1 bc	9.6 ± 0.6 abcd	7.4 ± 2.5 cd	251 ± 18 a	30.7 ±
	8	4	17.9 ± 2.0 bc	71.1 ± 5.0 abcd	13.2 ± 1.8 def	11.5 ± 0.3 cd	6.8 ± 2.4 cde	7.4 ± 2.5 cd	219 ± 12 a	21.1 ±
	8	23	14.4 ± 1.9 cde	43.2 ± 1.4 de	9.5 ± 1.7 f	7.4 ± 0.1 e	4.1 ± 2.1 ef	5.1 ± 2.5 ef	200 ± 0 ab	20.6 ±
	16	4	11.0 ± 0.6 def	64.8 ± 0.0 abcd	11.1 ± 0.7 ef	8.1 ± 1.0 e	5.9 ± 0.5 def	4.1 ± 2.5 f	126 ± 8 b	20.1 ±

16	23	8.3 ± 2.5 f	30.4 ± 2.3 e	3.5 ± 0.3 g	1.7 ± 0.8 f	2.1 ± 0.2 f	1.3 ± 2.5 fg	130 ± 20 b	21.2 ±

[a]The results are mean from analysis of two samples or extracts from each of the two productions of jam at each production temperature (n=4). Different letters in the same column indicate significant differences (P<0.05) based on ANOVA one way variance analysis followed by Tukey's comparison test.

Highlights

- High processing temperature reduced bioactive compounds in strawberries
- Processing temperature had no effect on bioactive compounds in raspberries
- Storage explained most of the variation in bioactive compounds in jams
- Bioactive compounds and color were more stable in raspberries than in strawberries
- Cold storage of jam is highly recommended versus storage at room temperature

Declaration of Interest Statement:

Authors declare no conflict of interest

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795 Author Contributions

796 B.K. Martinsen planned and conducted the experiments, performed the analysis and
797 the data processing and drafted the manuscript. G. Skrede planned the experiments
798 and was supervisor in the project. K. Aaby assisted in data processing and
799 interpretation of the results. All authors contributed considerably in writing the
800 manuscript.

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