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Effects of ripeness and cultivar on chemical composition of strawberry (*Fragaria* × *ananassa* Duch.) fruits and their suitability for jam production as a stable product at different storage temperatures

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ABSTRACT

Effects of ripeness (nearly ripe, ripe, fully ripe) and cultivar ('Blink', 'Polka' and 'Senga Sengana') on colour and chemical composition of strawberry fruits and their suitability for jam production, evaluated as stability during storage at 4 and 20 °C for 3 and 6 months, were investigated. Quality traits of fruits and jams were significantly affected by both ripeness stage and cultivar. However, after 6 months of storage, particularly at 20 °C, the effects of fruit ripeness and cultivar were considerably reduced. During jam storage, anthocyanins, ascorbic acid, chroma and hue were least stable in jams made from the least ripe fruits. Quality traits in jams made from 'Senga Sengana' were best preserved during storage, while quality and chemical composition in jams made from 'Blink' changed the most. In conclusion, fully ripe fruits were best suited for jam processing. Storage at low temperature was preferable and 'Senga Sengana' was the most and 'Blink' the least suitable cultivar for processing.

1. Introduction

Strawberry fruits with great flavour and highly desirable taste are common and widely consumed both fresh and processed. Due to the economic importance of the species, many studies have been carried out to evaluate effect of different factors on sensorial and nutritional traits of the fruits and their products. Physical and sensory quality of strawberry fruits are associated with traits like size, firmness, colour, pH, sugar/acid ratio, taste and aroma (Kafkas, Kosar, Paydas, Kafkas, & Baser, 2007; Montero, Mollá, Esteban, & López-Andréu, 1996; Nunes, Brecht, Morais, & Sargent, 2006; Shin, Ryu, Liu, Nock, & Watkins, 2008). Nutritional properties are related to the content of ascorbic acid and secondary plant metabolites, such as phenolic compounds, which have been reported to have potential beneficial health properties (Kafkas et al., 2007; Kosar, Kafkas, Paydas, & Baser, 2004; Pineli et al., 2011; Tulipani et al., 2008). Significant differences in phenolic profile have been observed in strawberry cultivars (Aaby, Mazur, Nes, & Skrede, 2012; Kosar et al., 2004). Besides genetic and environmental factors, ripeness (Tulipani et al., 2011) and storage conditions (Shin et al., 2008) affect overall fruit quality. Harvesting at the right maturity stage is crucial for keeping optimal quality during storage and handling (Sturm, Koron, & Stampar, 2003).

The colour expression of strawberry fruits is associated with concentration and composition of anthocyanins. The major anthocyanins are pelargonidin-3-glucoside, pelargonidin-3-malonylglucoside, pelargonidin-3-rutinoside and cyanidin-3-glucoside, but the composition varies with genotype (Aaby et al., 2012; Tulipani et al., 2008). While total concentration of anthocyanins increases significantly during ripening, the anthocyanin composition,

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however, is hardly changed in the fruits in the late ripening stages (Aaby et al., 2012). Since strawberry fruits are a good source of ascorbic acid, which is one of the most important antioxidants in plants, the changes of this compound during fruits ripening was examined. Some studies have reported an increase in vitamin C content with increasing ripeness of strawberry fruits (Kafkas et al., 2007; Nunes et al., 2006; Tulipani et al., 2011), whereas Pineli et al. (2011) observed the highest concentrations of ascorbic acid in half ripe fruits.

The influence of different processing methods on preservation of bioactive compounds in different products have been studied (Hartmann, Patz, Andlauer, Dietrich, & Ludwig, 2008), and differences between cultivars and species after processing fruits into jams have been reported (Kim & Padilla-Zakour, 2004). Considerable losses were detected in the content of anthocyanins, ascorbic acid and total phenolics after processing. Quality of strawberry jam has been found to be significantly influenced by storage conditions (García-Viguera et al., 1999; Patras, Brunton, Tiwari, & Butler, 2009; Wicklund et al., 2005). In general, storage at higher temperatures for a longer period of time has negative influence on most of the quality parameters measured.

The hypothesis of the present study was that jam quality and stability is influenced by ripeness and genotype of strawberry fruits. Except for an early American study where jams were prepared from a blend of ripe and immature strawberry fruits (Spayd & Morris, 1981), effect of fruit ripeness on quality and storage stability of strawberry jams has not been investigated. Different cultivars might also be differently influenced by ripening. The main aim of the present study was thus to determine the effects of ripeness, cultivar, storage time (0, 3 and 6 months) and storage temperature (4 and 20 °C) and their interactions on stability of colour and bioactive compounds (ascorbic acid and phenolic compounds) in jams. The ripeness of the fruits were within the normal range of strawberry when harvested (partly red, red and dark red) and the cultivars studied ('Blink', 'Polka' and 'Senga Sengana') are commonly grown in Norway. Further objective was to investigate relationships between the measured quality parameters in the jams.

2. Materials and methods

2.1. Chemicals

Pelargonidin-3-glucoside was obtained from Polyphenols AS (Sandnes, Norway). Acetone, acetonitrile, L-(+)-ascorbic acid (AA), citric acid, sodium acetate, sodium carbonate, sodium dihydrogen phosphate dihydrate ($NaH_2PO_4{\cdot}2H_2O$), sodium hydroxide, disodium hydrogen phosphate dihydrate, disodium EDTA, *n*-dodecyltrimethylammonium chloride, methanol and potassium chloride were obtained from Merck KGAa (Darmstadt, Germany). Dehydro-L-(+)-ascorbic acid dimer (DHAA), tris[2-carboxyethyl]-phosphate, gallic acid, quercetin-3-rhamnosylglucoside (rutin), catechin, ellagic acid, Folin–Ciocalteu's phenol reagent and DL-malic acid were purchased from Sigma Chemical Co. (St. Louis, MO, USA). Metaphosphoric acid was purchased from Sigma–Aldrich Chemie GmbH (Steinheim, Germany). Chlorogenic acid and formic acid were obtained from Fluka (Buchs, Switzerland). Pectin LM-102 As was obtained from CP Kelco (Lile Skensved, Denmark). All solvents were of HPLC grade and water was of Milli-Q-quality (Millipore Corp., Bedford, MA, USA).

2.2. Plant material

Fruits of strawberry (*Fragaria* × *ananassa* Duch.), cultivars 'Blink', 'Polka' and 'Senga Sengana', were harvested from a commercial field in the South – East of Norway (60°46′N, 10°48′E) in 2010. The plants were grown in a two row planting system on low ridges. The middle of the ridges was 1.6 m apart, the distances between the double rows were 40 cm and the distances between plants were 30 cm giving about 42,000 plants/ha. The fields had a morainic loam soil with 6–8% humus and water pH was 5.5–5.7. Berries of the three cultivars were harvested at three times with 3–4 days intervals in the first part of July and graded in three ripening stages (nearly ripe = partly red, ripe = red and fully ripe = dark red) (Aaby et al., 2012). Samples were frozen at −20 °C within 3 h after harvest. Samples of the same ripening stage from the three harvests were mixed prior to analyses and processing.

2.3. Production of strawberry jam

Samples of frozen strawberries (2.4 kg) were mixed with water (250 ml) and heated to 85 °C before sugar (1.2 kg) was added, and the temperature was kept at 85 °C for 5 min. Then potassium sorbate (4 g dissolved in a small amount of water) and a pectin solution (16 g pectin type LM-102 as dissolved in 250 ml water) were added. The temperature of the mixture was reduced to 70 °C, and 16 ml of a 50% solution of malic acid (w/v) was added followed by further cooling to 55 °C. The jam was then filled in 400 g glass jars and immediately sealed with metal lids. Some samples were directly frozen at −20 °C, and the other stored in darkness at 4 and 20 °C for 3 and 6 months. After the storage period all samples were frozen and kept at −20 °C until analysis.

2.4. Determination of dry matter (DM), soluble solids (SS), pH and titratable acids (TA) in the fruits

Prior to analyses thawed fruits (150 g) were homogenised using a food processor (CombiMax 700, Braun GmbH, Kronberg, Germany). The content of DM was determined by the vacuum drying method (Bøgh-Sørensen, 2002). Homogenised fruits (10 g) were dried in a vacuum oven (type RVT 360, Heraeus GmbH, Hanau, Germany) for 24 h at 70 °C and DM expressed as % (g/100 g of fresh weight (FW)). SS content was determined using a digital refractometer (RE40, Mettler Toledo, Japan) and expressed as °Brix (%). The pH was determined at 20 °C with a pH meter (827 pHlab, Metrohm, Switzerland). For determination of TA, homogenised samples (30 g) were further homogenised for 45 s using a Polytron® homogenizer (PT-MR 3100, Kinematica AG, Switzerland), and centrifuged at 39191g for 10 min at 4 °C (Avanti J-26 XP. Beckman Coulter, USA). The supernatant (5 ml) was diluted 1:10 with distilled water followed by titration to pH 8.1 with 0.1 M NaOH using an automatic titrator (T50, Mettler Toledo, Switzerland). The content of TA was calculated as citric acid (mg/100 g FW). All berries were analysed in duplicates for DM and TA, and triplicates for SS and pH.

2.5. Colour measurements

Fifteen randomly selected frozen fruits were thawed for 45 min at room temperature. Semi-thawed samples were homogenised using a food processor (CombiMax 700, Braun GmbH, Kronberg, Germany) and the colour of the puree was measured after 15 min, when the samples were completely thawed. The measurements were conducted with a Hunter Lab colour system (LabScan XE, Reston,Virginia, USA). The 1976 CIE L^*, a^* and b^* system was used for evaluation of colour (illuminant D65, 10° observer, mode (geometry): 0°/45°, and area view 0.5″, port size 0.7″. L^* defines lightness where lower values indicate darker colour (0 = black) and higher values indicate lighter colour (100 = white). Negative a^* values indicate green and positive values red colour, while negative b^* values imply bluish and positive values yellow colour. Hue angle (colour shade) was computed as arctan (b^*/a^*) and chroma