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Raspberry fruit quality changes during ripening and storage as assessed by colour, sensory evaluation and chemical analyses

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ABSTRACT

In order to identify the optimal harvest time and monitor changes in raspberry (*Rubus idaeus* L. cv. Glen Ample) fruit quality during ripening and storage, quality was assessed and compared by physical, chemical and sensory fruit quality criteria. Visual classification of fruit colour according to the Natural Colour System (NCS) chart and by physical measurement of fruit adherence to the receptacle or fruit compression resistance yielded parallel and highly significant results. The light red colour stage corresponding to NCS S code 3060-Y90R was identified as the optimal harvest stage for commercial fresh marketing of the 'Glen Ample' cultivar. Fruit harvested at this stage developed the same chemical and sensory qualities as in situ matured fruits and maintained high sensory quality after 8 days of storage in the dark at 2–3 °C. As the fruits mature, the concentration of titratable acids decreases, whereas the concentrations of anthocyanins and the sugar:acid ratio increase in parallel with colour development. While correlation analysis revealed a correlation between sensory traits like sweetness and acidity with sucrose and the sugar:acid ratio, respectively, the overall fruit tastefulness was not strongly correlated with any specific phytochemical component, thus illustrating the complex nature of this sensory trait. Due to its ease of performance, picking raspberry fruits related to a standardised colour chart is recommended for picking raspberry fruits with optimal quality.

1. Introduction

Red raspberry (*Rubus idaeus* L.) is grown throughout the temperate regions of the world as a commercially important berry crop. The fruit is highly valued for its flavour and high content of potentially important health-beneficial constituents (Mullen et al., 2002; Liu et al., 2002; Anttonen and Karjalainen, 2005; Rao and Snyder, 2010). It is a perishable commodity, and although new cultivars with firmer fruit have been released (Finn et al., 2008) the shelf life of raspberry is generally short. Identification of the optimal maturity stage for harvesting and correct post-harvest handling and storage of the fruit, are therefore, essential for successful marketing of fresh consumption raspberries.

Fruit colour and adhesion to the receptacle plug are the main criteria used by the producer for practical assessment of the right maturity stage for harvesting, while colour is also the main criterion used by the consumer to judge fruit quality. The main contributors to the red colour of the raspberry fruit are the anthocyanins. Only cyanidin-and pelargonidin-type anthocyanins are present in red raspberry, the former type predominating (Wang et al., 2009; Remberg et al., 2010; Mazur et al., 2014). Their synthesis is influenced by a number of environmental factors in both green leaves and in fruits. According to Grisebach (1982), light is the most important factor influencing anthocyanin biosynthesis in plants in general, and in vegetative tissues, anthocyanin biosynthesis is induced by UV light as an important photo-protective mechanism (Steyn et al., 2002). In 'Glen Ample' raspberry fruit, the concentration of total monomeric anthocyanins (TMA) was not significantly affected by post-flowering growth temperature in the 12–24 °C range or by photoperiod at 18 °C (Remberg et al., 2010; Mazur et al., 2014). It is well known and documented however, that postharvest colour changes and anthocyanin synthesis take place in immaturely harvested fruit of red raspberry (Wang et al., 2009) as well as in other berry species (Kalt et al., 1993; Sachs and Shaw, 1993), thus demonstrating de novo synthesis in detached fruits. Synthesis can occur in darkness, but the rate is slightly enhanced in light (Austin

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et al., 1960; Wang et al., 2009). While raspberry fruit anthocyanin concentration increases throughout ripening, the total phenolic concentration was found to decrease from the green to the light-red ('pink') stage, and thereafter to increase again until maturity (Wang and Liu, 2000). However, because fruit weight increases significantly during ripening, mainly due to increased water content, a significant dilution of all soluble fruit constituents is also taking place during fruit ripening. This is confounding much of the real concentration changes in fruit constituents that are taking place. As pointed out by Remberg et al. (2010), this bias is corrected for when data are expressed on dry weight basis.

While a number of investigations have examined the effects of fresh and frozen storage on raspberry fruit chemical composition (e.g. Kalt et al., 1999; Mullen et al., 2002 and references therein), experimental attempts to define and describe maturity stages as guidelines for selection of the best harvest time for raspberries are rare. Some studies in raspberries (Krüger et al., 2003; Krüger et al., 2011) have been restricted to the analysis of three stages of development: semi-ripe, ripe and over-ripe. Krüger et al. (2003) observed in four cultivars that the ripening stage had a large effect on firmness, titratable acidity (TA) and fruit colour, whereas storage conditions during three days had effects on the content of soluble solids (SS) and suitability for shipping. A subsequent chemical analysis of red raspberry (cv. 'Tulameen') at the three different stages of development, revealed that acidity decreased significantly, while total anthocyanins increased significantly with maturation stage with cyanidin-3-sophoroside, cyanidin 3-rutinoside and cyanidin 3-O-glucoside levels increasing with maturation but not cyanidin 3-glucosylrutinoside (Krüger et al., 2011). Further sensory analysis revealed that ripening had an effect on odour and taste whereas the effects of storage were small in comparison (Krüger et al., 2003). Hence, it was suggested that semi-ripe fruits could have improved suitability for shipping and some sensory assessments (Krüger et al., 2003).

In order to determine how early fruits can be harvested and still develop acceptable quality, Wang et al. (2009) harvested fruit of 'Caroline' raspberries at five maturity stages, arbitrarily classified as 5%, 20%, 50%, 80%, and 100% maturity, and studied their fruit quality chemical changes during storage in light and darkness at 24/16 °C (day/night) temperature. The authors found that fruit harvested at 5% or 20% maturity never developed the levels of SS, TA and sugars found in ripe berries at harvest, while those harvested at 50% or 80% maturity attained qualities comparable to in situ matured berries. Storage in light enhanced sugar and reduced acid content somewhat of 5% and 20% mature berries, but had negligible effect on fruit of more advanced maturity The authors conclude that raspberry fruit could be harvested as early as 50% maturity, when the fruits are firmer and less susceptible to mechanical injury, and still develop a quality comparable to fully mature fruit. However, no sensory assessment of fruit quality was provided.

In an attempt to describe more precisely the fruit quality changes taking place during raspberry fruit maturation and post harvest storage, and in particular, to define the right maturity stage for harvesting, we have assessed and compared physical, chemical and sensory fruit quality criteria that can be used for this purpose. It is hoped that this knowledge may benefit the fruit industry and the producers as well as the consumers.

2. Material and methods

2.1. Plant material and cultivation

Long canes of the raspberry cultivar 'Glen Ample', produced as described by Sønsteby et al. (2009), were cropped in a greenhouse at a commercial grower's nursery located on the west coast of Norway during the spring 2011 (Frekhaug, 60°31′ N; 5°14′ E). The plants were tipped at a height of 180 cm and grown in 3.5 L pots in rows with 5 plants per running m. The distance between the rows was 2.20 m. The plants were fertilized with a complete nutrient solution containing a 2:3 mixture of Calcinit™ (15.5% N, 19% Ca) and Superba™ Red (7–4–22% NPK + micronutrients) (Yara International, Oslo, Norway). The media electric conductivity (EC) was 1.3–1.6 mS cm^{-1}. The production started in mid February 2011 and the first berries were harvested the first week of May 2011. The berries used in this experiment were harvested on 17 May 2011.

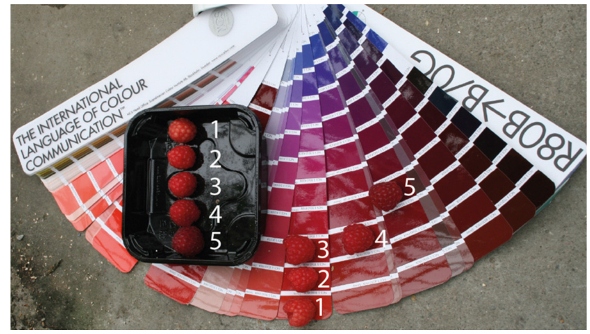

Fig. 1. The numbered colours selected for classification of the maturity stage at harvest in 'Glen Ample' raspberry.

2.2. Physical characterization of maturing raspberries

In order to pick berries with different degrees of maturity, five berry colours along an assumed maturity gradient were identified and used as a reference during the picking. The colours ranged from orange/red (colour one), light red (colour two), red (colour three), dark red (colour four) and dark red/lilac (colour five). These colours were visually classified according to the natural colour system®Ó (NCS; http://www.ncscolour.com/en/natural-colour-system/; see Fig. 1). Raspberries of the respective colour classes were handpicked, 2–3 berries from each plant, from two rows in the greenhouse, and placed in black, capped plastic containers (200 g). When full, the container with berries was transported to a cold room (2–3 °C) within 30 min. Four containers were collected for each colour class and used in the further analysis.

For further characterization of berries with different colours, we also measured the force needed to remove the berry from the receptacle in relation to colour. To measure the pull force, we first placed a piece of 15 cm duct tape around an individual berry so that the ends met surrounding the edge of the berry and the tape sticking to the side walls of the fruit. The loop of the tape was open to allow connection to the hook of a Pesola precision spring scale (Pesola AG, Baar, Switzerland; "Medio Line 300 g" scale for colour class 1–3 and" Light Line 100 g" scale for colour class 4 and 5). With the duct tape connected to the berry, it was slowly pulled off the receptacle. Maximum force monitored during the pull was recorded and this was replicated 12 times for each colour class. We also recorded berry weight in relation to colour by weighing three replicates of 20 berries each on a technical balance (±0.1 g).

In order to measure fruit firmness at harvest, we placed 50 raspberries from each maturation stage into a 1-litre cylinder and applied a load of 500 g with an adaptor fitting exactly the cylinder diameter on top of the berries. The volume of the berries was recorded before the load was added and after 6 min. From the volume change, %-compression was calculated. These measurements were done within 30 min after harvest. After 8 d of storage this compression method was not applicable as the berries became too soft and the compression method resulted in a fruit pulp.