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The effect of temperature, region and season on red colour development in apple peel under constant irradiance

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ABSTRACT

This study reports on red colour development in response to temperature for red and bi-coloured apple cultivars grown in South Africa, but also of global importance. 'Royal Gala' (RG),[1] 'Fuji' (FJ), 'Braeburn' (BB), 'Early Red One' (ERO) and 'Cripps' Pink' (CP) were sampled from two production areas, viz. Ceres and Grabouw, in the Western Cape Province of South Africa in the 2007–2008 and 2008–2009 seasons. Peel discs were punched from the shaded sides of fruit, placed on peltier temperature plates set to a temperature range from 16–31 °C with 3 °C intervals and exposed to photosynthetic photon flux (PPF) of 550–650 μmol m^{-2} s^{-1} for 72 h where after their change in hue was determined. The study focused on the effect of temperature on red colour development in the month before the onset of commercial harvest, which is when anthocyanin synthesis peaks in the cultivars grown in South Africa. Although apples from Ceres generally increased more in redness than apples from Grabouw, the general pattern of colour development over the temperature range studied was the same for fruit from both areas. Colour development generally showed a quadratic response to temperature with the greatest change in red colour developing from 19–25 °C in 2007–2008 and 16–22 °C in 2008–2009. Red colour development in RG peaked at a higher temperature range of 22–28 °C in 2007–2008. The response to temperature was less clearly defined in ERO where red colour developed over a broad temperature range and also in RG where differences were not significant in 2008–2009. The lower optimum temperature ranges for red colour development in 2008–2009 compared to 2007–2008 for FJ, BB and CP suggest that climatic conditions during fruit development affect the potential to synthesise anthocyanin. The "adaptation" of anthocyanin biosynthesis to climate may hinder the selection of suitable sites for cultivation of red and blushed cultivars.

1. Introduction

Fruit colour plays an important role in the international markets. Preference is generally given to the better-coloured apple fruit and thus fruit colour will be a factor when it comes to grading fruit for packing and exporting (Reay, 1999; Kevany et al., 2003). According to South African packing specifications (DAFF, 2010), first grade fruit of bi-coloured cultivars, e.g. Braeburn, Fuji, Royal Gala and Cripps' Pink require a minimum of 40–50% red blush coverage.

Anthocyanins accumulate and red colour develops maximally during apple ripening (Saure, 1990; Lancaster, 1992). Light and temperature are the major factors that determine the extent of red colour development in apple fruit (Saure, 1990; Lancaster, 1992; Reay and Lancaster, 2001). Anthocyanins in ripening apples are apparently induced at low temperatures (<10 °C) (Curry, 1997) and synthesis takes place under irradiation at mild temperatures (20–27 °C) in detached, mature apples (Saure, 1990 citing Nauman, 1964; Curry, 1997; Reay, 1999). Faragher (1983) found that maximum anthocyanin accumulation in attached mature 'Jonathan' apples occurred at 16–24 °C. The effect of temperature on red colour development is cultivar dependent (Saure, 1990). Curry (1997) reported that different apple cultivars have different optimum temperatures for maximal red colour development (i.e., 21, 23 and 25 °C for Braeburn, Gala and Fuji, respectively). Detached climacteric Red Chief 'Delicious' apples had a higher optimum temperature for anthocyanin accumulation (27 °C) compared to pre-climacteric apples (25 °C). Reay (1999) found two thirds less anthocyanin synthesis in 'Granny Smith' peel at 30 °C compared to 20 °C. A 3 h high temperature (30 °C) pre-treatment also reduced subsequent

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[1] RG = Royal Gala; FJ = Fuji; BB = Braeburn; ERO = Early Red One; CP = Cripps' Pink; PPF = photosynthetic photon flux.

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Table 1
Sampling dates of apple cultivars during the 2008–2009 season.

Harvest date	Royal Gala	Fuji	Braeburn	Early Red One	Cripps' Pink
13-Feb-09	X			X	
20-Feb-09	X	X			X
6-Mar-09	X	X	X	X	
20-Mar-09		X	X		X
3-Apr-09			X		X

anthocyanin synthesis at 20 °C (Reay, 1999). Apart from inhibiting anthocyanin synthesis (Reay, 1999), high temperature and irradiation also accelerates anthocyanin degradation. Irradiation of well-coloured 'Cripps' Pink' apples for 144 h at 37 °C resulted in a ≈50% decrease in anthocyanin and a 19° hue increase (Marais et al., 2001b).

Considering the importance of low night and mild day temperatures for anthocyanin synthesis in apple peel (Curry, 1997; Reay, 1999), it is not surprising that the high temperatures experienced in warm production areas such as the Western Cape Province, South Africa, give rise to poor red colour development (Wand et al., 2005). Since different cultivars have different optimum temperatures for anthocyanin synthesis, not all may be equally suited for all production areas. Knowing the optimum temperature for colour development for different cultivars can provide a good indication of where these cultivars can be grown.

This study focused on determining the optimum temperature range for anthocyanin accumulation under constant irradiance for red and bi-coloured apple cultivars grown in South Africa and also of importance elsewhere in the world, viz. Royal Gala, Braeburn, Fuji, Early Red One and Cripps' Pink at the peak of anthocyanin synthesis from about a month before scheduled commercial harvest. Fruit were harvested from two climatically distinct production areas to assess whether growing conditions may influence the temperature requirements for anthocyanin synthesis.

2. Materials and method

2.1. Plant material

'Royal Gala' (RG), 'Early Red One' (ERO), 'Braeburn' (BB), standard 'Fuji' (FJ), and 'Cripps' Pink' (CP) fruit were obtained from Oakvalley Estate in Grabouw (latitude: 34°08′S, longitude: 19°02′E, Altitude: 300 m) and Vastrap in Ceres (latitude: 33°14′S, longitude: 19°14′E, Altitude: 890 m). Both these regions are in the Mediterranean-type climatic region of the Western Cape Province of South Africa. Average monthly minimum and maximum temperatures recorded for these regions during the relevant months of the 2007–2008 and 2008–2009 seasons are presented in Fig. 1a and b, respectively. Apples were picked before 1100 HR from the same orchard row on each of the harvest dates with one apple picked at random from the inner canopy of each of six (RG and CP) or 12 trees. Only apples with a green/shaded side were picked. Fruit were placed in a cooler bag for transport to our laboratory and stored in the dark at 4 °C for 72 h to induce anthocyanin synthesis (Curry, 1997).

2007–2008 season: Fruit from both locations were harvested on three dates from about 2 weeks before scheduled harvest until commercial harvest on the dates presented in Table 1. For RG and CP six entirely green peel discs (15 mm in diameter, 5 mm thick; hue angles from 111–114°) were punched from the shaded side of each apple to yield a total of 36 discs. Discs were randomly placed on the 12 Peltier plates (5 cm × 6.5 cm) of an instrument (referred to as a "Celtec") constructed according to the design of Burke and Mahan (1993), with a H_2O-moistend filter paper between the discs and the plate. The temperature of each Peltier plate on the Celtec can be independently set, thereby facilitating temperature studies at the same irradiance. Each Peltier plate contained 3 discs for each of RG-Ceres, RG-Grabouw, CP-Ceres and CP-Grabouw. Each Peltier plate was covered with thin (0.5 mm) 100% crystal clear polyethylene wrap (Glad Wrap™, Glad products, Glad South Africa, Randburg, South Africa). A few holes were made in the plastic with a toothpick to prevent the build-up of CO_2 and, possibly, ethylene and to reduce condensation of water on the inside of the plastic.

Due to time constraints, FJ, BB and ERO were assessed on the same dates. Therefore, less space was available and fewer discs of these cultivars could be fitted on the Peltier plates of the Celtec. For each of these cultivars, one entirely green peel disc (hue angles from 110–114.5°) was punched from the shaded side of each apple to yield a total of 12 discs for each of FJ-Ceres, FJ-Grabouw, BB-Ceres, BB-Grabouw, ERO-Ceres and ERO-Grabouw. Discs were randomly placed on the 12 peltier plates of the Celtec as ascribed above so that each cultivar area combination was represented by 1 disc per plate.

2008–2009 season: RG, BB, FJ, ERO and CP apples were harvested from Grabouw and Ceres from about 1 month before scheduled harvest until commercial harvest on the dates presented in Table 1. Twelve apples were harvested on each date for every area cultivar combination with one disc punched from the green, shaded side of each apple. The same Celtec setup as for 2007–2008 was used and each area cultivar combination was represented by one disc per temperature plate. Hue angles of discs were measured before and 72 h after being placed on the Celtec.

2.2. Temperature treatments

Set temperatures of 16 °C, 19 °C, 22 °C, 25 °C, 28 °C and 31 °C were randomly assigned to the 12 plates of the Celtec so that there were two replicates of each temperature treatment. The Celtec was placed in a growth cabinet for 72 h set at 12 °C with 2 overhead lamps (400 W High Pressure Sodium; SON-T; Osram Mgbh, Munich, Germany) providing irradiance of 550–650 μmol m^{-2} s^{-1} photosynthetic photon flux (PPF) measured with a quantum meter (LI-189; Li-Cor, Lincoln, Nebraska, USA) at disc level. Disc temperature was measured with an infrared thermometer (Raynger MX4, Raytek Corporation, Santa Cruz, USA) to ensure that the required temperatures were maintained. Peel temperatures of discs in each plate, as well as the moisture level of the filter paper on which discs were placed, were assessed at least twice daily.

2.3. Colour measurement

We initially intended to assess anthocyanin accumulation in peel discs, but found that anthocyanin concentrations poorly reflected on visual and instrumental assessment of disc colour. The reason for this was that anthocyanin sometimes accumulated in a ring around the wounded periphery of peel discs. Cautious not to confound the data by wounding-induced anthocyanin synthesis, red colour development was rather assessed by measuring disc hue angle in the centre of each disc. Hue angle was measured with a chromameter (NR-3000; Nippon Denshoku, Tokyo, Japan) before and again 72 h after placement on the Celtec. Hue angles recorded ranged between 21° (red) and 114.5° (yellow-green).

2.4. Maturity indexing

Flesh firmness (assessed by means of a penetrometer on two opposite sides of each apple using an 8 mm plunger) were assessed in 2007–2008. Internal ethylene levels were measured at harvest during the 2007–2008 season, which proved the fruit to be in the desired pre-climacteric state, i.e., core ethylene <0.5 μL L^{-1}. Unfortunately, we do not have maturity data for the 2008–2009 season. However, sampling dates in the 2008–2009 season as in the 2007–2008 season were determined by the commercial