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Does strain affect fruit color development, anthocyanin content and fruit quality in 'Gala' apples? A comparative study over three seasons

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Abstract

The effect of strain and season on fruit color development, anthocyanin content and fruit quality was evaluated over a 3 year period (2004-2006) in 'Gala' apples (*Malus* x *domestica* Borkh.) at Lleida (northeastern Spain). The assessment period ranged from 4 wk before, to one wk after, commercial harvest. Based on fruit color (hue angle values and averages for red color covering the fruit surface) and anthocyanin content, the most colored strains were 'Buckeye Gala', 'Royal Beaut' (barely semi-striped) and 'Ruby Gala' (blushed). 'Brookfield', 'Schniga' (both striped) and 'Obrogala' (semi-striped), provided similar values with an intermediate level of color, while 'Galaxy' and 'Mondial Gala' (both striped) were the least colored varieties. The most important increase in both fruit color and anthocyanin content was recorded from 2 wk before commercial harvest and continued to increase after commercial harvest. Highly colored strains developed a red color on both sides of the fruit with greater averages of fruit surface color area, while less colored strains exhibited differences in color intensity between opposite sides, more bicolored fruits, and lower fruit color area. Season had a differential effect on fruit color of medium and low colored strains. However, in highly colored strains, skin color, anthocyanin content and average fruit surface area tend to be similar from one season to another. The relationship between hue angle, L* or a*/b* ratio and anthocyanin content allowed a cheap, easy, non-destructive prediction of anthocyanin content.

Fruit size and yield were, in general, similar for all strains. Other fruit quality parameters, such as fruit firmness, soluble solids content (SSC), titratable acidity (TA), and starch index, did not significantly differ among strains for the different harvest dates. Fruit quality parameters were not significantly different with respect to seasonal differences nor strain. Differences among strains in fruit color and anthocyanin content were not related to differences in fruit quality parameters and starch degradation. Consequently, color is not a good harvest index for colorful strains. We suggest that starch index could be a better index for picking these strains.

'Gala' is the second most important apple (*Malus* × *domestica* Borkh.) cultivar in the European Union (EU) after 'Golden Delicious'. Italy, France and Spain are the main producing countries. 'Gala' apple has become very popular in Europe where the high quality of this fruit is highly appreciated by consumers. 'Gala' has also received special attention from fruit growers in the main producing and exporting areas of the world, such as the U.S.A., Chile, Brazil and New Zealand.

The marketplace demands fruit of a specific size coupled with intense or adequate red color especially for red and bicolored apples such as 'Red Delicious', 'Gala', 'Fuji' and 'Jonagold', and this is based primarily on aesthetics. Lack of color can reduce commercial value (21) and is generally associated with poor visual consumer acceptance (5, 8). In addition acceptable fruit size (counts/weights) for highest returns would be helpful. For red and bicolored apple cultivars, the intensity and quality of their red skin color and fruit size are important parameters within the grading standards for European Union (EU) countries (10) and also influence both consumer acceptance and sales. A knowledge of how to develop appropriate fruit color and ensure good fruit size and eating quality is important for maintaining competitiveness in the apple industry, given the intensity of competition in the marketplace and the fact that consumer requirements have increased and product differentiation has become more and more important (4).

Obtaining suitable color in summer ('Gala', 'Elstar') and mid-season cultivars ('Deli-

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cious', 'Jonagold') is a problem in areas with hot summers and conditions that are not appropriate for fruit color development, as is the case in most southern European countries. The easiest and cheapest way to counteract poor color is to plant new strains that enhance the desired characteristics, and particularly fruit color (31). The majority of world apple production is based on chance mutations from original cultivars such as 'Gala', 'Delicious', 'Jonagold' and 'Fuji', and a large number of highly colored strains which offer a significant improvement in fruit color. Several researchers reported that limb mutations in 'Gala' apples affected only fruit appearance but not quality parameters and particularly internal eating quality (22, 28, 29, 35, 37, 39). Other authors found that 'Delicious' (14, 40) and 'Fuji' apples (25) had poor eating quality in redder apple selections.

The main pigment responsible for red color in apples is cyanidin-3-galactoside (idaein), which belongs to the family of red pigments known as anthocyanins. Idaein is derived from cinnamic acid by L-phenylalanine deamination, a reaction catalyzed by phenylalanine ammonia-lyase (PAL) (12, 26). PAL activity and the development of red color are directly regulated by environmental factors such as light (2, 36) and temperature (2, 6, 13,18), and also are influenced by cultivar (1, 9, 11, 17, 22, 30, 38, 40), rootstock and cultural practices (pruning, fertilization, etc.) (26, 30).

The objective of this study, in which eight 'Gala' strains were harvested at five different dates in the 2004, 2005 and 2006 growing seasons, was to determine the effect of strain, harvest date and season on fruit color development, anthocyanin content and fruit quality parameters. We also tried to determine the relationship, if any, between colorimetric values and the anthocyanin concentration of apple skin.

Materials and Methods

Plant material and climatic conditions. Eight 'Gala' strains developing different patterns of skin color were tested. The striped strains were: 'Brookfield Gala' ('Brookfield®Gala' Baigent), 'Schniga' ('Gala Schnitzer®'), 'Galaxy' ('Galaxy®'), and 'Mondial Gala' ('Mondial®Gala' Mitchgla). Semistriped strains were: 'Buckeye Gala'('Buckeye®Gala' Simons), 'Royal Beaut', 'Obrogala' ('Delbard®Gala'). One blushed strain, 'Ruby Gala' ('Rosso®Gala'), was included. Cultivars were grafted onto M.9 EMLA rootstock and were planted in January 2001 as 1-yr-old trees at the IRTA-Estació Experimental de Lleida, Mollerussa (Spain). Trees were grown in a Typic Xerofluvent soil with an average depth of 0.85 m, pH=8.4, elevation 260 m. The spacing was 4 m x 1.5 m. Trees were trained to a vertical axis system and were minimally pruned in winter. Summer prunning was applied during the three years in mid-June, removing the most vigorous shoots to improve light penetration into the canopy. The rows were oriented from NE to SW. The trees were drip-irrigated with two drippers per tree delivering 4 $L \cdot h^{-1}$ water. Standard commercial management practices recommended for the area were followed, including fertilization, plant disease and pest control, using the guidelines of integrated fruit production. Chemical thinning was applied all the seasons and consisted of a tank mix of **NAA** (naphthalene acetic acid) plus carbaryl diluted in 1000 $L \cdot ha^{-1}$ of spray solution, when fruitlet size of the king flower reached 10 mm diameter, followed by hand thinning in early June, in order to have similar cropload for all cultivars, established at 5 fruits$\cdot cm^2$ trunk cross-sectional area.

Each strain was planted randomly in plots of six trees. Full bloom was recorded on the 10th, 11th and 5th April for the 2004, 2005 and 2006 seasons, respectively. Fruit from each strain was collected at 2-wk intervals on five harvest dates, from 78 days after full bloom (DAFB) to 134 DAFB as represented in Fig. 2 and 5. Commercial harvest in the area took place at 120 DAFB, when flesh firmness was <8 kg and soluble solids content was >11%.

This area of Spain is frequently subject to periods of high summer temperatures (>30ºC) and low rainfall. In the pre-harvest period and during the harvest period (from 78 to 134 DAFB), the weather conditions were favorable for fruit color development in 2004. In 2005, conditions were usual for a warm area, while 2006 was the warmest season (Fig. 1). During this period, the average daily maximum and minimum temperatures (mean ± SE) were 30.5ºC ± 4.1ºC, 15.7ºC ± 2.1ºC; 30.9ºC ± 4.1ºC, 15.9ºC ± 2.1ºC; 32.7ºC ± 4.2ºC, 15.5ºC ± 2.1ºC; for the 2004, 2005 and 2006 seasons, respectively. Mean average rainfall for the same period and seasons were: 39.6 mm ± 5.2 mm, 35.1 mm ± 4.6 mm and 9.7 mm ± 1.2 mm, respectively.

Fruit color and fruit size measurements. Two trees per strain were selected from each plot of six trees, based on uniformity of tree size and crop load. The trees selected had shown no fruit color reversion in the previous two seasons (2002 and 2003). On the first tree of each strain, 20 fruits from the inner and outer canopies were selected and marked on 25 June 2005 (76 DAFB). Ten fruits were selected from each (east and west) side of each tree at two different heights: five from near the top (from 2.0-1.2 m above ground level) and five from near the bottom (1.2-0.6 m above ground level). Fruit color measurements were carried out five times at approximately the same location on both (exposed and shaded) sides of each fruit from 78 DAFB to the last harvest at 134 DAFB (Fig. 2 and 5). Apple skin color was measured with a Minolta Chroma Meter CR-200 portable tristimulus colorimeter (Minolta Corp, Osaka, Japan). Values were recorded in Commission Internationale d'Eclairage (CIE) colour space coordinates (L*, a* and b*). Hue angle was calculated as arctangent (b*/a*) x 57.3 and expressed in degrees, as reported by Iglesias et al. (22). Measurements were taken at two equatorial locations, 180º apart, on each fruit; on both the side exposed to sunlight (ES), and the shaded side (SS).

On the second tree of each strain, 20 fruits were randomly harvested on the same five dates, following the same procedure used for fruit color determinations, in order to determine fruit quality parameters and anthocyanin content.

The four remaining trees were individually harvested each one through two harvests as in commercial orchards. During each pick (116 DAFB and 128 DAFB), yield harvested was recorded for each strain, and average surface color was measured using an electronic grading calibrator manager (Model S2010, Sammo, Cesena, Italy). The criteria established for the first early harvest (116 DAFB)

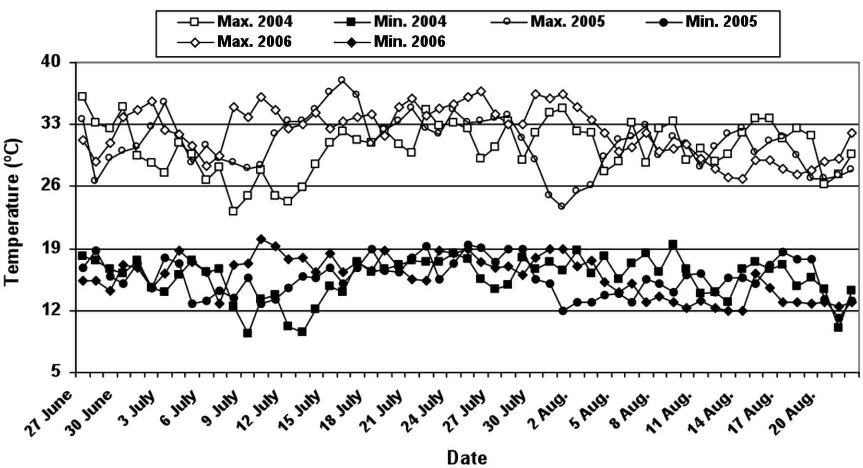

Fig. 1. Daily maximum and minimum temperatures over the period preceding commercial harvest and after harvest for the 2004, 2005 and 2006 seasons in Lleida, Spain.

were: fruit color > 50% of fruit surface with good red color development and fruit size > 70 mm (EU extra premium crop). All the remaining fruits were harvested at the second pick. Fruit size distribution, based on fruit diameter categories with 5 mm intervals, and average percentages of red color covering the fruit surface (<50%, 50-80%, >80%), were individually determined for the whole crop using the same grading calibrator.

Anthocyanin content. Due to destructive harvesting for the first four sampling dates (78, 92, 106 and 120 DAFB), the 20 fruits used for anthocyanin content measurements were the same as those used to analyze fruit quality parameters (SSC, TA, starch index) but different than those used for color determination in the field (with colorimeter). On the last date (134 DAFB), anthocyanin content was determined at the same points on each fruit at which chromaticity values were recorded. This allowed us to correlate the two parameters (fruit color and anthocyanin content). Anthocyanins from either 12 (in the cases of the first to fourth sampling dates of 2005 season, because 8 fruits were used for sensory evaluation) or 20 fruits for the rest of assessments, were extracted from fruit skins using a single 11 mm diameter skin disk, removed at each color measurement location, which had previously been treated in 10 ml of a solution of 50 methanol (26.4 M): 1 HCl (35%): 49 water. Extraction was carried out overnight and in the dark at 4ºC. Absorbance of extracts was measured with a Cecil series 1000 spectrophotometer (Cecil Instruments, Cambridge, England) at 532 nm. Anthocyanin concentration was subsequently determined using a molar extinction coefficient of 3.43 x 10^4 and data were expressed in $nmol \cdot cm^{-2}$.

Fruit quality parameters. Flesh firmness was determined using a penetrometer (Penefel, Copa technologie, St-Etienne du Gres, France) mounted on the bench of the lab with an 11 mm diameter plunger tip. Two readings were taken from opposite peeled sides of 20 randomly selected fruits per date and strain. Results were expressed as kg. Soluble solids concentration (SSC) and titratable acidity (TA) were measured in juice pressed from 4 subsamples of wedges from 5 unpeeled apples per date and cultivar. SSC was determined with an Atago-Palette 100 digital calibrated refractometer (Atago Co., Tokyo, Japan), and results were expressed as %. TA was determined by titrating 10 ml of juice with 0.1 N sodium hydroxide (NaOH) to pH 8.2 using phenolphthaleine and the results were expressed as g malic acid$\cdot L^{-1}$. Starch degradation was analyzed using standard iodine test on each of 20 fruits per treatment (strain × harvest date) or 12 fruits per treatment in the fourth sampling dates of 2005 season. Starch pattern was scored from 1 (black: full starch on the core and cortex areas) to 10 (white: low starch on the core and cortex).

Data analysis. A factorial design was used to evaluate the effect of strain on fruit color (hue angle and average surface covering of fruit color), anthocyanin content, fruit quality parameters, fruit weight and yield. Season and strain were designated as fixed effects and tree and fruits as random effects. Each individual value, per season, strain, date, fruit and fruit side (ES: exposed side, SS: shaded side), was considered as a replication unit. For each season, date and strain, fruit color values obtained represented the average of 20 fruits per tree and fruit side, and anthocyanin values were based on 12 or 20 fruits, as previously reported. All data were tested with analysis of variance (GLM procedure) using the SAS program package (32). The statistical significances of strains and interactions were tested at $P \leq 0.05$. When the strain and season interaction effects were statistically significant (F-test), based on the mean square error for each sampling date and parameter evaluated, LSMEANS were compared with Tukey's honestly significant difference (HSD) test at $P \leq 0.05$ the level of significance.

Results and Discussion

Fruit color. The mean values of hue angle corresponding to exposed (ES) and shaded (SS) sides for the 2004, 2005 and 2006 sea-

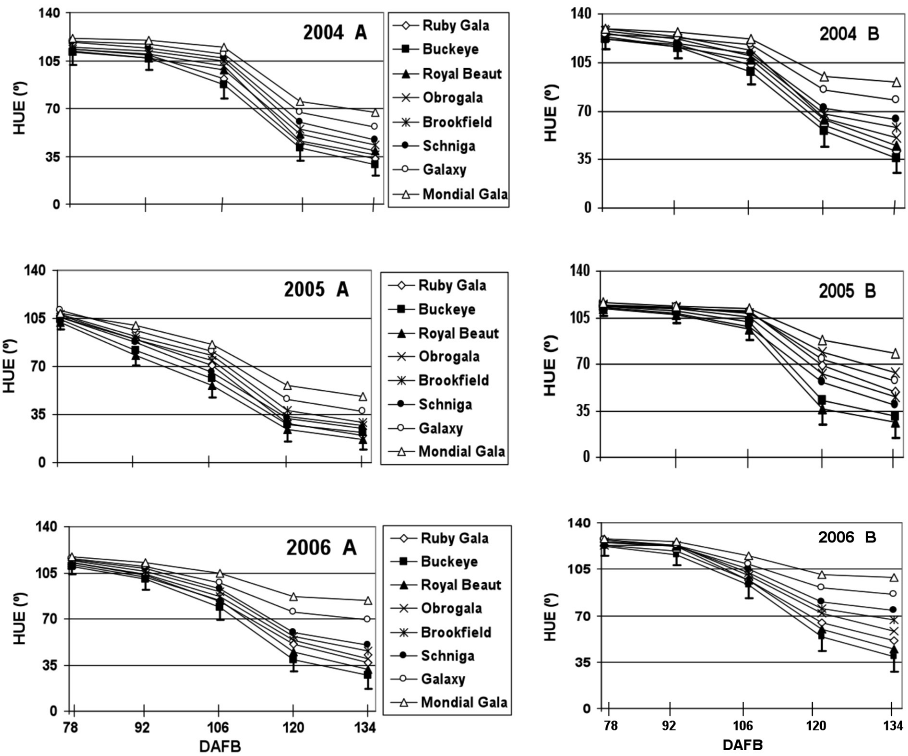

Fig. 2. Fruit color (expressed as a hue angle (°)) evolution on the exposed side (A) and shaded side (B) of fruit during the period preceding commercial harvest, at commercial harvest (120 DAFB) and after commercial harvest, for several ‘Gala’ apple strains in the 2004, 2005 and 2006 seasons. Vertical bars represent the HSD according to Tukey’s HSD test ($P < 0.05$) when the F-test was significant in the ANOVA. For all seasons *strain x date* interaction was significant at $P = 0.05$ for hue angle values. At commercial harvest *strain x season* interaction was signficant at $P = 0.05$ for hue angle values.

sons, and also for the sample period, are shown in Fig. 2. ‘Buckeye Gala’, ‘Royal Beaut’ and ‘Ruby Gala’ showed lower values for hue angle than the other strains, indicating higher red coloration. ‘Brookfield’, ‘Schniga’ and ‘Obrogala’ showed intermediate values, while higher values were recorded for ’Galaxy’, with ‘Mondial Gala’ being the least colored strain. Apple color progressively increased during fruit maturation (with a decrease in hue angle values for all strains), even in early stages and also after 120 DAFB. The last harvest (134 DAFB) produced the greatest and significant differences between strains (Fig. 2) and minimum values of hue angle for all the strains. Strains with values indicating higher color on the last two harvest dates also showed high color in the early stages.

Average percent fruit expressed as the mean value over two comercial harvest times at 116 DAFB and 128 DAFB (Fig. 3), for both surface color grades (>50% and >80%) showed significant differences between strains and seasons. The differences among strains were larger in seasons with less favorable conditions for fruit color development, such as 2006, and season x cultivar interaction was therefore significant. These results indicated greater and early fruit color for ‘Royal Beaut’ ‘Buckeye’ and ‘Ruby

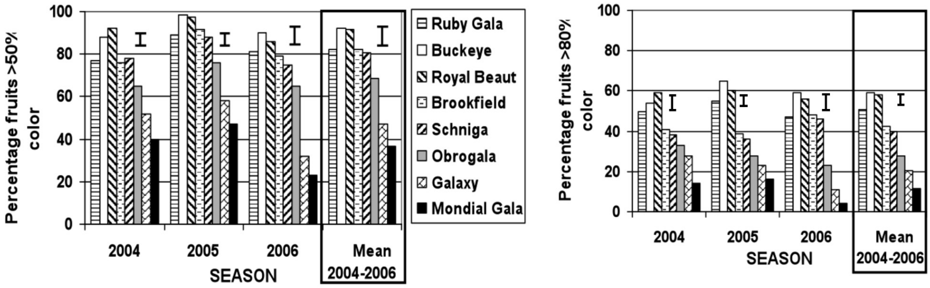

Fig. 3. Averages for fruit surface color >50% (left) and >80% (right) for different strains of 'Gala' at commercial harvest in the 2004, 2005 and 2006 seasons. Each value is the mean of two harvests at 116 DAFB (first early harvest) and 128 DAFB. Vertical bars for different seasons and average fruit color represent the HSD according to Tukey's HSD test ($P < 0.05$). (*Strain x season* interaction was significant at $P = 0.05$ for fruit color).

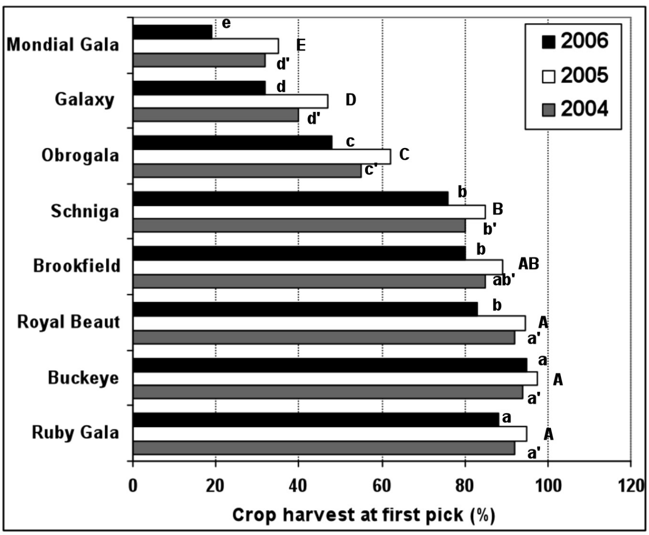

Fig. 4. Percentage of crop harvested at first early harvest (116 DAFB) for different strains of 'Gala' for 2004, 2005 and 2006 seasons. Strains with the same letter for the same season were not statistically different according to Tukey's HSD test ($P < 0.05$).

Gala', no significant differences between 'Obrogala', 'Brookfield and 'Schniga', and lower values for 'Mondial Gala' and 'Galaxy'. Higher coloring strains ('Royal Beaut', 'Buckeye', 'Ruby Gala') developed color earlier which resulted in a higher percentage of red color on the skin than less colored strains ('Mondial Gala' and 'Galaxy'), with the latter tending to be bicolored and with averages of fruit color more dependent on the season (Fig. 3). For this reason, the average of total yield corresponding to the first early harvest at 116 DAFB, was also affected by strain and season (Fig. 4). In all the seasons significantly greater yields were obtained on higher coloring strains as 'Buckeye', 'Royal Beaut' and 'Ruby Gala', intermediate values were recorded for 'Obrogala', 'Brookfield' and 'Schniga' and lowest ones for 'Galaxy' and 'Mondial Gala'.

Anthocyanin content. Anthocyanin content continuously increased during fruit maturation, especially in the 2 wk preceding and 1 wk week after the commercial harvest date, when the strains reached their maximum color (Fig. 5). As previously reported for hue values (Fig. 2), on the last three harvest dates significant differences were observed between strains, with greater anthocyanin contents being recorded on both sides (ES and SS) of fruits for 'Buckeye', 'Royal Beaut' and 'Ruby Gala'. 'Obrogala', 'Brookfield' and 'Schniga' produced intermediate values, followed by 'Galaxy', while 'Mondial Gala' had the lowest anthocyanin content.

Differences between strains in terms of hue values and anthocyanin content between opposite sides of fruits were more important for the last two harvest dates when color development was the greatest and were also affected by season. Greater differences between seasons and fruit sides (Fig. 2, 5 and 6) were associated with less colored strains. Similar values indicated more color and a more uniform distribution (Fig. 3). Important differences between sides (2-5 times greater on the ES) were observed in less colored strains ('Mondial Gala' and 'Galaxy'). In contrast, for highly colored strains ('Buckeye', 'Royal Beaut', 'Ruby Gala', etc.), values tended to be more similar between the two sides of the fruit, because a more intense red color tends to develop on both sides of these fruits. The reddest colored strains have high coloring potential both at early stages of fruit development and under the environmental conditions

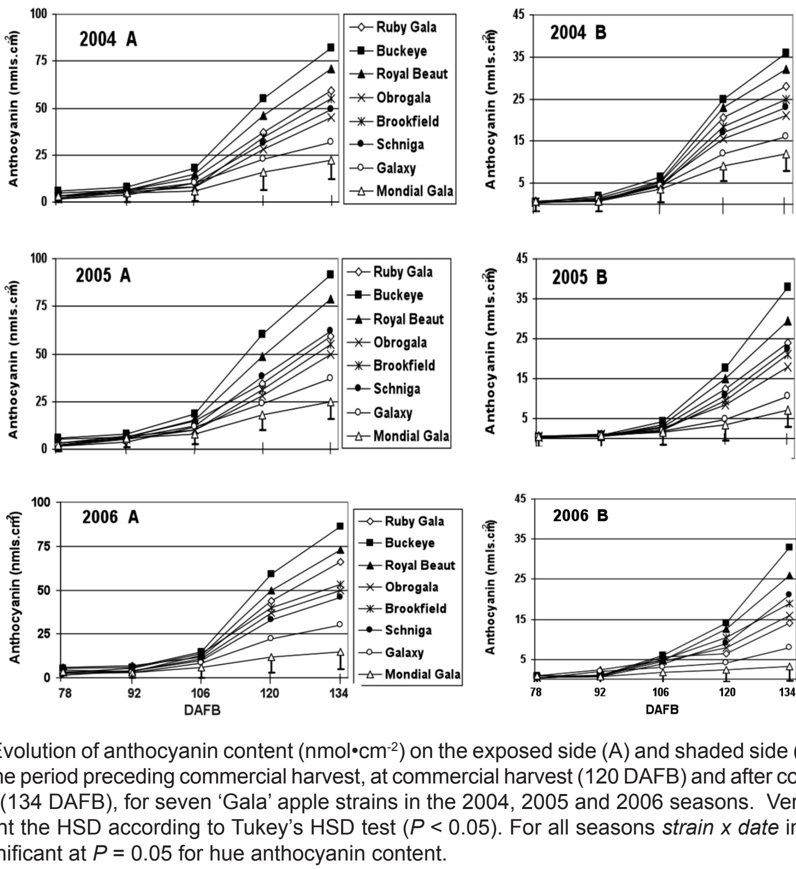

Fig. 5. Evolution of anthocyanin content (nmol•cm^{-2}) on the exposed side (A) and shaded side (B) of fruit during the period preceding commercial harvest, at commercial harvest (120 DAFB) and after commercial harvest (134 DAFB), for seven 'Gala' apple strains in the 2004, 2005 and 2006 seasons. Vertical bars represent the HSD according to Tukey's HSD test ($P < 0.05$). For all seasons *strain x date* interaction was significant at $P = 0.05$ for hue anthocyanin content.

associated with high temperatures or low-light conditions because anthocyanin synthesis is slightly dependent on exposure to light (9) and temperature (2, 13). In poor coloring strains, color development mainly depends on fruit maturity and season, as reported by Chalmers et al. (7), Arakawa et al. (1) and Lancaster (26). These results confirm the findings of previous work (15, 24, 35, 38) and Rutkowski et al. (30), who recorded different percentages of red blush when comparing various 'Gala' or 'Delicious' strains (9).

As in other cultivars, such as 'Red Delicious' (17, 34) and 'Jonagold' (27), high coloring 'Gala' strains tend to develop color early and the color is more intense at harvest (Fig. 2 and 5). Greene and Autio (15), Rapillard and Dessimoz (29) and White and Johnstone (41), reported significant differences among strains with respect to both onset and rate of red color development. At early stages of fruit development, other researchers (26, 29, 39) comparing 'Gala' strains reported less color for 'Royal Gala' and 'Mondial Gala' than for 'Galaxy', 'Obrogala' and 'Buckeye'.

White and Johnstone (41) reported that the intensity of red coloration in 'Gala' strains was strongly related to the total surface area covered but found no relationship between color intensity and the type of color in question (blushed or striped). Our results, which were partially reported by Iglesias et al. (22), show a greater proportion of surface red color and fewer differences between fruit sides in blushed and semi striped strains, such as 'Buckeye', 'Royal Beaut' and 'Ruby Gala' (Fig. 3), compared with striped ones.

When comparing seasons, hue angle (Fig. 2), average fruit surface color (Fig. 3) and anthocyanin content (Fig. 5), significant differences were found between strains. In high and medium colored strains, fruit color and anthocyanin content were similar in all three seasons, being less dependent on seasonal conditions (temperature). In less colored strains, such as 'Mondial Gala' and 'Galaxy', both parameters were associated with a significant decrease in fruit color in 2006, indicating a dependence of fruit color development on the season, more important in low colored strains (Fig. 6). For this reason *strain x season* interaction was consequently significant for average fruit color (Fig. 3), hue values and anthocyanin content (Fig. 5). In the 2004 and 2005 seasons, the lower maximum and minimum daily temperatures (Fig. 1) throughout the period preceding harvest provided more suitable conditions for the development of fruit red color with all the treatments (2, 13, 18, 19). In warm seasons like 2006, the difference between the exposed side and shaded side of better coloring strains show less difference than those of the poorly coloring strains (Fig. 2 and 5).

Seasonal effects of orchard temperature on fruit color development have been demonstrat-

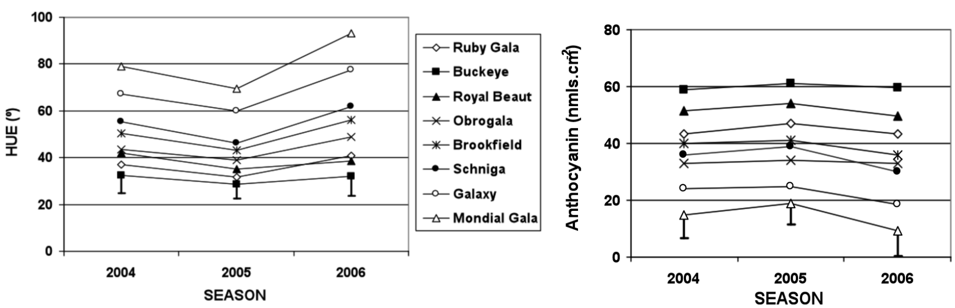

Fig. 6. Hue angle values and anthocyanin content (nmoles•cm^{-2}) of different 'Gala' apple strains in 2004, 2005 and 2006, for the last harvest date (134 DAFB). Values are means for the exposed and shaded sides of fruit. *Strain x season* interaction was significant at P = 0.05 for both hue values and anthocyanin content. Vertical bars for seasons and parameters represent the HSD according to the Tukey's test (*P* < 0.05).

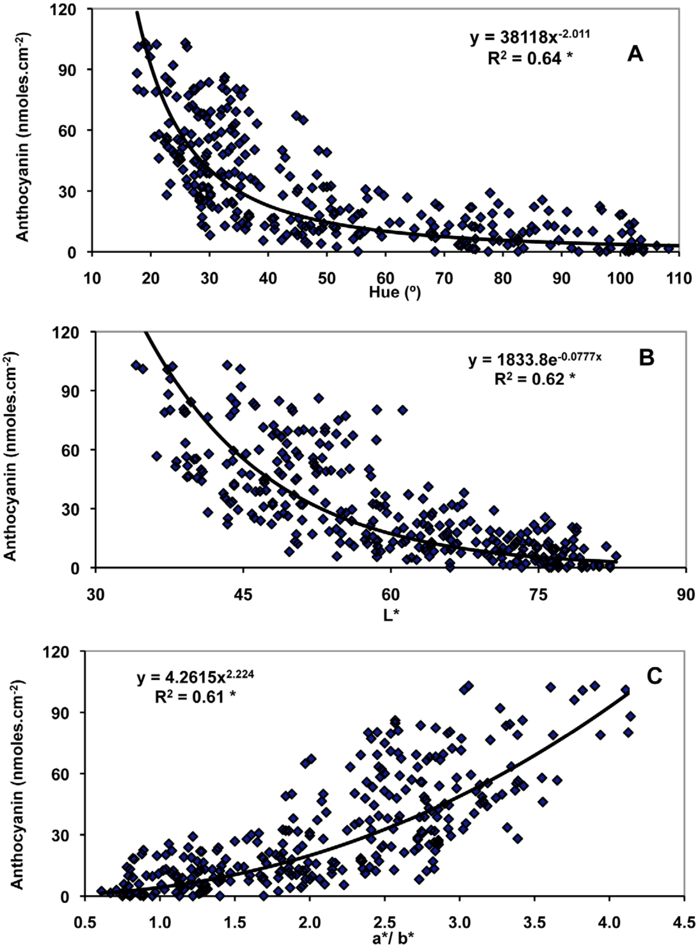

Fig. 7. Relationship between extractable anthocyanin content and hue angle (A), L* (B) and a*/b* ratio (C) values measured in the last harvest (134 DAFB) of the 2004, 2005 and 2006 seasons on fruit from seven 'Gala' apple strains (*: significant at P = 0.05).

ed through their effect on fruit color responses of 'Gala' apples to several strategies, such as orchard cooling (20), anti-hail nets (16, 21) and reflective mulch (23). Seasons that were favorable for fruit color development tended to mask the positive effects of those strategies used to increase fruit color.

Relationship between colorimetric values and anthocyanin content. The regression for anthocyanin content versus hue angle, L* and a*/b* ratio for all strains and seasons (2004, 2005 and 2006) at 134 DAFB (the last date) provided respective coefficients of determination (R^2) of 0.64 (hue angle), 0.62 (L*) and 0.61 (a*/b*) at $P \leq 0.05$ (Fig. 7). For 'Mondial Gala', which has the least color development and a striped appearance, the coefficient of determination for anthocyanin content *vs.* hue angle was 0.49. For 'Brookfield Gala', which has more color and also a striped appearance, the value was 0.69; for 'Buckeye Gala', also with greater color and a barely striped appearance, the value was 0.72. For 'Ruby Gala', with a high blushed color, the value was 0.94.

As with 'Delicious' apples strains (33, 34, 17), hue angle and L* in 'Gala' strains were inversely related to anthocyanin content, whereas a*/b* ratio was directly related to anthocyanin content (20, 22). Our results suggested good levels of prediction of anthocyanin content based on color values measured using the colorimeter. Furthermore, the positive relationship established between anthocyanin content and chromaticity parameters offers the possibility of using a portable colorimeter for rapid, cheap, non-destructive estimations of fruit anthocyanin content *in situ*.

Yield and fruit quality parameters. The total yields obtained for different strains were essentially the same and no significant differences were found among strains with respect to cumulative yields. The mean annual yield values for all strains were 27, 25 and 32 kg·tree^{-1} for the 2004, 2005 and 2006 seasons, respectively. These results were in accordance with those reported previously (15, 19) for 'Gala' strains. At commercial harvest (120 DAFB), no significant differences between strains were recorded with respect to fruit weight. Only 'Obrogala' produced low values. According to Walsh and Volz (38) and Rapillard and Dessimoz (29), fruit weight was not affected by 'Gala' strain. Rutkowski et al. (30) reported significant differences in fruit size when 'Gala' and 'Gala Must' were compared.

The evolution of fruit quality parameters over different harvest dates (mean values for 2004 to 2006 seasons) revealed an increase in fruit weight, soluble solids content (SSC) and starch index, and a decrease in fruit firmness and TA (Table 1). In contrast to results with fruit color, season had no a differential effect on quality parameters for the different strains and *season x strain* interaction was therefore not significant. As far as the values of different strains for the three seasons at commercial harvest were concerned, lower values for fruit firmness, titratable acidity and soluble solids content and a higher starch index were recorded in 2006, indicating earlier fruit ripening in the warmest season (data not shown). Autio et al. (3) and Rutkowski et al. (30) reported also year to year variations in fruit quality.

Comparisons of all strains for a specific harvest date showed similar values. It was not possible to establish any significant differences based on fruit quality parameters despite previously reported differences in skin color. At 106 DAFB, a date prior to commercial harvest, most of the strains achieved 11% SSC, the minimum value established by the EU for the commercial sale of 'Gala' apples. At commercial harvest, values were near 12% SSC and they continued increasing until the last harvest date (134 DAFB). For a given harvest date (Table 1), maturity stage, based on different quality parameters such as fruit firmness, SSC and starch index, was the same for all strains and was not related to the degree of skin color, average fruit surface color or anthocyanin content as shown in Fig. 2, 3 and 5. These results concur with those of other researchers (37, 39, 29, 35, 22) for 'Gala' (15, 28), 'Fuji' (25) and 'Delicious' apples (8, 17). Greene and Autio (15), based on background color, fruit firmness and starch index, reported that some strains of 'Gala' had an early maturity. Surface color alone is therefore not a good predictor of maturity for 'Gala' apples and cannot be used as a harvest index to determine the optimum harvest window because it is dependent on strain and season (38). For this reason starch index combined with fruit color, could be used to determine commercial harvest date for high colored strains. Starch index values from 5 to 7 are recommended to provide the best consumer acceptance in 'Gala' strains. Iglesias et al. (22) reported a close relationship between internal fruit maturity and consumer acceptance when different 'Gala' strains were compared. Harvest at immature stages even with full color development resulted in a significant decrease in the percentage of consumers satisfied. Anthocyanin levels can be also used as an index of maturity in 'Gala', except with highly colored strains because

Table 1. Mean values[z] corresponding to the 2004, 2005 and 2006 seasons for fruit weight, fruit firmness, soluble solids content (SSC), titratable acidity (TA) and the starch index (0-10) for seven 'Gala' apple strains, during the period preceding commercial harvest, at commercial harvest (120 DAFB), and after commercial harvest (134 DAFB).

Date (DAFB)	Strain	Weight (g/fruit)	Firmness (kg)	SSC (%)	TA (g/l)	Starch Index (0-10)
78 DAFB	Ruby Gala	90.3 ab	13.2	10.1	4.5	1.3
	Buckeye	92.7 a	13.7	9.9	5.0	1.2
	Royal Beaut	89.1 ab	13.4	9.4	4.9	1.2
	Obrogala	83.1 c	13.6	9.9	4.8	1.3
	Brookfield	85.9 bc	13.6	10.0	4.8	1.1
	Schniga	89.1 ab	13.5	10.0	5.0	1.3
	Galaxy	95.0 a	13.4	10.1	4.3	1.2
	Mondial Gala	89.5 ab	13.6	10.3	4.8	1.1
	P value	*0.039*	*0.321*	*0.241*	*0.119*	*0.147*
92 DAFB	Ruby Gala	133.3 a	13.2	10.2	4.9	2.6
	Buckeye	139.8 a	12.2	10.0	4.7	2.7
	Royal Beaut	132.0 ab	12.9	10.1	4.7	2.6
	Obrogala	117.6 b	12.2	10.3	4.6	2.6
	Brookfield	134.3 a	12.5	10.0	4.4	2.5
	Schniga	138.6 a	13.2	10.3	4.5	2.6
	Galaxy	128.7 ab	12.7	10.2	4.7	2.6
	Mondial Gala	124.5 ab	12.6	10.5	4.9	2.6
	P value	*0.023*	*0.0680*	*0.341*	*0.284*	*0.180*
106 DAFB	Ruby Gala	160.2 a	11.6	11.2	3.9	4.2
	Buckeye	152.4 b	11.2	10.9	3.9	4.1
	Royal Beaut	165.7 a	11.7	11.0	4.0	4.0
	Obrogala	149.9 b	11.2	11.1	3.9	4.2
	Brookfield	162.7 a	11.7	11.0	3.9	4.1
	Schniga	151.5 b	12.3	11.3	4.1	3.9
	Galaxy	161.5 a	11.3	11.3	3.6	4.4
	Mondial Gala	155.7 ab	11.7	11.5	4.0	4.5
	P value	*0.038*	*0.128*	*0.102*	*0.059*	*0.096*
120 DAFB (comercial harvest)	Ruby Gala	190.6 a	8.8	12.7	3.4	5.8
	Buckeye	199.2 a	8.6	12.7	3.3	6.2
	Royal Beaut	197.6 a	8.5	12.8	3.4	6.2
	Obrogala	175.3 b	8.6	12.9	3.4	6.1
	Brookfield	190.0 a	8.8	13.0	3.2	5.9
	Schniga	201.5 a	8.7	12.8	3.4	5.7
	Galaxy	191.4 a	9.3	12.8	3.0	6.1
	Mondial Gala	188.9 a	8.8	13.3	3.5	6.0
	P value	*0.015*	*0.412*	*0.030*	*0.312*	*0.280*
134 DAFB	Ruby Gala	203.3 ab	7.7	13.5 ab	2.8	8.9
	Buckeye	213.9 a	8.3	13.7 ab	3.1	8.7
	Royal Beaut	216.1 a	7.7	13.6 ab	3.1	8.5
	Obrogala	186.6 c	7.2	14.0 a	3.0	9.3
	Brookfield	206.5 ab	7.5	13.7 ab	2.9	8.9
	Schniga	205.7 ab	7.4	13.3 b	2.9	9.3
	Galaxy	205.0 ab	8.3	14..0 a	3.3	9.1
	Mondial Gala	195.7 bc	7.7	13.3 b	2.8	9.1
	P value	*0.011*	*0.418*	*0.025*	*0.152*	*0.158*

[z] Means followed by the same letter between strains for the same date and parameter do not differ at the 5% level of significance ($P \leq 0.05$) by Tukey's test. For a particular date, the interaction *season x strain* was not significant. For all seasons the *strain x date* interaction was not significant (5% level) for quality parameters. At commercial harvest the *strain x season* interaction was not significant for quality parameters.

high levels are reached at early stages of fruit development; however, their determination is difficult and expensive.

Based on the results, we conclude that in highly colored strains, color development does not coincide with the other maturity parameters the same way as in less colored strains.

New highly colored strains of 'Gala' are available and they constitute the best option for fruit growers, and particularly those planting new orchards in warm areas, because they provide greater fruit color and less dependance on the season compared to poorly colored strains. We did not observe any differences in standard quality parameters among strains, except fruit size for 'Obrogala', but we did note significant differences in the intensity and coloration patterns (blushed, semiestriped, striped). These differences did not, however, have any influence on internal fruit quality parameters if the strains in question were harvested within the optimum harvest window. This essentially means that fruit color type and color intensity cannot be considered as maturity indicators for highly red colored strains.

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