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Fruit Surface Colour as Related to Quality Attributes in Two Plum (*Prunus domestica* L.) Cultivars at Different Maturity Stages

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Summary

The fruit of 'Opal' and 'Victoria' plums (*Prunus domestica* L.) were harvested at commercial harvest time at the Ullensvang Research Centre, western Norway. The fruit were sorted into three maturity groups (MG1–3) according to their visual surface colour: green, pink and bluish-red for 'Opal', and green, pink and violet-red for 'Victoria', combined with their initial firmness, as evaluated by finger pressure. Their size, weight, soluble solids content, sensory firmness assessment, and colour parameters L* (lightness), a* (green/red) and b* (blue/yellow) were measured, and the Chroma and Hue angle indices and the colour index for red grapes (CIRG) were calculated. The fruit of increasing maturity were established across the maturity groups, as indicated by both increased soluble solids content and decreased the sensory firmness assessment from MG1 to MG3. The differences in the colour parameters and indices between the fruit in the three maturity groups were more or less similar for both cultivars. MG2 contained fruit that appeared to be a mixture of MG1 and MG3 fruits in terms of the colours, which resulted in large standard deviations for the colour parameters/indices in MG2. This appeared to cause the problem of sorting these plum cultivars by colour, whereby surface colour development during on-tree ripening along with the colour parameters/indices did not allow visual sorting of the fruit into three maturity groups. None of the colour parameters/indices correlated systematically and significantly with the quality parameters of weight, size, soluble solids content and the sensory firmness assessment within each of the maturity groups. However, high and systematic correlations were found between soluble solids content and the sensory firmness assessment on the one hand, and all of the colour parameters/indices on the other, when calculated over the total test material of each cultivar.

Key words. colour – European plum – firmness – sensory evaluation – size – soluble solids content – weight

Introduction

Fruit surface colour is an important indicator of maturity and quality in many fruit species (Drake et al. 1982; McGuire 1992; Abdi et al. 1997a). During ripening, colour changes in many stone fruits are associated with chlorophyll breakdown and anthocyanin accumulation (Lancaster et al. 1997), as for sweet cherry (Gao and Mazza 1995; Goncalves et al. 2007), grape (Ryan and Revilla 2003), and plum (Abdi et al. 1997b; Usenik et al. 2009). Together with firmness (Sams 1999), colour is the main quality attribute used to make decisions on strategies along the marketing chain.

'Opal' and 'Victoria' are plum cultivars (*Prunus domestica* L.) that are commonly grown in northern Europe (Ericsson 1976; Nilsson 1989; Wang and Vestrheim 2003). They are described as having slightly different skin colours: both of these plum cultivars have a green background colour that changes into yellow or yellow-green. With increasing maturity, the fruit develop a pink to bluish-red ('Opal') or a faint violet-red ('Victoria') blush (Nilsson 1989). Both of these cultivars are typical alternate bearers, and fruit grown on trees that bear too much fruit develop small fruit with a greyish colour (Nilsson 1989).

Colour measurements based on CIELAB (Commission Internationale de l'Eclairage) are now commonly used for a wide range of biological materials, and the results are usually represented by the Hunter (L_L, a_L, b_L) or the CIELAB (L*, a*, b*) scales (McGuire 1992; Valero et al. 2003; Usenik et al. 2008). From these parameters, the following indices can be calculated: Hue angle (Little 1975; Menniti et al. 2004; Usenik et al. 2008), Chroma (Serrano et al. 2003; Valero et al. 2004; Usenik et al. 2009) and colour index for red grapes (CIRG) (Carreno et al. 1995a;

Usenik et al. 2009); this last index was introduced as a parameter that can measure ripening in red grapes (Carreno et al. 1995b). Changes in the quality attributes of fruit size, soluble solids content (SSC) and firmness are often associated with fruit maturation in plum fruit (Ericsson 1976).

At present, much effort is put into investigations for the non-destructive determination of the maturity stage of fruit, based on methods like waveguide spectroscopy (Ragni et al. 2012), near infra red spectral data (Sánchez et al. 2012), acoustic data (Muramatsu et al. 1997) and the use of an impact device (Ragni et al. 2010; Valero et al. 2007). A common practice of farmers in Norway is to grade plums according to their maturity at harvest, as part of the decision support system along the marketing chain. The traditional non-destructive determination of maturity is, however, often not satisfactory. The fruit of yellow-reddish plum cultivars like 'Opal' and 'Victoria' are difficult to grade by visual colour and firmness estimated by finger pressure. The aim of this study was to examine the reliability of this method of grading these plum cultivars post-harvest. This study also focused on how the fruit surface colour changes relative to several fruit quality parameters that are usually associated with fruit maturity. The hypothesis was thus expressed as: "Does plum surface colour relate to quality attributes at different maturity stages?"

Materials and Methods

Plant material

Approximately 10 kg fruit of 'Opal' and 'Victoria' plums were harvested from five homogenous trees chosen at random at the experimental orchard at Ullensvang Research Centre, western Norway (60°19' N, 6°39' E). This was carried out at the commercial harvest time; i.e., when more than 50% of the fruit had started to developed a yellow ground colour. The trees were spindle trained on 'St. Julien A' rootstock, and received conventional orchard management practices. Immediately after harvest, the fruit were sorted into three maturity groups (MG1, MG2 and MG3) according to their visual surface colour of green, pink and bluish-red ('Opal') and green, pink and violet-red ('Victoria'), as demonstrated by (Abdi et al. 1997b). This colour assessment was combined with the initial firmness of the fruit, as evaluated by finger pressure. Thirty fruit of homogenous colour and firmness were sampled for each maturity group, as evaluated by a trained operator; these were tagged as numbers 1–30. These fruit were then used for further measurements of the quality attributes, allowing quality analyses both within each maturity group and of single fruit over the total test material as a single pool. Additionally, 150 representative fruits from each MG were divided into 10 equal and representative samples from each group for the sensory firmness evaluations. The experiment was conducted in a single environment and in a single year.

Colour measurements

Average fruit surface colour was evaluated according to the CIELAB scale, as the Hunter L*, a*, b* scales (McGuire 1992). Measurements were made with a CR-200 Minolta chromameter (Minolta Camera Co. Ltd., Osaka, Japan) on the two opposite cheeks of the fruit at the equatorial plane, at 90 ° from the most exposed side on each individual fruit. The parameter L* separates colour into bright and dark and reflects the colour 'lightness', the parameter a* evaluates colour changes along the green/red axis, and parameter b* evaluates colour changes along the blue/yellow axis (Little 1975). Chroma ($C = \sqrt{(a^{*2} + b^{*2})}$) is a measure of colour intensity or saturation, with low values representing dull colours and high values representing vibrant colours (Little 1975; Crisosto et al. 2002). Hue angle ($H = \tan^{-1}\cdot(b^*/a^*)$) is expressed in degrees and is a measure of colour that, for example, from 0 to 90 ° spans from red to orange to yellow (Crisosto et al. 2002; Little 1975). The CIRG (CIRG = (180 − H)/(L + C) is an index that is suitable for measuring colour changes related to fruit maturity, as tested on red grapes (Carreno et al. 1995a) and plums (Usenik et al. 2008).

Instrumental firmness measurement

Fruit firmness was measured using a Durofel® penetrometer (Copa-Technologie S.A., Paris, France) for individual fruit on the two opposite cheeks at the equatorial plane at 90 °, on the suture line. The Durofel® is a non-destructive, handheld penetrometer that is equipped with a plunger of 0.25 cm^2 area with a scale ranging from 0 to 100 (0, soft; 100, firm); the results represent mainly the elasticity of the fruit skin, more than the overall fruit flesh firmness.

Sensory firmness assessment

Sensory assessment of fruit firmness was carried out using 15 fruits from each MG, and involved ten experienced panellists who used thumb and forefinger to give scores for the fruit on a scale from 1 (firm) to 5 (soft). Coded batches were given to the assessors in a laboratory illuminated with red light, to camouflage the fruit surface colours. All of the panellists were experienced long-term assessors in our laboratory. To promote the reproducibility of their assessments, they were asked to assess fruit firmness sensorially on fruits of instrumentally determined firmness before the actual sessions began.

Determination of fruit size and soluble solids

The size of each individual fruit was measured at the equatorial plane using digital slide callipers, and the fruits were also weighed. The SSC of the individual fruit was measured using a portable Atago PR-101 refractometer (Atago Co. Ltd., Tokyo, Japan), on juice samples of five drops from each fruit.

Statistical data analysis

The data for the plum quality attributes were processed by repeated measures analysis, using the General Linear Model procedure (SAS Software 1999). The least-squares means of the experimental groups were obtained using the LSM procedure and were compared at the 5 % probability level (SAS 1999). Relationships between the quality attributes were assessed by Pearson correlation coefficients within each maturity group, and as combinations of maturity groups using the MiniTab Statistical Software Programme package.

Results

The 'Victoria' cultivar had larger fruit than the 'Opal' cultivar, when measured both as size and weight, while the 'Opal' fruit had higher SSC and firmness. The instrumental and sensory assessments of firmness differed significantly between the three maturity groups (Table 1). The sensory assessments of firmness did not differ significantly between the two cultivars (Table 1).

The mean values of the colour parameters L*, a* and the CIRG were significantly different between the cultivars tested, which indicated that the fruit of 'Victoria' had darker (L*) and greener (a*) fruit than those of 'Opal', while the corresponding mean values of b*, Chroma and Hue angle were not statistically different between the cultivars (Table 2).

SSC increased significantly over the three MGs for both of the cultivars (Table 1). The sensory firmness assessment also decreased statistically significantly over the MGs (Table 1). The changes in size and weight were less consistent between the MGs; there was a tendency for increased weight from MG1 to MG3 for both cultivars, while the increases in size were less systematic (Table 1).

The colour parameters L*, a* and b* all discriminated statistically significantly between the maturity groups in both cultivars, as did the Chroma and Hue angle indices, and the CIRG (Table 2). Of the correlation coefficients given in Table 3 (for 'Opal') and Table 4 (for 'Victoria'), attention needs to be paid particularly to the following: L*, a* and b* did not correlate with weight and size within each maturity group nor within combinations of groups in either of the cultivars. These parameters correlated to some extent with SSC, in MG2 and MG3 more than in MG1, for both cultivars. L*, a* and b* correlated more or less consistently with the sensory firmness assessment, with L* and b* generally better than a*.

The differences in colour parameters/indices between the fruit in the three MGs were more or less similar in both of the cultivars. However, when further examining the distribution of both the a* and the b* (Fig. 1), and to some extent the L* values (Fig. 1), it appeared that MG2 contained fruit with much more diverse values, with both 'Victoria' and 'Opal'. This resulted in large standard deviations for all of the colour parameters in MG2 (Table 2). For instance, MG2 of 'Opal' included fruit with negative a* values, as was typical for MG1 only, and also with positive

Table 1. Quality attributes of the two plum cultivars within the three maturity groups, as judged by fruit surface colour and initial firmness measured instrumentally by Durofel and estimated sensorially by finger pressure.

Cultivar (n = 30)	Maturity group	Mean quality attribute				
		Size (mm)	Weight (g)	SSC (%)	Durofel (0–100)	Sensory firmness assessment (1–5)
'Opal'	1	34.2 ± 2.6^{b}	29.1 ± 4.4^{b}	11.7 ± 1.3^{c}	74.0 ± 7.0^{a}	2.00 ± 0.9^{c}
	2	35.1 ± 1.5^{a}	32.8 ± 4.3^{a}	13.7 ± 1.4^{b}	67.0 ± 7.8^{b}	2.70 ± 0.8^{b}
	3	34.5 ± 1.8^{ab}	33.1 ± 4.9^{a}	16.8 ± 1.7^{a}	51.3 ± 7.0^{c}	3.77 ± 0.9^{a}
	Mean	34.6	31.7	14.1	64.1	2.82
'Victoria'	1	37.3 ± 1.5^{b}	39.9 ± 5.1^{b}	12.0 ± 1.8^{b}	69.9 ± 7.5^{a}	1.88 ± 0.6^{c}
	2	38.9 ± 2.1^{a}	44.9 ± 7.2^{a}	12.7 ± 2.4^{b}	57.0 ± 80^{b}	2.88 ± 0.7^{b}
	3	38.6 ± 2.2^{a}	44.6 ± 6.9^{a}	15.0 ± 0.3^{a}	43.0 ± 6.9^{c}	3.60 ± 0.7^{a}
	Mean	38.3	43.1	13.2	56.6	2.79
	P	0.000	0.000	0.042	0.000	NS

Means followed by different letters are significantly different within columns ($P \leq 0.05$). P indicates significance level between cultivar means. Data are means ± standard deviations. NS: not significantly different.
SSC, soluble solids content. Durofel, instrumental firmness assessment (0–100), 0 = soft, 100 = firm. Firmness, sensory firmness assessment (1–5), 1 = firm, 5 = soft

Table 2. Characteristics of the colour parameters in the two plum cultivars of the three maturity groups judged by the fruit surface colour and initial firmness estimated by finger pressure.

Cultivar (n = 30)	Maturity group	Mean colour parameter					
		L_L	a_L	b_L	Chroma	Hue angle	CIRG
'Opal'	1	52.0 ± 3.2[a]	−9.15 ± 3.2[c]	30.9 ± 3.9[a]	32.3 ± 4.3[a]	−1.29 ± 0.1[c]	2.17 ± 0.2[c]
	2	42.8 ± 5.2[b]	7.56 ± 5.7[b]	19.8 ± 5.9[b]	22.4 ± 3.4[b]	0.85 ± 0.9[a]	2.79 ± 0.4[b]
	3	32.2 ± 2.6[c]	13.64 ± 2.6[a]	6.7 ± 3.2[c]	15.3 ± 3.5[c]	0.43 ± 0.1[b]	3.84 ± 0.5[a]
	Mean	42.3	4.02	19.1	23.4	−0.003	2.93
'Victoria'	1	52.9 ± 2.8[a]	−7.95 ± 3.4[c]	27.8 ± 2.3[a]	29.0 ± 2.9[a]	−1.19 ± 0.5[c]	2.22 ± 0.2[c]
	2	49.0 ± 4.7[b]	−1.34 ± 5.1[b]	22.1 ± 4.3[b]	22.8 ± 4.2[b]	−0.50 ± 1.3[b]	2.55 ± 0.3[b]
	3	36.6 ± 3.6[c]	11.65 ± 3.7[a]	11.6 ± 3.4[c]	17.0 ± 2.1[c]	0.78 ± 0.3[a]	3.37 ± 0.3[a]
	Mean	46.2	0.78	20.5	22.9	−0.303	2.71
	P	0.003	0.029	NS	NS	NS	0.032

Means followed by different letters are significantly different within the columns ($P \leq 0.05$). P indicates significance level between cultivar means. Data are means ± standard deviations. NS: not significantly different.
L_L, lightness; a_L, colour change along the green/red axis; b_L, colour change along the blue/yellow axis; Chroma, colour saturation index; Hue angle, intensity of the dominating colour; CIRG, colour index for red grapes, as changes related to fruit maturity.

a* values that were as large as the largest a* values in MG3 (Fig. 1). Similar types of distributions were seen for the L* and b* (Fig. 1) values, and for the Chroma index and CIRG (Fig. 2), while the Hue angle values were unevenly distributed.

Discussion

The 'Victoria' cultivar had larger fruit than 'Opal', which is in good agreement with descriptions of Nilsson 1989. The sensory firmness assessment differed significantly between the MGs within both cultivars, but not between the cultivars; this latter can be expected; fruit of the two cultivars were not compared, but fruit within each cultivar were compared.

The increased SSC and decreased sensory firmness assessment from MG1 to MG3 indicated increased maturity over the three MGs, which corresponded to some degree to the results with different harvest times in plums reported by (Usenik et al. 2009). However, the size increase over the MGs was less systematic when using the present method, as described by (Abdi et al. 1997b), to obtain plant material of different degrees of maturity, when compared with using a number of harvest times across an interval of a few days, as reported by (Usenik et al. 2009). Nevertheless, the increasing maturity of the fruit was established in the present MGs for both cultivars, as indicated by both increased SSC and decreased sensory firmness assessment from MG1 to MG3.

The fruit of 'Victoria' had higher L* values and lower a* values than the 'Opal' fruit. The mean values of b* were high for both cultivars (but not significantly different), which indicated that yellow was dominant over blue, in contrast to the results published for blue-coloured cultivars (Valero et al. 2003; Usenik et al. 2008, 2009). The Chroma and the Hue angles were not statistically different between the cultivars, which indicated similarities both in colour saturation (Chroma) and position along the red/orange/yellow axis (Hue angle). The mean values of the CIRG were slightly higher in 'Opal' than in 'Victoria', which indicated that 'Opal' probably had more blue tints in the fruit surface than 'Victoria' had, as discussed for red grapes by (Carreno et al. 1995a).

Lightness (L*) decreased from MG1 to MG3, as also reported by (Valero et al. 2003) and (Usenik et al. 2008, 2009). However, these fruit had pronounced higher L* values in MG1 than the corresponding unripe blue cultivars reported by (Valero et al. 2003) and (Usenik et al. 2008, 2009). These differences were not very pronounced in the more mature fruit (MG3).

The a* values (as development along the green/red axis) developed from negative (green) to positive values (red) from MG1 to MG3. This is contradictory to the results reported for blue-coloured plums by (Valero et al. 2003) and (Usenik et al. 2008), where all of the a* values were positive, also for unripe fruit, and decreased with increased ripeness. It is most likely that this was caused by the development of the blue colour in their material, which would camouflage any changes occurring along the green/red axis.

The b* values (as development along the blue/yellow axis) showed positive values only. This is in contrast to the results presented by (Valero et al. 2003) and (Usenik et al. 2008), and demonstrated a lack of blue colour. Furthermore, b* decreased from MG1 to MG3, indicating the

Table 3. Pearsons correlation coefficients between the colour parameters and the quality attributes for the 'Opal' plums for the three maturity groups, as judged by visual surface colour and initial firmness estimated by finger pressure.

Maturity group	Quality attribute	Pearsons correlation coefficients for colour parameter					
		L_L	a_L	b_L	Chroma	Hue angle	CIRG
1	Size	0.219	0.080	0.043	0.017	−0.070	−0.126
(n = 30)	Weight	−0.074	0.231	−0.097	−0.129	−0.251	0.098
	SSC	0.150	0.316	0.194	0.115	−0.469**	−0.125
	Firmness[a]	−0.641***	0.393*	−0.537**	−0.541**	−0.292	0.619***
2	Size	0.493**	−0.428**	0.520**	0.420**	0.052	−0.510**
(n = 30)	Weight	0.270	−0.226	0.302	0.239	0.013	−0.274
	SSC	−0.410*	0.522**	−0.334	−0.117	0.115	0.282
	Firmness[a]	−0.593***	0.399**	−0.605***	−0.772***	0.147	0.666***
3	Size	0.000	−0.125	0.154	−0.006	0.198	0.036
(n = 30)	Weight	−0.104	−0.232	0.077	−0.110	0.146	0.140
	SSC	−0.392*	−0.206	−0.323	−0.259	−0.366*	0.339
	Firmness[a]	−0.566***	0.356	−0.438**	−0.436**	−0.395*	0.498**
1 + 2	Size	0.022	0.156	−0.024	−0.127	0.277*	−0.012
(n = 60)	Weight	−0.209	0.322*	−0.214	−0.296**	0.341**	0.207
	SSC	−0.559***	0.704***	−0.528***	−0.482***	0.554***	0.523***
	Firmness[a]	−0.645***	0.498***	−0.623***	−0.658***	0.364**	0.662***
2 + 3	Size	0.310*	−0.336**	0.344**	0.254*	0.112	−0.240
(n = 60)	Weight	0.051	−0.154	0.092	0.013	0.016	0.013
	SSC	−0.723***	0.540***	−0.705***	−0.608***	−0.216	0.687***
	Firmness[a]	−0.705***	0.398**	−0.687***	−0.733***	0.137	0.714***
1 + 2 + 3	Size	0.036	0.058	0.032	−0.042	0.207*	−0.022
(n = 90)	Weight	−0.270**	0.305**	−0.255*	−0.316**	0.323**	0.271**
	SSC	−0.804***	0.762***	−0.793***	0.735***	0.490***	0.788***
	Firmness[a]	−0.764***	0.611***	−0.747***	−0.760***	0.398***	0.762***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

L_L, lightness; a_L, colour change along the green/red axis; b_L, colour change along the blue/yellow axis; Chroma, colour saturation index; Hue angle, intensity of the dominating colour; CIRG, colour index for red grapes, as changes related to fruit maturity.
SSC: soluble solids content

[a] Firmness, sensory firmness assessment

development of yellow colour and also tints of blue from MG1 to MG3, similar to results in plums both at different harvest stages (Valero et al. 2003; Usenik et al. 2008) and for maturity development during storage (Valero et al. 2003).

Chroma correlated consistently and significantly with the sensory firmness assessment; however, the Hue angle showed no consistent correlations with any of the quality attributes tested. The CIRG correlated with the sensory firmness assessment, which was more consistent in 'Victoria' than in 'Opal', and with SSC in MG3 for both cultivars. When combining the results from two or three of the MGs, high and significant correlations were found between all of the colour parameters on the one hand, and all of the quality attributes, except for size and to some extent weight, on the other. Chroma values decreased from MG1 to MG3, which indicates that the fruit developed from dull to vibrant colours with increasing maturity, which is similar to results reported by (Usenik et al. 2008), with President plums during storage (Valero et al. 2004), and with the storage of four plum cultivars (Serrano et al. 2003). However, (Serrano et al. 2003) reported that 'Opal' and 'Victoria' plums had higher Chroma values at all ripening stages, except for the Golden Japan cultivar.

Hue angle values increased from MG1 to MG3 in 'Victoria', which mainly indicated the development of yellow colour from MG1 to MG3. This was contradictory to corresponding results reported for blue plum cultivars (Usenik et

Table 4. Pearsons correlation coefficients between the colour parameters and the quality attributes for the 'Victoria' plums for the three maturity groups, as judged by visual surface colour and initial firmness estimated by finger pressure.

Maturity group	Quality attribute	Pearsons correlation coefficients for colour parameter					
		L_L	a_L	b_L	Chroma	Hue angle	CIRG
1	Size	0.043	0.166	−0.118	−0.130	0.121	0.060
(n = 30)	Weight	0.041	0.136	−0.056	−0.083	0.051	0.036
	SSC	0.215	−0.071	0.061	0.053	0.086	−0.161
	Firmness[a]	−0.571***	0.496**	−0.473**	−0.510**	−0.054	0.555***
2	Size	0.089	0.039	0.040	0.094	−0.105	−0.093
(n = 30)	Weight	0.086	0.045	0.173	0.253	−0.108	−0.151
	SSC	−0.192	0.243	−0.101	−0.049	0.075	0.136
	Firmness[a]	−0.550**	0.358	−0.417*	−0.444*	0.405*	0.488**
3	Size	0.011	0.333	−0.044	0.375*	−0.169	−0.197
(n = 30)	Weight	0.068	0.240	0.074	0.343	−0.066	−0.223
	SSC	−0.518**	0.420*	−0.486**	−0.002	−0.513**	0.418*
	Firmness[a]	0.313	−0.036	−0.223	0.352	−0.118	0.377*
1 + 2	Size	−0.128	0.307	−0.263*	−0.256*	0.091	0.191
(n = 60)	Weight	−0.114	0.285	−0.163	−0.151	0.066	0.136
	SSC	−0.127	0.201	−0.138	−0.110	0.121	0.128
	Firmness[a]	−0.664***	0.631***	−0.650***	−0.684***	0.399**	0.667***
2 + 3	Size	0.093	0.027	0.062	0.185	−0.122	−0.149
(n = 60)	Weight	0.062	0.050	0.095	0.219	−0.083	−0.132
	SSC	−0.491***	0.476***	−0.463***	−0.267*	0.186	0.469***
	Firmness[a]	−0.595***	0.470***	−0.540***	−0.558***	0.440***	0.596***
1 + 2 + 3	Size	−0.139	0.258*	−0.200	−0.166	0.113	0.119
(n = 90)	Weight	−0.160	0.270**	−0.179	−0.147	0.135	0.131
	SSC	0.499***	0.493***	−0.490***	−0.360***	0.303**	0.493***
	Firmness[a]	−0.743***	0.703***	0.733***	−0.765***	0.586***	0.746***

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

L_L, lightness; a_L, colour change along the green/red axis; b_L, colour change along the blue/yellow axis; Chroma, colour saturation index; Hue angle, intensity of the dominating colour; CIRG, colour index for red grapes, as changes related to fruit maturity.
SSC: soluble solids content

[a] Firmness, sensory firmness assessment

al. 2008), for 'Fortune' and 'Angeleno' plums (Menniti et al. 2004), and for sweet cherries (Goncalves et al. 2007). This most likely resulted from a lack of blue colour in all of our material, resulting in positive b* values only, which is different from results reported in blue-coloured fruit. This lack of blue colour (positive b* values only, which produces no Hue angles between 360 and 270 °) means that we avoided the problem of the need to modifying the Hue angles for such values (Carreno et al. 1995a, 1995b; Usenik et al. 2008). For 'Opal', the Hue angles did not increase systematically over the MGs, as it did for 'Victoria', and it appears that the Hue angles are the least reliable of the colour parameters for the measurement of maturity development in plum fruit that are coloured like 'Opal' and 'Victoria'.

The CIRG values increased from MG1 to MG3 in both of the cultivars, similar to results reported for red grapes (Carreno et al. 1995a) and plums (Usenik et al. 2008). Although 'Opal' and 'Victoria' have a significant red constituent in their surface colour, as with Don Mariano grapes (Carreno et al. 1995b), the CIRG appears to be no more reliable than the other colour parameters tested as a tool to measure maturity development in these plums.

It is most likely that we are seeing here the causes of the problem with using surface colour to estimate postharvest maturity in these plum cultivars. Colour develop-

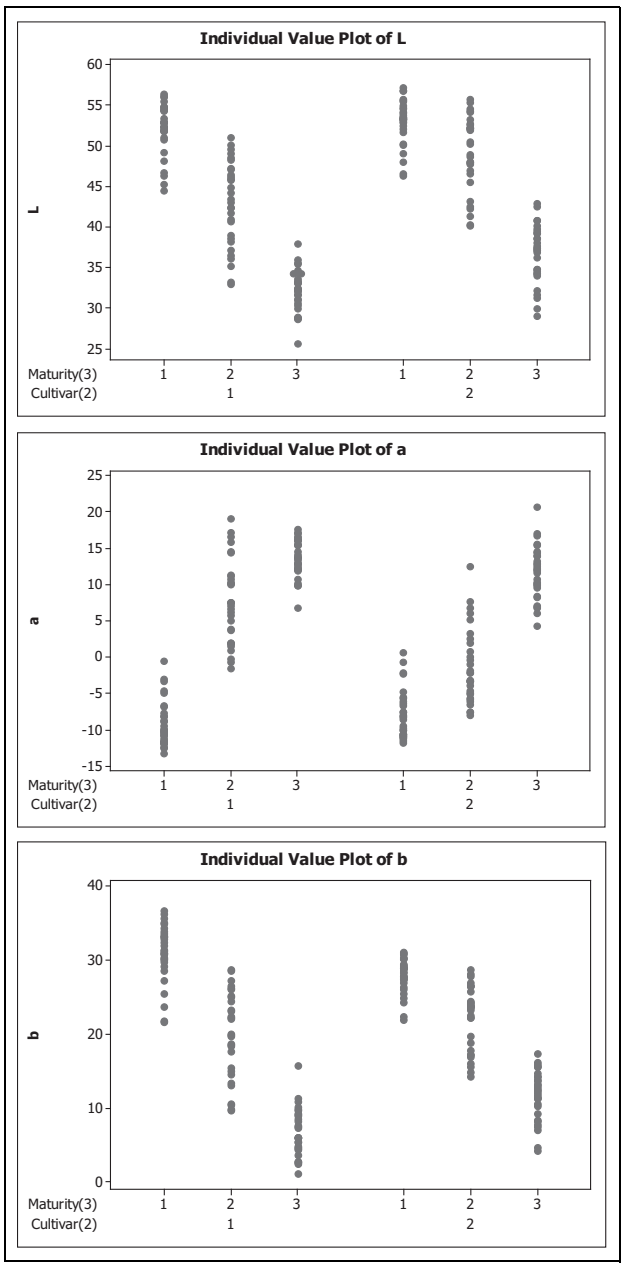


Fig. 1. Distribution of Hunter L_L values (lightness), Hunter a_L values (changes along the green/red axis), and Hunter b_L values (changes along the blue/yellow axis) as measured at harvest in 'Opal' (cultivar 1) and 'Victoria' (cultivar 2) plums after sorting the fruit into the three maturity groups (1–3) by visual colour and initial firmness estimated by finger pressure.

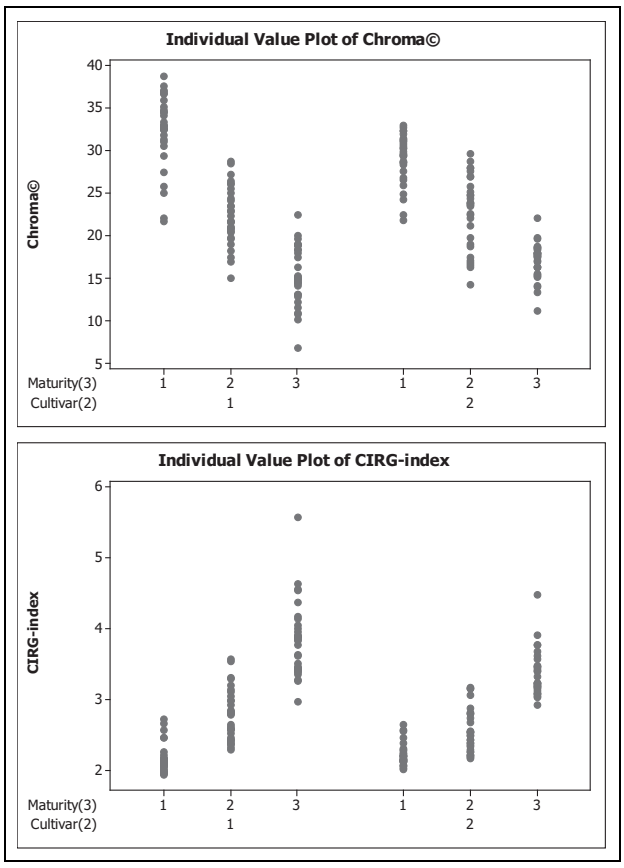


Fig. 2. Distribution of Hunter Chroma values (colour saturation) and CIRG values (for following colour changes in red-coloured grapes) as measured at harvest in 'Opal' (cultivar 1) and 'Victoria' (cultivar 2) plums after sorting the fruit into the three maturity groups (1–3) by visual colour and initial firmness estimated by finger pressure.

ment during on-tree ripening, along with the colour parameters L* (lightness), a* (green/red) and b* (blue/yellow), and also with the Chroma index and the CIRG, do not allow visual sorting of these fruits into three MGs. The middle maturity group (MG2) ended up with fruit that were a mixture of the MG1 and MG3 fruit, regarding their colours. Fruit with colour development as typical for overburdened trees (which show small, greyish fruit) might also complicate the colour determination, both as measured instrumentally, and by sensory evaluation. Thus it is most likely that the sorting of these fruit into two maturity groups only would be more successful.

The reason why the colour parameters did not correlate with fruit size and weight appeared to be a result of the method used to establish the maturity groups (Abdi et al. 1997a). There were little or no systematic changes in the sizes and weights obtained between the maturity groups, which is contradictory to methods where the fruit were harvested on different days (Abdi et al. 1997a; Valero et al. 2003; Usenik et al. 2008, 2009).

The SSC increased systematically with the maturity group, which was reflected in high correlations with all of the colour parameters. This indicates that the loading of carbohydrates into the fruit coincided with the colour development.

L*, a*, b* and Chroma correlated more or less consistently with the sensory firmness assessment evaluations, which indicates that the overall colour development coin-

cided well with the degradation of cell and cell wall components that comprise the fruit texture (Sams 1999).

The Hue showed no consistent correlations with any of the quality attributes tested, and it appeared to be of little value for the measurement of maturity development in these plum cultivars. (Usenik et al. 2008) also found non-systematic changes in Hue values over their maturity groups of t1 to t5, in two out of the four cultivars they tested.

The CIRG correlated well with all of the sensory firmness assessment measurements; and in 'Victoria' more consistently than in 'Opal', and with SSC in MG3 in both of the cultivars. The lack of correlation between the CIRG and SSC in MG1 and MG2 in both of the cultivars was probably linked to the small differences measured in the SSC between these two MGs for both cultivars tested.

Conclusions

The present study demonstrates that it is possible to discriminate the maturity stages of the yellow-reddish plum cultivars 'Opal' and 'Victoria' on the basis of initial firmness, as estimated by finger pressure. On the other hand, using surface colour to estimate post-harvest maturity does not allow the visual sorting the fruit into three maturity groups. For the correlations, none of the quality parameters of these plums correlated with the colour parameters within each maturity group. However when tested over the total test material of both of these cultivars, high correlation was found between SSC and the sensory firmness assessment on the one hand, and between SSC and all of the colour parameters on the other hand.

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