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# Fruit Firmness as Related to Quality Attributes in Two Plum Cultivars (*Prunus domestica* L.) of Different Maturity

**Lars Sekse[1] • Ursula Wermund[1,3] • Rajko Vidrih[2] • Marjan Simčič[2] • Eivind Vangdal[1*]**

[1] Norwegian Institute for Agriculture and Environmental Research, Division Horticulture and Urban Greening, Ullensvang, N-5781 Lofthus, Norway
[2] Institute of Food Science and Technology, Biotechnical Faculty, University of Ljubljana, Jaminkarjeva 101, 1000 Ljubljana, Slovenia
[3] Department of Agricultural Economics, Imperical College at Wye, University of London, Wye, Ashford, Kent, TN25 5AW, UK

*Corresponding author*: * **eivind.vangdal@bioforsk.no**

## ABSTRACT

Fruit of the multicoloured plum cultivars 'Opal' and 'Victoria' were sorted into three maturity groups MG1, MG2 and MG3 according to their visual surface colour combined with firmness as evaluated by fingers. Fruit firmness was measured by penetrometers Durofel® and PNR 10® and by sensory evaluation. 'Victoria' had larger fruit and lower soluble solids content than 'Opal'. Durofel® values indicated that 'Victoria' had firmer fruit than 'Opal', while PNR10® measurements did not discriminate statistically between cultivars. All firmness measurements, both instrumental and by sensory evaluation discriminated highly significant between MGs within each cultivar. SSC increased over the three maturity groups in both cultivars. All measured colour parameters varied significantly between MGs in both cultivars; L*, b* and Chroma decreased from MG1 to MG3 while a corresponding increase was found in a*, Hue angle and CIRG index. In 'Opal', Durofel® values correlated hardly with any of the quality attributes within each MG, but better in 'Victoria'; more in MG1 and MG2 than in MG3. In 'Opal', PNR10® values correlated with most of the colour parameters within MG1 and MG2, but not MG3, in 'Victoria' similarly best in MG2. Sensory firmness evaluation discriminated between the three MGs. The two penetrometers tested discriminated between fruit firmness in three maturity groups. However; instrumental colour measurements did not always correlate well with penetrometer measurements. Further, it was revealed that it was difficult to grade plums with this type of colour development during ripening into three maturity groups by sensory evaluation of a combination of firmness and colour; the results indicated that grading the fruit into two groups only would likely give more reliable results.

**Keywords:** colour, European plum, size, soluble solids content, weight
**Abbreviations: MG**, maturity group; **SSC**, soluble solid contents

## INTRODUCTION

Fruit texture is regarded an important quality parameter in fruits in general (Bourne 1979; Sams 1999; Amos 2007) and in stone fruits such as plums (Pérez-Vicente *et al*. 2002; Serrano *et al*. 2003; Valero *et al*. 2003; Menniti *et al*. 2004; Valero *et al*. 2004, 2007; Usenik 2008). Cell wall strength, cell to cell adhesion, cell turgor and tissue anatomy all contribute to the overall texture of fruits, and the contribution from each of these factors may identify which factors need to be targeted to control postharvest textural change (Heyes and Sealey 1996). Firmness of stone fruits is dependent on the degree of polymerisation of pectin side chains in the cell wall as demonstrated in cherries (Batisse *et al*. 1996; Choi *et al*. 2002), and loss of fruit firmness is associated with enzymatic activities degrading the middle lamella and primary cell wall (Fils-Lycaon and Buret 1990; Barrett and Gonzales 1994).

'Opal' and 'Victoria' plums (*Prunus domestica* L.) are commonly grown in northern Europe (Olafson 1974; Ericsson 1976; Nilsson 1989; Wang and Vestrheim 2003). 'Opal' has firm, very juicy fruit flesh and medium thick fruit skin, while 'Victoria' is a plum with thin skin and coarse fruit flesh. Further, both of them have a green background colour which develops into yellow or yellow-green. With increasing maturity the fruit develop a pink to bluish-red ('Opal') and faint violet-red ('Victoria') blush (Olafson 1974; Nilsson 1989). Both cultivars are typical alternate bearers, and fruit grown on trees bearing too much fruit develop small fruit with a greyish colour (Olafson 1974).

Penetrometers are widely used to measure fruit texture (Magness and Taylor 1925; Bourne 1979) as are colour measurements based on CIELAB (Commission Internationale de l'Eclairage, 1986) to measure surface colours in fruits (Little 1975; McGuire 1992).

Changes in the quality attributes fruit size, soluble solids content (SSC), surface colour and firmness are often associated with plum fruit maturation (Ericsson 1976; Usenik *et al*. 2008).

Common farmers' practice in Norway has been to grade plums based on maturity degree at harvest as part of the decision support system along the marketing chain. It was, however, often proven that fruit of yellow-reddish plum cultivars like 'Opal' and 'Victoria' was difficult to grade by visual colour combined with firmness as estimated by fingers.

In addition to examining the reliability of this method of grading such plums, this work also focused on how fruit firmness changed along with several fruit quality parameters usually associated with fruit maturation.

## MATERIALS AND METHODS

Fruit of 'Opal' and 'Victoria' plums were harvested at commercial harvest time from the experimental orchard at Ullensvang Research Centre, Western Norway (60°19′N, 6°39′E) on August 27 and September 21 2001, respectively. The trees were spindle trained on rootstock 'St. Julien A' planted in 1993 and received conventional orchard management practices. Immediately after harvest, fruit were sorted, as demonstrated by Abdi *et al*. (1997), into three maturity groups (MG1, MG2 and MG3, respectively) according to their visual surface colour: green, pink and bluish-red

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**Table 1** Mean values (± standard deviation) of size, weight, soluble solids content (SSC), colour (a* represent changes along the green/red axis) and firmness as measured by two penetrometers Durofel® and PNR10® in two plum cultivars of three maturity degrees as judged by overall fruit surface colour and firmness estimated by fingers. n = 30.

| Cultivar | Maturity MG 1-3 | Size mm | Weight g | SSC % | a* | Durofel 0-100 | PNR10 mm |
|---|---|---|---|---|---|---|---|
| 'Opal' | MG1 | 34.2 ± 2.6 b | 29.1 ± 4.4 b | 11.7 ± 1.3 c | -9.15 ± 3.2 c | 74.0 ± 7.0 a | 0.27 ± 0.10 c |
| | MG2 | 35.1 ± 1.5 a | 32.8 ± 4.3 a | 13.7 ± 1.4 b | 7.56 ± 5.7 b | 67.0 ± 7.8 b | 0.51 ± 0.12 b |
| | MG3 | 34.5 ± 1.8 ab | 33.1 ± 4.9 a | 16.8 ± 1.7 a | 13.64 ± 2.6 a | 51.3 ± 7.0 c | 0.69 ± 0.11 a |
| | Mean | 34.6 | 31.7 | 14.1 | 4.02 | 64.11 | 0.49 |
| 'Victoria' | MG1 | 37.3 ± 1.5 b | 39.9 ± 5.1 b | 12.0 ± 1.8 b | -7.95 ± 3.4 c | 69.9 ± 7.5 a | 0.27 ± 0.08 c |
| | MG2 | 38.9 ± 2.1 a | 44.9 ± 7.2 a | 12.7 ± 2.4 b | -1.34 ± 5.1 b | 57.0 ± 80 b | 0.46 ± 0.14 b |
| | MG3 | 38.6 ± 2.2 a | 44.6 ± 6.9 a | 15.0 ± 3.3 a | 11.65 ± 3.7 a | 43.0 ± 6.9 c | 0.82 ± 0.24 a |
| | Mean | 38.3 | 43.1 | 13.2 | 0.78 | 56.6 | 0.51 |
| | P | 0.000 | 0.000 | 0.042 | 0.029 | 0.000 | NS |

Means followed by different letters are significantly different within a column ($p \leq 0.05$). p indicates significance level between cultivar means.

('Opal') and green, pink and violet-red ('Victoria'), combined with firmness as evaluated by fingers. 30 fruit were sampled from each maturity group, were tagged with number 1-30 and were then used for further measurement of quality attributes, allowing quality analyses both within each MG and of single fruit over the total test material. 150 representative fruits from each MG were divided into 10 equal and representative samples from each group for sensory firmness evaluations.

Fruit firmness was measured by two different penetrometers in individual fruit on the two opposite cheeks at the equatorial plane at 90° on the suture line (means of the two measured penetrometer values from each fruit was calculated) and by sensoric evaluation:

- Durofel® (Copa-Technologie S.A., Paris, France), a non-destructive, handheld penetrometer equipped with a plunger of 0.25 $cm^2$ area with a scale ranging from 0 – 100 (0 = soft and 100 = firm). It was described to mainly measure the elasticity of the fruit skin more than the overall fruit flesh firmness (Planton 1992).
- PNR 10® (Sommer und Runge KG, Berlin, Germany) equipped with a spherical end (0.50 mm diameter, total weight 115 g) that was vertically positioned with the sphere perpendicular to the fruit surface and allowed to sink into it driven by its own weight in 15 seconds (the longer the distance (mm), the softer the fruit). Fruit was positioned in a bevelled holder (polyethylene ring, 19 mm inner diameter) to prevent bruising on the opposite side (Pérez-Vicente *et al*. 2002).
- Sensory evaluation of fruit firmness was carried out using 15 fruits of each MG by 10 panelists well used to handle fruit, using thumb and forefinger giving scores on a scale from 1 (firm) to 5 (soft) in a laboratory illuminated with red light to camouflage fruit surface colours.

Average fruit surface colour was evaluated according to the Commission Internationale de l'Eclairage, 1986 (CIE) and presented by the Hunter (L* a* b*) scale (McGuire 1992). Measurements were made with Minolta chromameter CR-200 (Minolta Camera Co. Ltd., Osaka, Japan) on the two opposite cheeks 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 'lightness', the parameter a* represents colour change along the green/red axis, and parameter b* similarly colour change along the blue/yellow axis (Little 1975). The calculated parameter 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). 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 (Little 1975). CIRG index (CIRG = (180 – H)/(L + C) is an index suitable for measuring colour changes related to fruit maturity as tested on red grapes (Carreño *et al*. 1995) and plums (Usenik *et al*. 2008).

Size of each individual fruit was measured by a digital slide calliper at the equatorial plane and by weight. Soluble solids content (SSC) in individual fruit was measured by a portable Atago PR-101 refractometer (Atago Co. Ltd., Tokyo, Japan); juice samples consisted of five drops from each fruit.

Pearson's correlation coefficients both within each MG and as combination of MGs were tabulated. Statistical analysis was carried out using Minitab™ Statistical Software (2007) (correlations) and SAS (SAS Institute, 1988) release 6.03 (comparison of mean values).

## RESULTS

'Victoria' had larger fruit than 'Opal' measured as both size and weight, while 'Opal' fruit had higher SSC than 'Victoria' (**Table 1**).

Firmness as measured with the Durofel® showed that 'Victoria' had firmer fruit than 'Opal', while PNR10® measurements did not discriminate statistically between cultivars (**Table 1**).

All firmness measurements, both instrumental (**Table 1**) and by sensory evaluation (**Table 3**) discriminated highly significant between MGs within each of the cultivars tested. Sensory evaluation also revealed that MG1 and MG2 had significantly different firmness between cultivars, while MG3 had not (**Table 3**).

SSC increased significantly over the three maturity groups in both cultivars (**Table 1**).

Changes in size and weight were less consistent between the maturity groups; a tendency of increased weight from MG1 to MG3 was found in both cultivars, while increase in size was less systematic (**Table 1**).

Variation in colour parameters between cultivars and MGs can briefly be outlined as (a* mean values shown in **Table 1**):

- L* (lowest in 'Opal'), a* (highest in 'Opal') and CIRG-index (highest in 'Opal') differed significantly between cultivars, while there were no such significant differences in b*, Chroma or Hue angle.
- All colour parameters varied significantly between MGs in both cultivars; L*, b* and Chroma decreased from MG1 to MG3 while a corresponding increase was found in a*, Hue angle and CIRG index.

Of the many correlation coefficients presented in **Table 2**, attention should be paid particularly to the following:

- Only few and sporadic significant correlations were obtained within each MG between penetrometer measurements and the quality attributes size, weight and SSC, but SSC, and to some extent weight, correlated significantly with firmness when combining two or more MGs.
- Durofel® measurements correlated hardly with any of the quality attributes within each MG in 'Opal', although higher coefficients were generally obtained in MG3 than in MG1 and MG2. They correlated more or less significant within each MG with most of the colour parameters in 'Victoria'; better in less ripe (MG1 and MG2) than in MG3.
- PNR10® measurements correlated highly significant with all the colour parameters / indexes in MG2 but Hue angle, and in MG1 (less significant) but b* and Chroma, while no significant correlation was obtained in MG3 in 'Opal'. In 'Victoria' they correlated similarly with all colour parameters / indexes in MG2, but only with L, Chroma and CIRG-index in MG3; a tendency also found in MG1.

10 panelists discriminated highly significant sensory

**Table 2** Pearson's correlation coefficients between different quality attributes and measured firmness by two different penetrometers in two plum cultivars graded into three maturity groups by sensory firmness and colour evaluation.

| Maturity group MG1-3 | Quality attributes | 'Opal' Durofel | 'Opal' PNR10 | 'Victoria' Durofel | 'Victoria' PNR10 |
|---|---|---|---|---|---|
| MG1 | Size | 0.036 | -0.437** | -0.197 | 0.086 |
| N=30 | Weight | 0.140 | 0.088 | -0.255 | 0.121 |
| | SSC | 0.131 | 0.364* | 0.148 | -0.173 |
| | L | 0.047 | -0.408* | 0.592*** | -0.445* |
| | a | -0.068 | 0.424* | -0.475** | 0.287 |
| | b | 0.165 | -0.223 | 0.437* | -0.334 |
| | Chroma | 0.157 | -0.262 | 0.482** | -0.355 |
| | Hue angle | 0.028 | -0.504** | 0.116 | -0.228 |
| | CIRG index | -0.097 | 0.362* | -0.538** | 0.396* |
| MG2 | Size | -0.170 | -0.321 | 0.215 | -0.301 |
| N=30 | Weight | -0.163 | -0.171 | 0.021 | -0.105 |
| | SSC | 0.092 | 0.215 | -0.145 | 0.269 |
| | L | 0.010 | 0.638*** | 0.627*** | -0.588*** |
| | a | 0.048 | 0.762*** | -0.440* | 0.377* |
| | b | -0.018 | -0.593*** | 0.471** | -0.443* |
| | Chroma | 0.154 | -0.770*** | 0.486** | -0.456* |
| | Hue angle | -0.223 | -0.013 | -0.436* | 0.420* |
| | CIRG index | 0.009 | 0.782*** | -0.570*** | 0.537** |
| MG3 | Size | 0.292 | -0.118 | 0.048 | -0.270 |
| N=30 | Weight | 0.133 | 0.036 | -0.126 | -0.131 |
| | SSC | -0.006 | 0.264 | -0.367* | 0.250 |
| | L | 0.422* | -0.288 | 0.445* | -0.475** |
| | a | 0.305 | -0.226 | -0.024 | -0.240 |
| | b | 0.309 | -0.146 | 0.364* | -0.326 |
| | Chroma | 0.353 | -0.221 | 0.453* | -0.675*** |
| | Hue angle | 0.258 | -0.106 | 0.261 | -0.100 |
| | CIRG index | -0.410* | 0.283 | -0.555*** | 0.689*** |
| MG1+2 | Size | -0.193 | -0.012 | -0.229 | 0.124 |
| N=60 | Weight | -0.187 | 0.261* | -0.307* | 0.210 |
| | SSC | -0.189 | 0.603*** | -0.116 | 0.201 |
| | L | 0.335** | -0.835*** | 0.705*** | -0.671*** |
| | a | -0.378* | 0.823*** | -0.665*** | 0.603*** |
| | b | 0.357* | -0.812*** | 0.674*** | -0.653*** |
| | Chroma | 0.429*** | -0.794*** | 0.702*** | -0.666*** |
| | Hue angle | 0.451*** | 0.633*** | -0.408*** | 0.431*** |
| | CIRG index | 0.335** | 0.837*** | -0.703*** | 0.680*** |
| MG2+3 | Size | 0.175 | -0.276* | 0.150 | -0.252 |
| N=60 | Weight | -0.031 | -0.033 | -0.017 | -0.102 |
| | SSC | -0.505*** | 0.578*** | -0.434*** | 0.429*** |
| | L | 0.640*** | -0.782*** | 0.797*** | -0.761*** |
| | a | -0.353** | 0.577*** | -0.686*** | 0.574*** |
| | b | 0.634*** | -0.760*** | 0.740*** | -0.698*** |
| | Chroma | 0.646*** | -0.727*** | 0.706*** | -0.705*** |
| | Hue angle | 0.152 | -0.220 | -0.565*** | 0.500*** |
| | CIRG index | -o.657*** | 0.725*** | -0.794*** | 0.813*** |
| MG1+2+3 | Size | 0.002 | -0.051 | -0.184 | 0.046 |
| N=90 | Weight | -0.214* | 0.285** | -0.284** | 0.150 |
| | SSC | -0.635*** | 0.769*** | 0.435*** | 0.466*** |
| | L | 0.742*** | -0.888*** | 0.853*** | -0.839*** |
| | a | -0.639*** | 0.845*** | -0.816*** | 0.739*** |
| | b | 0.747*** | -0.870*** | 0.839*** | -0.812*** |
| | Chroma | 0.731*** | -0.853*** | 0.839*** | -0.803*** |
| | Hue angle | 0.453*** | 0.592*** | -0.660*** | 0.634*** |
| | CIRG index | 0.754*** | 0.842*** | -0.853*** | 0.874*** |

* p≤0,05, **p≤0.01, ***p≤0.001

firmness evaluation between fruit in the three MGs (**Table 3**). In 'Opal' no statistically significant differences were found between evaluation scores by the 10 panelists, contrary to in 'Victoria' where a significant difference was obtained between panelists (**Table 4**).

## DISCUSSION AND CONCLUSIONS

'Victoria' had larger fruit than 'Opal', which is well in accordance with descriptions by Olafson (1974) and Nilsson (1989). Postharvest quality of plums is defined by several quality indexes, but SSC and firmness is the most important (Paz *et al.* 2008). Among other quality attributes like appearance, flavour and nutritional value, SSC and firmness as well define consumer acceptance. Since SSC and firmness are easily determined, fruit distribution centers demand specific values for both parameters (Crisosto *et al.* 2004).

Increasing SSC and a* and decreasing firmness, as measured by both penetrometers and by sensory evaluation, from MG1 to MG3 indicated increasing maturity over the three groups, corresponding to some degree to the results with different harvest time in plums reported by Usenik *et al.* (2008). However, size increase over the maturity groups was less systematic when using the present method described by Abdi *et al.* (1997) to obtain plant material of different maturity degrees. Nevertheless, fruit of increasing maturity were established in the present maturity groups in both cultivars, as indicated by both increased SSC and decreased firmness from MG1 to MG3.

Currently, growers and produce store managers mostly rely on destructive methods while nondestructive firmness measurements are done predominantly in scientific purposes. Taking in mind nondestructive methods, near-infrared spectroscopy seems promising to determine both SSC and firmness (Paz *et al.* 2008; Louw and Theron 2010).

Durofel® measured an average firmness loss from MG1 to MG3 of 22.7 points (31%) in 'Opal', while a corresponding firmness loss in 'Victoria' was 26.9 points (39%), showing that a slightly higher firmness loss occurred in 'Victoria' than in 'Opal'. This discrepancy was likely resulting from the different constituents of the total firmness of the two cultivars tested; 'Opal' with its firm, very juicy fruit flesh and medium thick fruit skin seemed to develop more elasticity in the skin over the MGs than did 'Victoria' with its correspondingly thin skin and coarse fruit flesh.

PNR10® measured the average firmness in both cultivars to 0.27 mm in MG1; 'Opal' lost firmness corresponding to 0.42 mm (61%) from MG1 to MG3, while the corresponding firmness loss in 'Victoria' was 0.55 mm (67%). The PNR® measurements then confirmed the higher firmness loss in 'Victoria' compared to 'Opal' as measured by Durofel® (**Table 1**). Hence, 'Opal' seemed to have a slower degradation of some of the components constituting the total fruit texture than had 'Victoria'. These results were comparable to corresponding results reported by Usenik *et al.* (2008); firmness loss in 4 plum cultivars harvested at 5

**Table 3** Mean values of sensoric firmness scores (scale 1 – 5; 1 = very firm, 5 = very soft) of two plum cultivars of three maturity levels as measured by 10 panelists. n = 150, p = 0.05.

| Colour | 'Opal' | 'Victoria' |
|---|---|---|
| 1 | 1.99 ± 0.77$^{cy}$ | 2.42 ± 0.87$^{cx}$ |
| 2 | 2.80 ± 0.81$^{by}$ | 3.16 ± 0.75$^{bx}$ |
| 3 | 3.61 ± 0.83$^{ax}$ | 3.67 ± 0.80$^{ax}$ |

Means followed by different letters are significantly different within column ($^{abc}$), and within rows ($^{xy}$)

**Table 4** Mean values of sensoric firmness scores (1 – 5, where 1 = firm, 5 = soft fruit flesh) in plums from two cultivars ('Opal' and 'Victoria') made by 10 panelists. n = 45.

| Panelist no. | 'Opal' | 'Victoria' |
|---|---|---|
| 1 | 2.78 ± 1.28 | 2.84 ± 0.93$^{c}$ |
| 2 | 2.69 ± 1.08 | 3.04 ± 0.93$^{bc}$ |
| 3 | 2.84 ± 1.20 | 2.82 ± 1.28$^{c}$ |
| 4 | 2.82 ± 0.98 | 3.58 ± 0.62$^{a}$ |
| 5 | 2.91 ± 1.16 | 3.18 ± 0.83$^{abc}$ |
| 6 | 2.91 ± 1.04 | 3.33 ± 0.71$^{ab}$ |
| 7 | 2.82 ± 1.11 | 3.11 ± 0.96$^{abc}$ |
| 8 | 2.93 ± 0.75 | 3.16 ± 0.95$^{abc}$ |
| 9 | 2.49 ± 0.99 | 2.89 ± 0.80$^{c}$ |
| 10 | 2.56 ± 0.79 | 2.87 ± 0.94$^{c}$ |
| P | NS (p≥0.05) | 0.001 |

Means followed by different letters are significantly different or 6 different harvest times (t1-t6) lost between 31 and 63% firmness from t1 to t5/t6. The measured firmness percentage loss from MG1 to MG3 was pronounced higher as measured by PNR10® than by Durofel®, likely resulting from differences in the physical properties of the fruit flesh. The considerable variability in physical and pomological properties of plum cultivars is also reported by (Ertekin *et al*. 2006).

Variation in colour parameters between cultivars and MGs can briefly be outlined as (a* mean values shown in **Table 1**):

- L* (lowest in 'Opal'), a* (highest in 'Opal') and CIRG-index (highest in 'Opal') differed significantly between cultivars, while there were no such significant differences in b*, Chroma or Hue angle.
- All colour parameters varied significantly between MGs in both cultivars; L*, b* and Chroma decreased from MG1 to MG3 while a corresponding increase was found in a*, Hue angle and CIRG index.

Nearly no significant correlation was obtained either within each MG or in combination of MGs between penetrometer measures on one side and weight and size on the other side (**Table 2**). This was most likely related to the method used to establish MGs as discussed above; little or none systematic size or weight increase occurred over the MGs in any of the two cultivars. However, some correlation was found between weight and firmness when combining all MGs, contrary to size and firmness, where nearly no correlation occurred. The reason can be seen in **Table 1**; there is a more systematic increase from MG1 to MG3 in weight than in size in both the two cultivars.

Firmness correlated systematically with SSC only when MGs were combined. As Døving and Måge (2002) pointed out, some of the penetrometers tested in strawberry, among others PNR10®, needed larger samples than 30 fruits to produce reliable results. This may be a reason for lack of correlation as tested within MGs.

Measurements made with the two penetrometers correlated distinctly different with the different colour parameters / indexes within cultivars (**Table 2**).

No significant correlation was obtained within MGs between Durofel® measurement values and any of the colour parameters / indexes in 'Opal'; highest correlation was obtained in MG3. Contrary, in 'Victoria' Durofel® measurements correlated significantly with all colour parameters / indexes but Hue angle, generally better correlation in MG2 and MG1 than in MG3. This demonstrated that increased elasticity in the fruit skin as measured by Durofel® coincided with colour development only in the late ripening phase (MG3) in 'Opal', but in all three MGs in 'Victoria'. The distribution of mean values of firmness as measured by Durofel® is shown for all MGs and both cultivars in **Fig. 1**. Rather widespread distribution occurred within all MGs and also overlapping more or less between all MGs in both cultivars. This was contradictory to the corresponding distribution of all of the colour parameters / indexes, where mean values in MG2 where distinctly more widespread than in MG1 and MG3. This was reflected also in a larger standard deviation of the MG2 observations than correspondingly in MG1 and MG3 (data not shown).

PNR10® measures correlated significantly with all colour parameters / indexes in MG2 in 'Opal', to some degree also in MG1, but not in MG3. In 'Victoria', significant correlation was obtained between PNR10® measures and three of the parameters / indexes; L*, Chroma and CIRG index; better correlation in MG3 and MG2 than in MG1. This demonstrated that loss of firmness in the fruit flesh as measured by PNR10® coincided with colour development in 'Opal' more in the early phase of maturity (MG2 and MG1) than in MG3, while in 'Victoria' this occurred more or less within all the MGs. The distribution of mean values of firmness as measured by PNR10® is shown for all MGs and both cultivars in **Fig. 2**. A much more widespread distribution of the values in MG3 than in MG1 and partly in MG2 in 'Victoria' may explain the better correlation between firmness and colour parameters / indexes in MG3 than in the other two MGs.

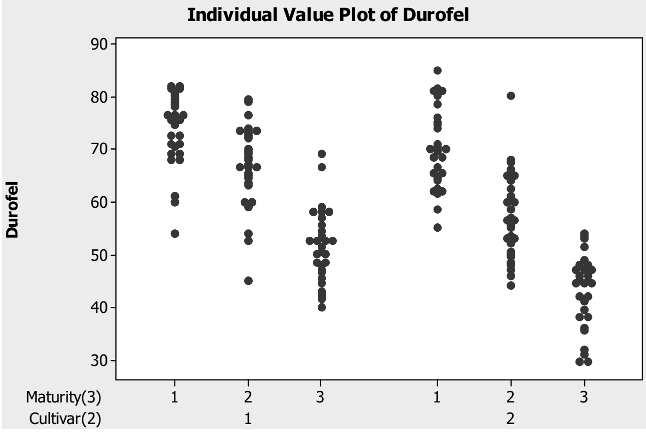


**Fig. 1 Distribution of average firmness measurements as measured by Durofel® penetrometer (scale 0-100; 100 = very firm, 0 = very soft in cultivars 'Opal' (1) and 'Victoria' (2) at three levels of maturity (1-3) as graded by sensory evaluation of colour and firmness.**

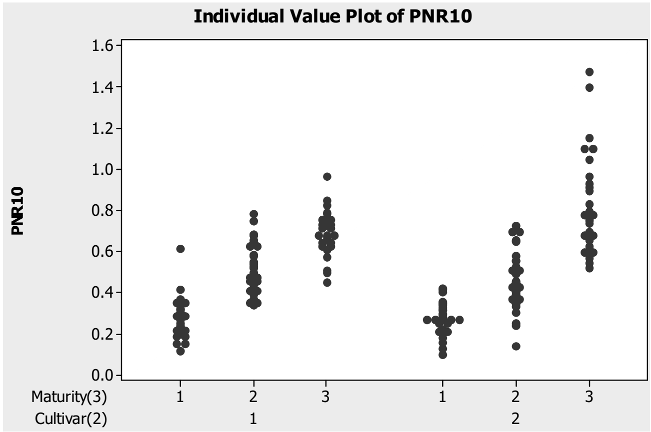


**Fig. 2 Distribution of average firmness measurements as measured by PNR10® penetrometer (mm deformation) in the cultivars 'Opal' (1) and 'Victoria' (2) at three levels of maturity (1-3) as graded by sensory evaluation of colour and firmness.**

When combining two or more MGs, high correlation was obtained between all firmness measurements and all colour parameters / indexes (**Table 2**), strengthening a hypothesis that development of firmness and colour is closely coinciding in these plum cultivars.

Nondestructive sensory evaluation as made by 10 panelists proved that fingers are well suited to measure firmness in such plum types (**Table 3**), and that thorough calibration of the panel is likely necessary to obtain reliable results as comparing individual panelists (**Table 4**). In this study, the panelists were able to discriminate the firmness within three MGs with statistically significant differences at both cultivars. Regarding other nondestructive measurements of firmness, ultrasonic method was tested during storage of plums (Mizrach 2004). When compared ultrasonic measurements with conjunction with destructive measurements of the firmness, the correlation coefficient ($r^2$) amounted to 0.71, thus confirming quite good correlation. Sonic analyses usually give wide variation in measurements, so to minimize the variation the test on water status of the fruit is recommended (Mizrach 2004). As reported by Valero *et al*. (2007), each nondestructive firmness tester measures different fruit physical properties (i.e. elasticity, force to provoke fruit failure). Direct comparisons of the fruit firmness as measured by different nondestructive devices should be avoided.

Our study revealed that the two penetrometers tested discriminated well between fruit firmness in three maturity groups. However; instrumental colour measurements did not always correlate well with penetrometer measurements, confirming results reported by Abdi *et al*. (1999) from experiments with Japanese type plums. Further, it revealed that grading plums with this type of colour development during ripening into three maturity groups by sensory evaluation of firmness and colour was not successful; grading the fruit into only two groups would likely have been better, since overlapping in instrumental firmness evaluation between MG1 and MG2, between MG2 and MG3, but less between MG1 and MG3 occurred in the two cultivars tested.

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