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Cultivar and Weather Conditions Determine Pre- and Postharvest Fruit Firmness in Sweet Cherries (*Prunus avium* L.)

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Summary

Fruit samples of seven sweet cherry cultivars grouped into three different groups of fruit flesh firmness (soft-fruited: 'Ranna Ljaskovska', 'Vista' and 'Sunburst', medium firm: 'Ulster' and 'Sylvia' and firm cultivars: 'Van' and 'Lapins') were harvested over a three week period with 3–4 d intervals prior to, during and after normal harvest time in 1997 and 1998 in Ullensvang, western Norway. Fruit firmness was measured at each harvest date along with measurements of soluble solids content (SSC), air temperature, precipitation and estimation of fruit colour. Corresponding samples picked at normal harvest date were stored in normal air atmosphere at temperatures 2 °C and 8 °C, respectively, and firmness was measured during storage with 3–5 d intervals. All the tested cultivars reached normal firmness, colour and SSC at harvest both years. Fruit were generally darker in 1998 than in 1997. All cultivars showed a more or less distinct reduction in firmness over the period prior to and slightly after normal harvest. Exceptions were 'Sunburst' in the 1998-season, that increased in firmness after normal harvest date, and the two firmest cultivars that increased in firmness over the ripening period in 1997. Generally, firmness increased during the first part of storage followed by a decrease after 1–2 weeks, the decrease being usually earlier and more distinct at 8 °C than at 2 °C. 'Van' in 1998 showed no change in firmness development throughout the storage period but a small increase in the last part. 'Lapins' in 1997 had, however, a pronounced drop in firmness in the middle of the storage period followed by an increase. All the tested cultivars were more firm at normal harvest time in 1998 than in 1997, except the two firm-fleshed cultivars 'Van' and 'Lapins'. The warm and sunny 1997-summer produced softer fruits than the cold and rainy 1998-season, except for the firm-fleshed cultivars. It was anticipated that the many contradictory results of sweet cherry fruit firmness reported by other authors may be caused by differences in weather conditions as demonstrated.

Key words. air temperature – fruit texture – penetrometer – precipitation – ripening – storage temperature

Introduction

Several factors contribute to the overall texture of fruits, such as cell wall strength, cell to cell adhesion, cell turgor and tissue anatomy (Heyes and Sealey 1996). Fruit firmness as measured by penetrometer is a widely used measure for fruit texture. It is regarded an important quality parameter in sweet cherries; cultivars with soft fruit are usually grown for local markets only, while fruit of firm-fleshed cultivars can be shipped over long distances and time (Cliff et al. 1996). Firmness of the sweet cherry fruit is dependent on the degree of polymerisation of pectin side chains in the cell wall (Batisse et al. 1996; Choi et al. 2002a), 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). Another important component in fruit flesh firmness is the internal turgor pressure, as reported in sweet cherry and grape by Lustig and Bernstein (1987), modelled for the tomato fruit by Hertog et al. (2004) and reported in nectarine by Heyes and Sealey (1996).

Sekse (1995a) found that water supply to sweet cherry trees influenced cuticular fracture development in the fruit, and concluded that such water supply was important for its internal turgor pressure. Further, Hovland and Sekse (2004a, b) found that both the degree of ripening and environmental conditions on the fruit surface influenced apoplastic water uptake by the fruit. Sams (1999) reviewed environmental factors on firmness in fruits in general, and found evidence for preharvest weather conditions influencing fruit firmness. Wet and humid weather conditions prior to and during harvest are, by cherry growers, often associated with soft fruit vulnerable to postharvest deterioration.

Preharvest firmness development in sweet cherries was reported by several authors, often with differing results. Barret and Gonzales (1994) and Choi et al. (2002b) found that firmness decreased rapidly and con-

tiniously prior to and throughout maturation in the cultivars tested. Drake and Elfving (2002) found, however, that delayed harvest in 'Lapins' did not reduce fruit firmness. Muskovics et al. (2006) experienced the same; firmness values more or less stabilised in the last part of the ripening period for three cultivars tested. Toivonen et al. (2004) found systematic reduced preharvest fruit firmness in only two out of three cultivars in two years.

Sweet cherries for export markets are stored in controlled atmosphere (CA) or in modified atmosphere packaging (MAP) near 0 °C. However, in many regions fruit is sold in local, regional or domestic markets in temperature regimes above 0 °C in normal air atmosphere (Sekse 1988).

Postharvest firmness development in sweet cherries was reported by several authors, often with differing results; Esti et al. (2002) found that two cultivars responded differently to cool storage as regarding firmness development, while Kappel et al. (2002) reported fruit softening during air storage of sweet cherries. Barret and Gonzales (1994) found increased firmness in cherries during air storage, as did Chen et al. (1981) in 'Bing', and Drake and Fellman (1987) in 'Rainier'. Similar results were reported by Wang and Vestrheim (2002a, b) in both sweet and sour cherries, while Meheriuk et al. (1995) reported constant firmness in cherries over the first 8 weeks of modified atmosphere (MA) storage then followed by a decrease.

Edin et al. (1997) characterised and grouped a range of sweet cherry cultivars after their fruit flesh firmness at harvest. Sweet cherries may be harvested prior to full ripeness to obtain firmer fruit and improved shelf life, often reducing the overall fruit quality (Edin et al. 1997; Drake and Elfving 2002).

This paper reports on changes in pre- and postharvest fruit firmness in soft-fruited, medium firm and firm sweet cherry cultivars from two growing seasons with pronounced differences in weather conditions.

Materials and Methods

Fruit was sampled from trees grown in the cultivar testing field at Ullensvang Research Centre, western Norway (60°19' N, 6°39' E). Trees were standing in light, sandy soil and was drip irrigated (Ystaas and Frøynes 1998). Representative fruit samples containing three replicates of 15 fruit each of seven cultivars were harvested from 3–5 trees of each cultivar with 3–4 d intervals over a two week period prior to and one week after normal harvest time during 1997 and 1998 ('Ranna Ljaskovska' and 'Vista' in 1998 only, 'Lapins' in 1997 one replicate only, due to small amounts of fruit) (Table 1). Cultivars were chosen after flesh firmness; soft-fleshed ('Ranna Ljaskovska', 'Vista' and 'Sunburst'), medium firm ('Ulster' and 'Sylvia') and firm ('Van' and 'Lapins') (Planton 1992; Edin et al. 1997). Fruit were morning-picked from the upper half and south-oriented part of the trees and immediately brought to the laboratory for quality measurements. Similarly, a total of 4 kg (1997) and 5 kg (1998) fruit from each cultivar were picked at normal harvest date, divided into two equal samples which were stored in air at two different temperatures, 2 °C and 8 °C in cardboard boxes covered with polyethylene film on top. Quality measurements (firmness, SSC, colour) were carried out at each harvest date and each storage date (Table 1).

Fruit firmness was measured at 20 °C on all single fruits at two locations diametrically opposite on the cheeks of each fruit. A dynamometer (Durofel®25, Ctifl, France) with a 0.25 cm^2 plunger expressing firmness over a scale with 0 as minimum and 100 as maximum (Planton 1992) was used. Firmness mean values were tabulated for groups of sampling dates (Table 2 and 3). Fruit colour was estimated on 15 representative single fruits of each harvest and storage date using a sweet cherry colour comparator chart from Centre technique interprofessionel de fruits et legumes (Ctifl, France) with a scale rating from 1 (light red) to 7 (dark mahogany). Soluble sol-

Table 1. Bloom dates (80 % open flowers), harvest dates, days in storage (number of days between harvest and quality assessment) and soluble solids content (SSC) (in 1997) in seven sweet cherry cultivars in 1997 and 1998 at Ullensvang, western Norway.

	Year	'R. Ljask.'	'Vista'	'Ulster'	'Van'	'Sylvia'	'Sunburst'	'Lapins'
Bloom Date	1997	–	–	30.05.	31.05.	02.06.	30.05.	29.05.
	1998	18.05.	16.05.	16.05.	16.05.	19.05.	16.05.	10.05.
Harvest Date	1997	–	–	30.07.	30.07.	30.07.	04.08.	11.08.
	1998	10.07.	27.07.	03.08	03.08	07.08.	13.08.	25.08.
Days in storage	1997	–	–	2, 6, 9, 15, 19, 23	2, 6, 9, 15, 19, 23	2, 6, 9, 15, 19	4, 10, 14, 18	3, 7, 11, 15
	1998	4, 7, 11, 14, 18	4, 8, 11, 15, 18	4, 7, 11, 14, 18, 21, 25	4, 8, 11, 15, 18, 22	4, 7, 11, 14, 18	5, 8, 12, 15, 19	3, 7, 10, 13, 17
SSC at harvest	1997	–	–	16.5	18.7	16.4	17.7	17. 1

'R. Ljask.' = 'Ranna Ljaskovska'

Table 2. Changes in fruit firmness in seven sweet cherry cultivars during on-tree ripening in two years. Mean values of three replicates of 15 fruits each and two measurements per fruit (Durofel®; scale 0–100) prior to (–), at (0) and after (+) normal harvest date.

Year	Days –/+ normal harvest		'Ranna Ljask.'	'Vista'	'Sunburst'	'Sylvia'	'Ulster'	'Van'	'Lapins'
1997		–20							77.1^{c}
	–16/	–14			53.2^{c}				70.3^{b}
	–10/	–8			54.8^{c}	61.3^{b}	63.1^{b}	66.6^{a}	65.0^{a}
	–7/	–6			47.7^{b}				66.6^{a}
	–4/	–3				58.7^{ab}	62.1^{ab}	68.6^{ab}	
		0			43.6^{a}	60.8^{b}	63.4^{b}	68.8^{ab}	71.5^{b}
	+5/	+7				57.4^{a}	60.0^{a}	71.2^{b}	
1998		–16			67.7^{e}				
	–13/	–12			64.9^{de}				78.0^{b}
	–10/	–8		79.0^{d}	64.7^{d}	73.0^{c}			
	–7/	–6	58.9[1]^{b}	74.3^{c}	56.3^{bcd}	68.5^{b}	73.9^{d}	72.4^{b}	75.8^{b}
	–4/	–3	49.8^{a}	69.0^{b}	59.6^{c}	67.7^{b}	70.7^{c}	69.7^{ab}	75.2^{b}
		0	46.7^{a}	60.7^{a}	49.8^{a}	63.8^{a}	69.5^{bc}	68.1^{a}	71.4^{a}
	+3/	+4		59.7^{a}	55.3^{b}	67.2^{b}	68.0^{b}		
	+5/	+7						68.2^{a}	
	+10/	+12				65.1^{a}	63.0[2]^{a}		

'Ranna Ljask.' = 'Ranna Ljaskovska'
Mean values within a column followed by different letters are significantly different (P = 0.05) according to Student-Newman-Keuls test (SAS Institute 1988).
[1]n=90, 2n=44

ids content (SSC) was measured in samples of three drops of juice from each of 10 representative fruits of each harvest and storage date using an ATAGO DBX 50® (Atago Co., Ltd., Tokyo, Japan) table refractometer (1997: only at optimum harvest date) (Table 1, Fig. 4).

Meteorological observations (temperature and precipitation) were recorded at Ullensvang Research Centre (Norwegian Meteorological Institute (NMI) 2006). Daily mean temperature was calculated as the mean of highest and lowest temperature within each 24 hour period (Fig. 1).

The experiment was analysed statistically using the General Linear Model of SAS (SAS Institute 1988).

Results

Sweet cherries reached full bloom (80 % open flowers) in Ullensvang in late May in 1997 and middle May in 1998 (Table 1). The harvesting period lasted from first half of July for the very early-ripening 'Ranna Ljaskovska' to early to middle August for the later ripening cultivars. Due to low temperatures in August 1998 (Fig. 1), harvest of 'Lapins' was delayed to late August that year (Table 1). The soft-fruited cultivars 'Ranna Ljaskovska' and 'Vista' had low colour and SSC values at normal harvest time, somewhat higher for 'Sunburst'. The medium firm cultivars 'Ulster' and 'Sylvia' reached medium colour and SSC at harvest, while the firm cultivars 'Van' and 'Lapins' were harvested at medium to high colour scores and fairly good SSC-values (Table 1, Fig. 2, 3 and 4).

The soft-fruited cultivars had low firmness at normal harvest date except for 'Vista', the medium firm cultivars had intermediate firmness and the firm cultivars had high firmness values. Fruit of all the tested cultivars were more firm at normal harvest time in 1998 than in 1997 except the two firm-fleshed cultivars 'Van' and 'Lapins', which showed no variation in firmness at harvest between the two years (Table 2).

All cultivars showed a more or less distinct reduction in firmness over the period prior to and slightly after normal harvest. Exceptions were 'Sunburst' in the 1998-season, that increased in firmness after normal harvest date, and the two firmest cultivars that increased in firmness over the ripening period in 1997 (Table 2).

Generally, firmness increased during the first part of storage, followed by a decrease after 1–2 weeks, the decrease being usually earlier and more distinct at 8 °C than at 2 °C (Table 3). Exceptions were 'Ranna Ljaskovska' that showed, as the only one, a continuous decline in firmness throughout the storage period, 'Sunburst' that increased during storage at 2 °C in 1997, 'Van' in 1998 that was fairly constant in firmness during storage and 'Lapins' in 1997 that decreased in firmness early followed by a distinct increase at the end of the storage period (Table 3).

The two years 1997 and 1998 were distinct different regarding temperature and precipitation in the cherry season in Ullensvang; 1997 had 8 d with precipitation <1 mm per day and temperatures varying between 16 and 23 °C (July–August), while 1998 had 30 d with precipitation > 1 mm and low temperatures ranging between 11 and 16 °C throughout the same period (Fig. 1).

Table 3. Changes in fruit firmness (Durofel®25; scale 0–100) in seven sweet cherry cultivars from harvest (0) and during air storage at two temperatures and two years. n=45.

Temperature	Year	Days in storage	'Ranna Ljask.'	'Vista'	'Sun-burst'	'Sylvia'	'Ulster'	'Van'	'Lapins'
2 °C	1997	0			43.6^{a}	60.8^{a}	63.4^{a}	68.8^{ab}	71.5^{1c}
		2 – 4			47.0^{ab}	66.4^{b}	72.9^{c}	71.4^{b}	66.8^{1ab}
		5 – 7				67.2^{b}	69.3^{b}	74.2^{c}	64.2^{1a}
		8 – 10			48.4^{b}	66.6^{b}	70.0^{bc}	72.5^{bc}	
		11 – 13							69.4^{1bc}
		14 – 15			47.1^{1ab}	64.6^{b}	64.7^{a}	71.0^{b}	70.3^{1c}
		18 – 19			50.3^{b}	61.7^{a}	64.1^{a}	66.6^{a}	
		23					67.3^{1ab}	70.1^{1ab}	
	1998	0	46.7^{c}	60.7^{abc}	49.8^{a}	63.8^{a}	69.5^{bc}	68.1^{ab}	71.4^{a}
		2 – 4	46.5^{2c}	61.9^{c}		66.1^{ab}	73.2^{d}	68.0^{ab}	72.1^{ab}
		5 – 7	44.2^{bc}		53.9^{b}	69.0^{cd}	69.7^{cd}		74.7^{b}
		8 – 10		66.9^{d}	54.1^{b}			66.6^{a}	71.0^{a}
		11 – 13	44.9^{bc}	61.4^{bc}	59.5^{c}	66.8^{bc}	70.2^{c}	69.4^{b}	73.4^{ab}
		14 – 15	41.5^{ab}	57.8^{ab}	54.1^{b}	70.2^{d}	69.6^{bc}	68.1^{ab}	
		17 – 19	38.4^{a}	57.2^{a}	53.4^{ab}	69.4^{d}	67.0^{ab}	69.6^{b}	73.4^{ab}
		21 – 23					69.6^{bc}	66.6^{3a}	
		25					65.5^{a}		
8 °C	1997	0			43.6^{a}	60.8^{b}	63.4^{b}	68.8^{c}	71.5^{1d}
		2 – 4			49.6^{b}	64.3^{c}	66.9^{c}	65.4^{b}	64.6^{1c}
		5 – 7				65.4^{cd}	67.0^{c}	74.2^{d}	59.3^{1a}
		8 – 10			45.5^{a}	67.6^{d}	65.2^{bc}	66.9^{bc}	
		11 – 13							61.5^{1ab}
		14 – 15			44.9^{a}	63.5^{bc}	61.3^{ab}	65.4^{b}	62.2^{1bc}
		19				57.2^{a}	58.6^{a}	62.5^{a}	
	1998	0	46.7^{c}	60.7^{c}	49.8^{b}	63.8^{abc}	69.5^{c}	68.1^{ab}	71.4^{bc}
		2 – 4	42.9^{b}	60.4^{c}		66.1^{3c}	68.8^{c}	68.6^{5ab}	72.0^{c}
		5 – 7	41.5^{3b}		53.9^{bc}	69.9^{d}	70.0^{4c}		73.7^{3c}
		8 – 10		61.1^{c}	56.7^{c}			67.8^{ab}	67.9^{b}
		11 – 13	39.9^{b}	49.3^{b}	51.9^{b}	63.2^{3ab}	65.3^{b}	69.7^{b}	66.6^{b}
		14 – 15	36.4^{a}	43.9^{a}	44.2^{a}	65.9^{3bc}	63.7^{b}	70.0^{b}	
		17 – 19				62.3^{a}	58.4^{4a}	69.2^{ab}	59.5^{a}
		22						66.4^{a}	

Mean values within a column followed by different letters are significantly different (P = 0.05) within each temperature/year, according to Student-Newman-Keuls test (SAS Institute 1988).
^{1}n=15, ^{2}n=30, ^{3}n=44, ^{4}n=40, ^{5}n=43

Discussion

The levels of fruit surface colour and soluble solids content reached at commercial harvest time were well in accordance with similar data obtained in the cultivar testing program in Ullensvang (Ystaas and Frøynes 1998). With one exception ('Ulster'), all cultivars were harvested with darker colour in the 1998-season than in 1997. This was likely due to a combination of two different factors. First, the 1998 season had lower night temperatures that would promote fruit development (Marshall 1954). Secondly, the long-lasting ripening season in 1998 provided more time for colour development compared to the 1997 season. This confirms the results reported by Gonçalves et al. (2007) on weather influence on colour development in cherries.

According to Edin et al. (1997) 'R. Ljaskovska' and 'Sunburst' had insufficient fruit firmness (<56), 'Vista' and 'Sylvia' had soft fruit (56–62.9), 'Ulster' and 'Van' had firm fruit (63–70) and 'Lapins' very firm fruit (>70) at normal harvest (Table 2).

In the ripening period the cultivars tested showed distinct differences in their on-tree fruit firmness development. The soft-fruited cultivars decreased linearly and continuously in fruit firmness; regression line (day *vs* firmness) (equations not shown; all significant at P =

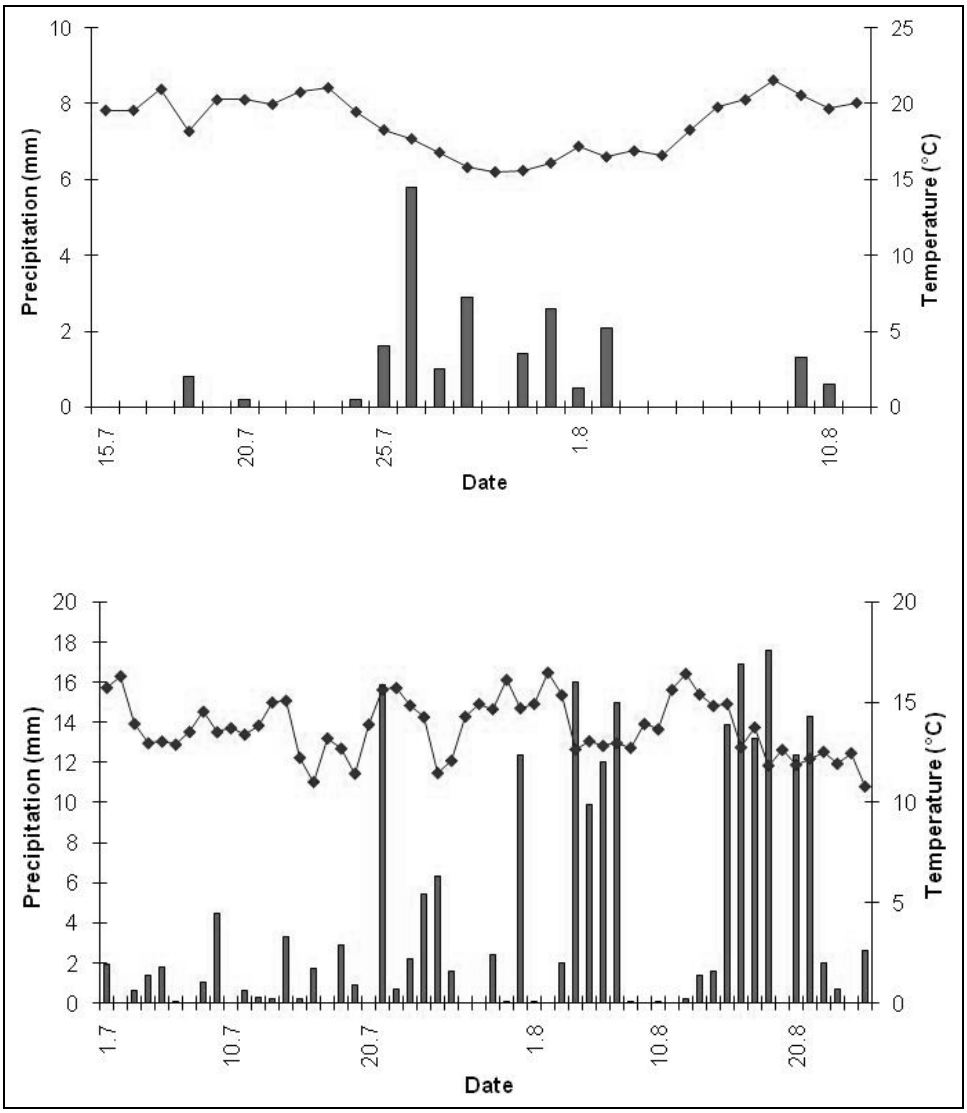


Fig. 1. Precipitation (bars) and temperature (dotted line) prior to and during the sweet cherry harvesting season in 1997 (upper) and 1998 (lower) at Ullensvang, western Norway (Nmi 2006).

0.05) slopes were found to be −2.0, −1.8, −1.3 and −1.4 for 'R. Ljaskovska', 'Vista' and 'Sunburst' (1997 and 1998), respectively, indicating an average firmness loss of 1.3 to 2.0 points per day as measured with the Durofel®25 device. This is in accordance with results obtained by Barret and Gonzales (1994) and Choi et al. (2002b). 'Sylvia' and 'Ulster' had corresponding slopes 0.0 and −0.1 (1997) and −0.6 and −0.8 (1998), respectively, indicating no firmness change in the last part of the growing season in 1997, while a pronounced reduction in firmness appeared in the 1998-season. Similar results were measured partly by Toivonen et al. (2004) and Muskovics et al. (2006). 'Van' and 'Lapins' had corresponding slopes +0.3 and +0.6 (1997) and −0.6 and −0.6 (1998), respectively, showing that firmness increased in the last part of the 1997 growing season, confirming the results reported for 'Lapins' by Drake and Elfving (2002), while a decrease similar to the other cultivars appeared in 1998.

The pronounced differences found in firmness at harvest and in firmness development during ripening between the two seasons were most likely effects of weather conditions. The 1997-season was, under western Norway conditions, relatively dry and warm and produced fruit with lower firmness in the soft and medium-firm cultivars than correspondingly in the 1998-season, that was wet and cold (Fig. 1). This is in accordance with general theories (Sams 1999). Sekse (1995a) and Hovland and Sekse (2004a, b) reported that water accumulation in the sweet cherry fruit was influenced by environmental factors. The 1998 season had abundant water supply to the tree and limited conditions for the fruit to transpire water from its surface due to nearly constant high air humidity. The higher firmness level that was measured this season most likely had turgor pressure as an important component, like in the model developed for tomato (Hertog et al. 2004) and as reported in nectarines by Heyes and Sealey (1996). For each of the two firm-fleshed cultivars, however, their measured firmness at normal harvest did not differ between the two years. Results from this experiment did not reveal any explanation for this.

It is likely that these results can contribute to explain the many diverging results reported by other authors regarding sweet cherry fruit firmness (Barrett and Gonzales 1994; Choi et al. 2002b; Drake and Elfving 2002;

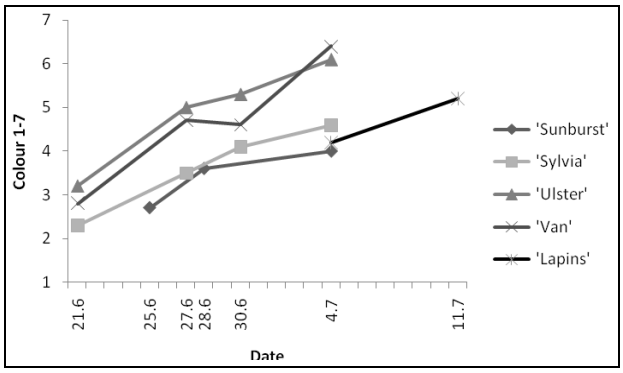


Fig. 2. Preharvest colour development in five sweet cherry cultivars in Ullensvang, Norway as measured by Durofel® (scale 1 (=straw colour) to 7 (=dark mahogany)) in 1997.

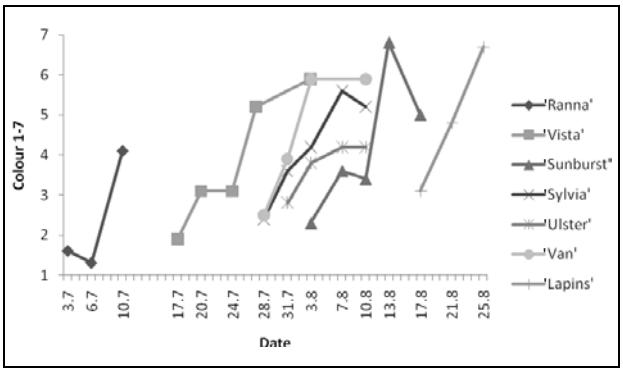


Fig. 3. Preharvest colour development in five sweet cherry cultivars in Ullensvang, Norway, as measured by Durofel® (scale 1 (=straw colour) to 7 (=dark mahogany)) in 1998.

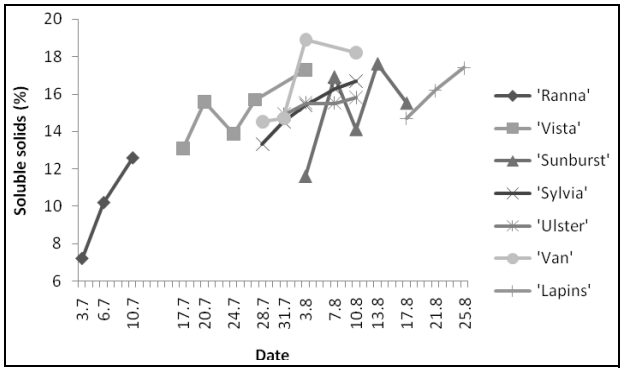


Fig. 4. Preharvest soluble solids development in seven sweet cherry cultivars in Ullensvang, Norway in 1998.

Toivonen et al. 2004; Muskovics et al. 2006); as reported in this paper, weather seemed to influence sweet cherry firmness development significantly during ripening.

Since both 'R. Ljaskovska' and 'Sunburst' had unacceptable low firmness at normal harvest time according to Edin et al. (1997), and showed a continuous reduction in firmness prior to harvest, an early harvest could be beneficial to improve fruit flesh firmness and shelf life for these two cultivars. On the other hand, early harvest seemed not always to be beneficial for improved firmness in the other cultivars tested; under some growing conditions firmness decreased and under others increased in the period around commercial harvest time.

Firmness development during air storage at 2 °C and 8 °C proved different between the groups of cherries as classified for firmness. 'Ranna Ljaskovska' lost firmness from the start of the storage, as similarly reported by Kappel et al. (2002). All other cultivars, with two exceptions, increased in firmess in the start of storage, more or less in accordance with results reported by Chen et al. (1981), Drake and Fellmann (1987), Barrett and Gonzales (1994) and Wang and Vestrheim (2002a, b). Exceptions were 'Van' in 1998 that showed a near constant firmness throughout the storage period, as was reported by Meheriuk et al. (1995) for MA-stored cherries. This might have a connection to its preharvest firmness development; it increased slightly in firmness prior to harvest that year, unlike the other cultivars. The reason why 'Lapins' (in 1997) had a distinct decline in firmness after the start of the storage and thereafter increase is not clear. It has most likely a connection to its preharvest development that year; it increased pronounced and significant in firmness prior to harvest, unlike the other cultivars.

According to Chen et al. (1981) and Drake and Fellmann (1987) loss of water may contribute to postharvest increase in firmness, while this is contrary to the results published by Lustig and Bernstein (1987), Heyes and Sealey (1996) and Hertog et al. (2004), reporting water and turgor pressure *per se* as a contributor to firmness, and water loss being more influential on the reduction in firmness preharvest than postharvest (Heyes and Sealey 1996). Likely is postharvest degradation of cell walls and cell structure of the type reported by Batisse et al. (1996), more than postharvest water loss from the cherry fruit, a main contributor to loss of firmness as typically measured by us in the soft-fleshed cultivars.

The 1997-season had pronounced higher temperatures and lower precipitation than had the 1998-season, which should produce fruit with highest fruit flesh firmness in the 1998-season as reported for all the soft-fleshed and medium firm cultivars tested, in agreement with Sams (1999). Which of the factors comprising the fruit texture as discussed by Heyes and Sealey (1996) causing the two cultivars with firmest fruit flesh ('Van' and 'Lapins') to react otherwise, is not clear.

Weather conditions such as those appearing in the 1998-season in Ullensvang have usually, by cherry growers, been associated with soft fruit vulnerable to postharvest decay. The results reported here indicated the contrary; firmer fruit was produced. It is likely that cuticular fracturing resulting in disintegration of the bearing structures of the fruit skin as described by Glenn and Poovaiah (1989) and Sekse (1995a) was responsible for any "soft" appearance as discussed by Sekse (1995b), and further for possible increased vulnerability to postharvest decay, as described by Børve et al. (2003).

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