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The Development of Cuticular Fractures in Fruits of Sweet Cherries (*Prunus avium* L.) Can Vary with Cultivar and Rootstock

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Abstract

The question of whether the development of cuticular fractures in fruits of sweet cherries varies by cultivar or rootstock was evaluated. Fruits were classified on a scale ranging from 1 (no visible fractures) to 5 (many distinct fractures). Two sweet cherry cultivars grown under similar conditions developed cuticular fractures differently; 62% of the 'Van' fruits were classified into class 3 while in 'Sunburst' there was a more even distribution among all five classes. Sweet cherry fruits from a trial with six different rootstocks developed different amounts of cuticular fractures; fruits of 'Ulster' showed significant differences among rootstocks, while fruits of 'Stella' varied less in fracture development. Another trial with 'Lapins' on nine different rootstocks in 2002 also produced fruits with different amounts of cuticular fractures. An investigation of the influence of cuticular fractures on cracking susceptibility of the fruits demonstrated that cultivars with many fractures cracked more easily than cultivars with unfractured cuticles.

Introduction

The sweet cherry fruit develops cuticular fractures under humid growing conditions. Such fractures have been described thoroughly by electron microscopy photographs (8, 9) and by stereo magnifier photographs (14, 10). Further, Sekse (10) showed that such fractures increased during conditions with artificially fluctuating soil water contents, indicating that fruit turgor pressure plays an important role in fracture development. He also proposed a method to quantify the amount of fractures and suggested theories on their importance in fruit cracking mechanisms (11, 12).

Cuticular fractures act as infection sites for pathogens; Børve et al. (3, 4) quantified an increase in fungal infection with increasing amount of cuticular fracturing. Fractures also seemed to increase water loss from the sweet cherry fruit surface; Knoche et al. (9) found an 8% increase of the total conductance of the cuticle due to fractures. They did not, however, classify the amount of fractures.

The influence of cultivar or rootstock on cuticular fracture development has not been examined before, nor has the influence of cuticular fractures on fruit cracking. The objectives of this study were 1) to compare two cultivars regarding their distribution among fracturing classes, 2) to investigate the influence of cultivars and rootstocks on cuticular fracture development, and 3) to determine the influence of cuticular fracturing on fruit cracking in two different cultivars.

Materials and Methods

Fruit material. Differences in fracture development between cultivars were compared at Ullensvang Research Centre, western Norway in 1995 in fruits of 'Van' (8.5 kg sample) and 'Sunburst' (5 kg sample) grown on Colt rootstock and picked randomly on the trees at optimum harvest time which was 5 August for 'Van' and 12 August for 'Sunburst'. The trees were covered with protective plastic shelters against rain and received drip irrigation. Similarly, fruits of 'Van' were harvested on 9 August in 2000 for the cracking index test.

Differences in fracture development among fruits grown on different rootstocks were compared in 1995 in fruits of 'Ulster' and 'Stella' grafted on six different clonal rootstocks (Damil, Camil, Weiroot 10, Weiroot 13, Charger and Colt), being part of an international rootstock trial established in 1988 with a split plot design with

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cultivars as main plots and rootstocks as sub-plots with five single-tree replicates (15). The trees were not covered against rain, nor were they irrigated. Samples of 90 fruits from each tree from three of the replicates were picked randomly from the trees at optimum harvest time; 'Ulster' on 1 August and 'Stella' on 8 August, 1995. Another rootstock trial established in 1999 with 'Lapins' was harvested on 5 August 2002. There were nine different rootstocks: Tabel Edabriz, P-HL-B, Damil, Gisela 5, Gisela 7, Piku 4.20, Weiroot 158, Colt and Maxma 14 from an international rootstock trial with a block design having four replicates, each replicate consisting of 2 trees. The trees were covered against rain. Samples of 60 fruits (20 from the north of the tree, 20 from the upper south side and 20 from the lower south side) from one tree per replicate were picked randomly. At harvest the soluble solids content (%) was measured from each of the three samples from each replicate.

Amount of cuticular fractures. Cuticular fractures were observed using a stereo magnifier (magnification 16X, objective 10X) and classified using a scale ranging from 1 (no visible fractures) to 5 (many distinct fractures covering large parts of the fruit surface) according to Sekse (10).

Fruit cracking index. Samples of 50 fruits and 3 replicates each from 'Sunburst' (1995) and 'Van' (1995 and 2000) and from each of the five fracturing classes were immersed in distilled water and observed for fruit cracking following the procedure of Vittrup Christensen (13); fruits were examined for cracks after two, four and six hours. Not all classes contained 150 fruits, causing a reduction in number of fruits in some of the fracture classes (Table 6).

Statistical analyses. Statistical analyses were made by means of ANOVA, GLM and REG procedure in SAS (SAS Institute, Cary, NC, USA).

Meteorological data. Meteorological data were collected at the meteorological station at Ullensvang Research Centre, close to the experimental orchard (Table 1).

Results and Discussion

Precipitation. More than 60 mm rain fell in the period 16-22 July 1995. Moreover, 13 days in July had precipitation > 1 mm (Table 1). The period 16 July to 9 August 2000 had less precipitation than 1995. In these periods, the fruits were in the growth phase III (6) and extra vulnerable to high turgor stress development. The lower precipitation in 2000 resulted in a lower cracking index (Table 5).

Effect of cultivar on distribution of cuticular fracture classes. Most of the fruits of the two cultivars developed cuticular fractures but with different frequency distribution patterns. For 'Van', a distinct majority (62%) of the fruits were classified into fracturing class 3, approximately 16% into each of the classes 2 and 4, while only a few fruits (2%) were without fractures (class 1) or were severely fractured (4% in class 5). 'Sunburst' had a more even distribution among all five classes; 26, 28 and 24% of the fruits were classified into each of the classes 2, 3 and 4, respectively. In classes 1 and 5 there were 14 and 9%, respectively. These differences in fracture development demonstrated clearly that fruits of different cultivars developed different amounts and distribution patterns of cuticular fractures

Table 1. Days in July and early August 1995, 2000 and 2002 with precipitation >1mm at Ullensvang Research Centre.

1995	Precipitation, mm	2000	Precipitation, mm	2002	Precipitation, mm
Jul 2	1.6	Jul 1	3.7	Jul 2	2.3
3	3.2	2	5.1	4	1.9
6	3.8	3	5.2	8	6.5
8	1.4	7	9.3	9	8.9
15	1.6	28	4.0	11	8.9
16	8.4	Aug 2	6.6	12	1.3
17	1.6	6	15.1	20	8.5
18	4.2	7	1.4	24	2.2
20	30.0	—	—	26	8.4
21	15.4	—	—	—	—
22	3.0	—	—	—	—
23	1.6	—	—	—	—
24	2.6	—	—	—	—
Aug 1	3.0	—	—	—	—
13	3.0	—	—	—	—

although grown under the same conditions. This could be explained in three ways; first, difference in shape of the fruits of the two cultivars promoted differences in fracture development as discussed theoretically by Considine and Brown (7) and analyzed by Yamamoto et al. (14). Second, the water supply to the trees of the two cultivars may have been different, causing differences in fracture development as well. Rootstock or cultivar/rootstock combination effects, as discussed below, may cause the latter. As a third alternative, there might be differences in the skin morphology of the different cultivars; Beyer and Knoche (2) found differences in stomatal density and in the conductance for water uptake between different cultivars. The latter could be caused by different thickness of the cuticle as suggested by Belmans and Keulemans (1).

Rootstock effects. Fruits from trees on different rootstocks developed different amounts of cuticular fractures, but the two cultivars compared in 1995 were not consistent in this respect (Table 2). 'Ulster' on different rootstocks developed significant differences in fractures; fruits on Colt had the fewest fractures, followed by Camil and Weiroot 10, Weiroot 13, while Charger and Damil topped the list. 'Stella', however, grown on the same rootstocks, showed few differences in fracture development among rootstocks; only fruits from Charger had significantly fewer fractures than fruits from the other rootstocks. The following year very few fruits in the same experimental plot developed cuticular fractures regardless of cultivar and rootstock, reflecting a dry period in July (4 days with precipitation over 2 mm) and early August (1 day with precipitation over 2 mm) that year.

Results from the rootstock trial with 'Lapins' (Table 3) also showed a rootstock effect on the development of cuticular fractures. Fruits on Maxma 14 and Tabel Edabriz had the fewest fractures, followed by P-HL-B, Weiroot 158, Colt and Gisela 7, Piku 4.20, Damil and Gisela 5. One explanation of these results could be that the rootstocks affected the degree of maturity. In some cases fruits from rootstocks with few cuticular fractures had a lower soluble solids content (Table 2 and Table 3). But this was not consistent; for example fruits from trees grafted on P-HL-B developed many cuticular fractures although the soluble solids content was low, indicating a low degree of fruit maturity. Rootstocks with heavy cropping could also have resulted in lower soluble solids content.

Another possible explanation of these results is that the cultivar/rootstock combination differentially supplied the trees with water, such that differences in fracture development caused by variations in fruit turgor pressure occurred. This was supported by significant ($P \leq 0.000$) interactions between cultivar and rootstock. Cline et al. (5) found that rootstock influenced fruit cracking in sweet cherries, but proposed no physiological explanations. Thus, a possi-

Table 2. Amount of cuticular fractures as classified into fracturing classes 1-5 and soluble solids content (%) at harvest in sweet cherry fruits of 'Ulster' and 'Stella' grown on six different rootstocks. Mean values of 90 fruits and 3 replicates for each cultivar and rootstock (1995).

	'Ulster'		'Stella'	
Rootstock	Cuticular fractures	Soluble solids	Cuticular fractures	Soluble solids
Damil	2.2 a[z]	18.2 a	2.2 a	17.0 a
Charger	2.1 a	18.0 a	2.0 b	17.1 a
Weiroot 13	1.9 b	17.2 a	2.3 a	17.8 a
Weiroot 10	1.8 c	17.3 a	2.2 a	17.9 a
Camil	1.8 bc	16.7 b	2.3 a	17.2 a
Colt	1.7 c	17.6 a	2.3 a	18.5 a

[z]Mean values within a column followed by different letters are significantly different (P=0.05) according to Student-Newman-Keuls test (SAS Institute, 1988).

Table 3. Amount of cuticular fractures as classified into fracturing classes 1-5 and soluble solids content (%) at harvest in sweet cherry fruits of 'Lapins' grown on 9 different rootstocks. Mean values of 60 fruits and 4 replicates for each rootstock (2002).

Rootstock	Cuticular fractures	Soluble solids
Tabel Edabriz	1.7 c[z]	15.3 c
P-HL-B	2.5 b	15.1 c
Damil	2.9 a	18.6 a
Gisela 5	3.0 a	18.1 a
Gisela 7	2.8 ab	17.6 ab
Piku 4.20	2.9 a	16.9 b
Weiroot 158	2.7 ab	17.6 ab
Colt	2.7 ab	17.0 b
Maxma 14	1.7 c	14.6 c

[z]Mean values within a column followed by different letters are significantly different (P=0.05) according to Student-Newman-Keuls test (SAS Institute, 1988).

ble explanation for their results may be found in differences in cuticular fracture development, as demonstrated here.

There were significant differences (P=0.008) between the soluble solid contents (Table 4) in fruits harvested from the north side of the trees and fruits harvested from the upper south side of the trees. The soluble solids content in fruits harvested from the lower south side were not different from either of the two other sites. Fruits harvested from the north side of the trees developed also significantly fewer cuticular fractures (P≤0.000) than fruits harvested from the upper and lower south side of the trees. These results were expected, since fruits from the north side receive less sun and are less mature than fruits from the south side. Fruits from the lower south side had lower soluble solids content and less cuticular fractures than fruits from the upper south side, although not significant, also a result of less sun and less degree of maturity.

Effects of cuticular fractures on fruit cracking. Fruits classified into the five different fracturing classes developed distinct differences in fruit cracks when compared in the cracking index test; close correlations were obtained between fracturing class and cracking index scores in both cultivars tested (Table 5). Sample correlation coefficients between fracturing class and cracking index for the two cultivars 'Sunburst' (1995) and 'Van' (1995 and 2000) were significant at the 0.001% level (Table 5). This demonstrated clearly that fruits with cuticular fractures develop fruit cracks more readily, which was expected since cuticular fractures give fruit surface water free access to the epidermal layers of the fruit, while an intact cuticle inhibits such free access. This is likely to be the result during rainy periods under orchard conditions as well.

Table 4. Amount of cuticular fractures (1-5) and soluble solids content (%) in sweet cherry fruits of 'Lapins' harvested from three different locations within the tree. Mean values of 60 fruits and 4 replicates from 9 different rootstocks (2002).

Location on the tree	Cuticular fractures	Soluble solids
North side	2.3 b[Z]	16.3 b
Lower south side	2.6 a	16.5 ab
Upper south side	2.7 a	17.6 a

[Z]Mean values within a column followed by different letters are significantly different (P=0.05) according to Student-Newman-Keuls test (SAS Institute, 1988).

Conclusions

Sweet cherry fruits from different cultivars grown under the same conditions developed cuticular fractures differently. Fruit shape and differences in water supply to the trees may contribute to these differences. It also was demonstrated that fruits from trees grown on different rootstocks developed cuticular fractures differently; in 'Ulster' and 'Lapins' the amount of cuticular fractures in the fruits differed significantly between rootstocks, while this tendency was much less pronounced in fruits of 'Stella'. Explanations for this inconsistency between cultivars in regard to fracture development were suggested; different cultivar/rootstock combinations may have resulted in different water supplying capacity to the trees, causing differences in fruit turgor pressure. This study also showed that fruits harvested at the north side of the trees developed fewer cuticular fractures and had lower soluble solids content compared to fruits harvest-

Table 5. Cracking index scores for fruits in fracture classes 1-5 in fruits of 'Sunburst' (1995) and 'Van' (1995 and 2000) after 6 hours.

Fracturing class	'Sunburst' (1995)		'Van' (1995)		'Van' (2000)	
	No. of fruits (no of replicates)	Cracking index scores	No. of fruits (no. of replicates)	Cracking index scores	No. of fruits (no. of replicates)	Cracking index scores
1	43 (2)	84.4	26 (1)	65.4	46 (3)	36.7
2	50 (3)	92.8	50 (3)	69.9	50 (3)	44.1
3	50 (3)	95.6	50 (3)	79.3	50 (3)	51.2
4	40 (3)	99.2	50 (3)	92.3	42 (3)	57.9
5	21 (2)	100.0	22 (2)	93.6	31 (3)	66.9
df	13		11		14	
r^{2*}	0.871		0.948		0.954	

*linear regressioin coefficient between fracturing class and cracking index using REG procedure, SAS.

ed from the south side of the trees. Further, it was shown that fruits having more cuticular fractures developed correspondingly higher amounts of fruit cracks when tested by the cracking index test.

Literature Cited

1. Belmans, K. and J. Keulemans. 1996. A study of some fruit skin characteristics in relation to the susceptibility of cherry fruit to cracking. Acta Hort. 410:547-550.
2. Beyer, M. and M. Knoche. 2002. Studies on water transport through the sweet cherry fruit surface: V. Conductance for water uptake. J. Amer. Soc. Hort. Sci. 127:325-332.
3. Børve, J., L. Sekse and A. Stensvand. 1997. Cuticular fractures as infection sites of *Botrytis cinerea* in sweet cherry fruits. Acta Hort. 468:737-730.
4. Børve, J., L. Sekse and A. Stensvand. 2000. Cuticular fractures promote postharvest fruit rot in sweet cherries. Plant Disease 84:1180-1184.
5. Cline, J. A., L. Sekse, M. Meland and A. D. Webster. 1995. Rain-induced fruit cracking of sweet cherries: I. Influence of cultivar and rootstock on fruit water absorption, cracking and quality. Acta Agric. Scand., Sect. B, Soil and Plant Sci. 45:213-223.
6. Coombe, B. G. 1976. The development of fleshy fruits. Ann. Rev. Plant Phys. 27:507-528.
7. Considine, J. and K. Brown. 1981. Physical aspects of fruit growth. Theoretical analysis of distribution of surface growth forces in relation to cracking and splitting. Plant Physiol. 68:371-376.
8. Glenn, G. M. and B. W. Poovaiah. 1989. Cuticular properties and postharvest calcium applications influence cracking in sweet cherries. J. Amer. Soc. Hort. Sci. 114:781-788.
9. Knoche, M., S. Peschel, M. Hinz and M. J. Bukovac. 2000. Studies on water transport through the sweet cherry fruit surface: characterizing conductance of the cuticular membrane using pericarp segments. Planta 212:127-135.
10. Sekse, L. 1995a. Cuticular fracturing in fruits of sweet cherry (*Prunus avium* L.) resulting from changing soil water contents. J. Hort. Sci. 70:631-635.
11. Sekse, L. 1995b. Fruit cracking in sweet cherries (*Prunus avium* L.). Some physiological aspects - a mini review. Sci. Hort. 63:135-141.
12. Sekse, L. 1996. Cuticular fracturing in the cherry fruit - causes and consequences. J. Exp. Bot. 47 (May 1996 Supplement): 52.
13. Vittrup Christensen, J. 1996. Rain-induced cracking of sweet cherries. pp. 297-327. In: Cherries. Crop physiology, production and uses; Webster, A. D. and N. E. Looney (Eds.). CAB International, Oxon, UK.
14. Yamamoto, T., K. Hosoi and S. Watanabe. 1990. Relationship between the degree of fruit cracking of sweet cherries and the distribution of surface stress of the fruit analysed by a newly developed system. J. Jpn. Soc. Hort. Sci. 59:509-517.
15. Ystaas, J. and O. Frøynes. 1996. Evaluation of size-controlling rootstocks for 'Stella' and 'Ulster' sweet cherries. Acta Hort. 410:197-204.