RESEARCH NOTE

Berry Abscission in *Vitis vinifera* L. cv. Waltham Cross: Changes in Abscission-related Factors during Berry Development

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During the 1999 season, changes in total soluble solids (TSS), titratable acids (TA), pedicel diameter, berry diameter, berry mass and fruit removal force (FRF) were determined at biweekly intervals from 27 until 111 days after full bloom (DAFB) for Waltham Cross table grapes. In addition, at each assessment stage, grape bunches were detached and held in the dark at about 25°C for 80 h. Thereafter, moisture loss, FRF, berry abscission potential as well as percentage berry abscission were determined. During stages I and II of fruit growth (27 to 54 DAFB), TSS did not change significantly, while TA increased. FRF increased significantly during this early stage of berry development, indicating a strengthening of the abscission zone tissue. During stage III (after 54 DAFB), a decline in FRF occurred, which coincided with a perceptible increase in TSS and a decrease in TA. Berry mass increased significantly from 27 to 111 DAFB. Pedicel diameter only increased significantly for the period 27 to 41 DAFB, while berry diameter increased significantly for the period 27 to 97 DAFB. Grapes sampled at 27 DAFB had a significantly lower FRF and significantly higher levels of berry abscission and moisture loss after the 80-hour period in the dark, compared with grapes sampled at a later stage. At 27 DAFB, the abscission zone developed between the pedicel and the rachis, thereafter it developed between the pedicel and the berry. Although FRF did not change significantly as berries ripened (from 83 to 111 DAFB), abscission potential and percentage berry abscission were significantly higher for grapes harvested at 83 DAFB at a TSS of 12.3°Brix than for grapes harvested more mature, at a higher TSS. Moisture loss correlated significantly (P<0.0001) with berry abscission, with a correlation coefficient of 0.84. Berry abscission also correlated significantly (P<0.0001) with abscission potential, pedicel and berry diameter, FRF (at sampling), FRF (after 80 h) and berry mass, but not with TSS or TA.

The numerous physiological and biochemical changes that occur during grape berry (*Vitis vinifera* L.) development have been subdivided into three growth stages (Coombe, 1973). The duration and manifestation of each growth stage varies according to cultivar and environmental conditions. Stage I is characterised by a rapid increase in berry size, firstly due to cell division, followed by cell enlargement (Coombe, 1976). During stage I, chlorophyll is the predominant pigment and berries display active metabolism, with high rates of respiration and rapid acid accumulation (Winkler *et al*., 1974). The levels of sugars remain almost constant and berries remain firm. Stage II is a slow growth phase during which the chlorophyll content decreases and maximum acid levels are attained. Stage III extends from the beginning of ripening until the grapes are fully ripe, and is characterised by a sudden change in appearance and composition of the berries. During this stage there is an acceleration of berry growth, a decrease in berry firmness and an increase in deformability, as well as an increase in glucose and fructose contents (Coombe, 1973). Furthermore, decreases in the concentration of organic acids, loss of chlorophyll from the skin, accumulation of anthocyanins and a decrease in respiration rate take place during stage III (Winkler *et al*., 1974).

The development of abscission potential at the abscission zone of fruit can be quantitatively indexed by measurement of the fruit removal force (FRF) (Wittenbach & Bukovac, 1974). However, there is an apparent lack of literature regarding changes in FRF during the different stages of grape berry development. Consequently, the association between FRF and the biochemical and physiological changes that occur during berry development is unknown.

The objective of this study was to determine how FRF is influenced by changes in abscission-related physiological factors during berry development in 'Waltham Cross' table grapes.

MATERIALS AND METHODS

A commercial 'Waltham Cross' (clone 22) vineyard near Paarl (lat. 33°45'S, long. 18°57'E) in the Western Cape, South Africa was used in this study. Vines on 'Richter 110' rootstock were planted in 1994 at a spacing of 3 x 1.5 m, trained onto a double-gable system and irrigated by micro-jet irrigation. Cultural practices as suggested by Van der Merwe and Geldenhuys (2001) for 'Waltham Cross' (clone 22) were followed.

The data plot consisted of nine rows in the 'Waltham Cross' (clone 22) vineyard. Nine randomly selected bunches were

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marked across the nine rows, and five berries per bunch were randomly selected for measurement of changes in berry and pedicel diameters. The same five berries per bunch were used for biweekly measurements, from 27 until 111 days after full bloom (DAFB) during the 1999 season. Berry and pedicel diameters were measured using a digital calliper (Mitutoyo Corp., Japan). For both measurements, the average of the five berries per bunch was considered a single replicate, i.e. there were nine replications.

An additional nine bunches were randomly harvested from the same plot at each sampling time for measurements of FRF to quantitatively index abscission potential. Fruit removal force was measured on five berries randomly selected per grape bunch. The berries were detached with their pedicels still attached. The average FRF-measurement of the five berries per bunch was considered a single replicate, i.e. there were nine replications. The tensile force required to remove a grape berry from its pedicel was measured with a specially designed clamp attached to a TA-XT2 texture analyser (Stable Micro Systems, England). The texture analyser was pre-set to apply a tensile force on the pedicel of the berry over a distance of 7 mm. The force, in Newton, necessary to detach the pedicel from the berry, was measured directly after sampling. Thereafter, the grape bunches were held in the dark at about 25°C for 80 h to stimulate abscission, according to a method used for sour cherry (*Prunus cerasus* L.) (Wittenbach & Bukovac, 1973). After this period, FRF was measured again, as well as the amount of berry abscission that occurred. All detached berries, as well as the berries that became detached when the bunch was given five gentle shakes, were recorded for berry abscission. The proportion of abscised berry mass relative to bunch mass was recorded as percentage berry abscission. Fruit abscission potential, i.e. the capacity of fruit to form an abscission layer after being detached from the plant, can be indexed by the decrease in FRF during the 80-hour period (Wittenbach & Bukovac, 1974). Therefore, berry abscission potential was indexed by the difference between FRF at sampling and FRF after 80 h in the dark, expressed as a percentage of FRF at sampling. Moisture loss during the 80-hour period was also determined. The nine grape bunches were weighed at sampling as well as after the 80-hour period. It was assumed that the loss in bunch mass during this period was mainly due to moisture loss. Moisture loss was expressed as a percentage of initial fresh mass measured at harvest.

Grape maturity at each sampling time was determined by measuring TSS (total soluble solids) and TA (titratable acids). For these measurements, three randomly selected bunches were removed from the sample plot at each sampling time. Juice of 50 randomly selected berries from each bunch was extracted in a liquidiser, and then filtered. The TSS of the filtrate, expressed as °Brix, was measured using a bench-top Palette PR100 digital refractometer with automated temperature compensation (Atago Co., Japan). Titratable acidity, expressed as percentage tartaric acid, was determined by titrating a 10-g aliquot of juice with 0.1 N NaOH to an end-point of pH 7, using a 665 Dosimat auto-titrator (Metrohm Co., Switzerland). From the same three bunches, 100 berries per bunch were randomly selected and weighed to determine average berry mass.

A completely randomised experimental design was used. There were nine replications for all variables measured, except TSS, TA and berry mass that were replicated three times. All statistical analyses were performed in accordance with the General Linear Means (GLM) and correlation (CORR) procedures in the Statistical Analysis System (SAS) (SAS Institute Inc., 1990). In the case of correlations, variables measured across sampling times were compared with levels of berry abscission, also across sampling times.

RESULTS AND DISCUSSION

From 27 to 54 DAFB, TSS did not change significantly, while TA increased during this period (Table 1). The FRF (at sampling), which measures the attachment of the pedicel to the berry, increased significantly during this early stage of berry development, indicating a strengthening of the abscission zone tissue. After 54 DAFB, a decline in FRF (at sampling) occurred, which coincided with a significant increase in TSS and a decrease in TA. As the berries matured, from 83 to 111 DAFB, the force required

TABLE 1

Changes in various parameters during berry development of 'Waltham Cross' table grapes.

Parameter	Days after full bloom[a]							Prob>Fb
	27	41	54	69	83	97	111	
TSS (°Brix)	5.5^{a}	4.3^{a}	4.2^{a}	7.7^{b}	12.3^{c}	16.4^{d}	17.4^{d}	0.0001
TA (%)	2.4^{c}	2.8^{d}	2.8^{d}	2.5^{c}	0.8^{b}	0.4^{a}	0.3^{a}	0.0001
Berry mass (g)	0.2^{a}	1.8^{b}	3.1^{c}	4.0^{d}	5.7^{e}	7.1^{f}	8.9^{g}	0.0001
Pedicel diameter (mm)	1.2^{a}	1.5^{b}	1.5^{b}	1.5^{b}	1.5^{b}	1.5^{b}	1.5^{b}	0.0001
Berry diameter (mm)	6.6^{a}	13.3^{b}	15.6^{c}	16.9^{d}	20.5^{e}	21.5^{f}	21.9^{f}	0.0001
Moisture loss (%)	6.3^{b}	0.7^{a}	0.4^{a}	0.8^{a}	0.3^{a}	1.2^{a}	0.1^{a}	0.0001
FRF (N) (at sampling)	5.1^{a}	8.9^{cd}	12.8^{e}	10.3^{d}	8.3^{bc}	7.9^{bc}	7.2^{b}	0.0001
FRF (N) (after 80 h)[c]	1.2^{a}	7.6^{d}	13.3^{f}	9.7e	4.5^{b}	6.0^{c}	5.6^{bc}	0.0001
Abscission potential (%)	75.0^{d}	14.2^{ab}	6.1^{a}	13.7^{ab}	43.7^{c}	23.9^{b}	22.9^{b}	0.0001
Berries abscised (%)	98.3^{c}	0.2^{a}	1.2^{a}	1.4^{a}	7.7^{b}	1.6^{a}	1.5^{a}	0.0001

[a] Variates in same row labelled with different superscripts indicate significant differences (P<0.01) according to LSD test.

[b] One-way ANOVA table with completely randomised design.

[c] Fruit removal force measured after the detached bunches were held in the dark at ≈25°C for 80 h.

to remove a berry from its pedicel did not change significantly. From 54 to 97 DAFB, the increase in TSS and the decrease in TA were significant. Berry mass increased significantly from 27 to 111 DAFB. The diameter of the pedicel only increased significantly from 27 to 41 DAFB, while berry diameter increased significantly for the period 27 to 97 DAFB.

At 27 DAFB, grape bunches had a significantly lower FRF at sampling and after 80 h in the dark, compared with grapes sampled at a later stage (Table 1). These grapes also showed a high abscission potential (75.0%). After the bunches had been subjected to 80 h in the dark, almost all of the berries abscised (98.3%). At this stage, the abscission zone developed between the pedicel and the rachis. Grapes sampled from 41 to 111 DAFB revealed significantly less berry abscission, and the abscission zone developed between the pedicel and the berry. As FRF (at sampling and after 80 h) increased significantly from 27 to 54 DAFB, abscission potential decreased. At 54 DAFB, FRF after 80 h was even higher than FRF at sampling. However, after 54 DAFB, there was a decline in FRF, thus a lesser force was required to separate the pedicel from the berry. At 83 DAFB, FRF (after 80 h) decreased significantly, compared with grapes harvested at 69 DAFB or at 97 DAFB. This resulted in an unexpectedly high abscission potential and significantly more berry abscission, compared with the other sampling dates (excluding 27 DAFB). Moisture loss, as measured after the 80-hour incubation period, was significantly higher for grapes sampled at 27 DAFB, compared with grapes sampled at later stages of berry development. Moisture loss correlated significantly ($P<0.0001$) with berry abscission, with a correlation coefficient of 0.84 (Table 2). Berry abscission also correlated significantly ($P<0.0001$) with abscission potential, pedicel and berry diameter, FRF at sampling, FRF after 80 h in the dark and berry mass. However, moisture loss provided the best correlation with abscission.

With reference to the three stages of berry development as described by Coombe (1973; 1976), the period from 27 to 54 DAFB can be considered as part of stages I and II of berry development, with stage III commencing shortly after 54 DAFB. In addition to the TSS level that remained almost constant and the TA level that increased to its maximum, these two phases can also be characterised by an increase in FRF. Although the term *veraison* is used by French viticulturists to denote the change in skin colour of grape berries from green, it is convenient to use this term in a wider context to embody the group of developmental changes evident during this stage (Coombe & Bishop, 1980). These additional changes include renewed expansion in berry size, a reduction in firmness, a loss of chlorophyll, an accumulation of flavonoids in the skin, an increase in glucose and fructose, and a decrease in tartaric and malic acids. Based on these criteria, *veraison* occurred at approximately 54 DAFB in 'Waltham Cross' in this study. The results also indicated that a decrease in FRF occurs at *veraison*, and that this decrease in FRF continues during stage III.

Although FRF (at sampling) did not change significantly as berries ripened (from 83 to 111 DAFB), the abscission potential and the percentage berries that abscised were significantly higher for grapes harvested at a TSS of 12.3°Brix than for more mature grapes, i.e. at a higher TSS level. These results correspond with previous research by Beyers (1936), who found that 'Waltham Cross' grapes harvested below 15°Brix were more susceptible to postharvest berry abscission than riper berries. Therefore, it is imperative to harvest 'Waltham Cross' grapes at optimum maturity, not only for better eating quality, but also to reduce the incidence of postharvest berry abscission. The minimum maturity permissible for export of 'Waltham Cross' grapes from South Africa is 16°Brix, and therefore the samples taken at 97 and 111 DAFB in this study would have been well within the minimum standards.

TABLE 2

Correlation coefficients (with significance levels in brackets) between berry abscission and other variables during berry development of 'Waltham Cross' table grapes.

Independent variable	**% Berries abscised**
Moisture loss (%)	0.844 (0.0001)
Abscission potential (%)	0.663 (0.0001)
Pedicel diameter (mm)	-0.611 (0.0001)
Berry diameter (mm)	-0.769 (0.0001)
FRF (N) (at sampling)	-0.515 (0.0001)
FRF (N) (after 80 h)	-0.631 (0.0001)
Berry mass (g)	-0.591 (0.0048)
TSS (°Brix)	-0.308 (0.1744)
TA (%)	0.260 (0.2549)

Fabri & Betti (1982) distinguished between two abscission zones on the grape berry stem (pedicel) where abscission can occur. The one abscission zone is situated where the pedicel is attached to the bunch rachis and the other abscission zone is situated where the berry is attached to the pedicel. In the current study, at 27 DAFB, the abscission zone developed between the pedicel and bunch rachis. However, from 41 to 111 DAFB, the abscission zone developed between the pedicel and the berry. The same tendency was observed in citrus (Goren, 1981) and cherry fruit (Wittenbach & Bukovac, 1974).

At 27 DAFB, the grape berries had a significantly lower FRF, as measured at sampling and after the 80-hour period, as well as a significantly higher abscission potential and incidence of berry abscission after 80 h in the dark, compared with grapes sampled at a later stage. Therefore, 'Waltham Cross' grapes at this stage of development appear to be very susceptible to berry abscission. Consequently, any adverse external factors, such as moisture or heat stress, that prevail during this period could possibly induce severe premature berry abscission. Grapes sampled at this stage

of development also showed significantly higher levels of moisture loss during the 80-hour period in the dark, and a significant correlation existed between moisture loss and berry abscission. It is suggested that high levels of moisture loss caused water stress in the berries, resulting in the accelerated production of ethylene (Berry & Aked, 1996). Since ethylene stimulates abscission (Burg, 1968), it is possible that moisture stress could increase berry abscission, providing a possible explanation for the significant correlation between these two factors.

From 27 to 54 DAFB, FRF increased and berry abscission potential decreased. It is probable that the activities of cell- wall-degrading enzymes were low during this period, resulting in a strengthening of the abscission zone tissue. At *veraison*, which occurred at approximately 54 DAFB, the abscission potential of berries was at a minimum, and then increased during further berry development. Thereafter, it is likely that the activity of cell-wall-degrading enzymes increased after *veraison*, resulting in a weakening of abscission zone tissue.

'Waltham Cross' grapes exhibited an inverse correlation between pedicel diameter and berry abscission. It is possible that this correlation was the result of moisture loss that occurred at 27 DAFB, rather than the stage of vascular tissue development, which is also known to influence abscission (Baird & Webster, 1979).

CONCLUSIONS

Grape berry abscission potential, as quantitatively indexed by the measurement of the FRF, showed significant changes during berry development of 'Waltham Cross' table grapes, from 27 to 111 DAFB. Therefore, at certain stages of fruit growth, 'Waltham Cross' grapes are more prone to berry abscission. At 27 DAFB, when berries were 6.6 mm in diameter, grape bunches had a significantly higher potential for berry abscission compared with grapes sampled at a later stage. 'Waltham Cross' has inherently straggly bunches with bare shoulders. Therefore, any abscission during berry development will aggravate bunch appearance. Consequently, it is extremely important that adverse factors such as moisture stress be avoided, especially during the period when 'Waltham Cross' grapes appear to be very susceptible to berry abscission. Of all variables measured, moisture loss showed the highest correlation with abscission. Grapes harvested at a TSS of 12.3°Brix (83 DAFB) had a significantly higher abscission potential than more mature grapes. Therefore, by harvesting 'Waltham Cross' grapes at optimum maturity (TSS of 16 – 17°Brix), berry abscission can be dramatically reduced. At *veraison*, the metabolism of grape berries changes drastically and, in addition to the rapid increase in sugars and the rapid decrease in acidity, a decrease in FRF occurs.

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