Quantitative and Instrumental Measurements of Grape Flesh Texture as Affected by Gibberellic Acid Application

Akihiko Sato*, Masahiko Yamada, Hiroshi Iwanami** and Nobuhito Mitani

Department of Grape and Persimmon Research, National Institute of Fruit Tree Science, Akitsu, Hiroshima 729–2494

Summary

To compare the texture of GA₃-treated and untreated berries, the deformation at the first major peak (DFP), an indicator of sensory difficulty of breakdown in mastication and the maximum force (MF), an indicator of firmness in a series of puncture tests, were measured using 14 genotypes of American grapes (*Vitis labruscana* Bailey), European (*Vitis vinifera* L.) grapes and interspecific hybrids (*V. labruscana* × *V. vinifera*). GA₃ was applied to clusters of each cultivar at full bloom and 10–16 days after full bloom. While the effect of the GA₃ treatment was insignificant for the DFP, GA₃-treated berries had a significantly higher MF than the control, indicating that GA₃ treatment increased flesh firmness. The genotype × treatment interaction for both DFP and MF was significant, suggesting that the response to the application of GA₃ varied, depending on the genotypes. It was possible that GA₃ treatment to a cultivar with soft flesh results in a change to crisp flesh (2.5 mm ≥ for DFP and 0.9 N ≤ for MF), which is a desirable texture for table grapes. Soluble solid concentration and titratable acidity in GA₃-treated berries were not different from those in untreated berries. Therefore, the effect of GA₃ on flesh firmness was suggested to be direct and not the result of a delay in berry ripening.

Key Words: firmness, gibberellic acid, plant growth regulator, texture, *Vitis*.

Introduction

The major grape cultivars for table use in the world are the European grape (*Vitis vinifera* L.) (Alleweldt et al., 1990; Alleweldt and Possingham, 1988). This species includes cultivars that produce large berries, with firm and easily breakable (crisp) flesh and a muscat flavor (Hedrick, 1925). However, the species is susceptible to fungal diseases (Winkler, 1962) and berry cracking when it is grown in climates with high rainfall. The American grape (*Vitis labruscana* Bailey), which includes the cultivars having *V. labrusca* parentage (Bailey and Bailey, 1930; Cahoon, 1986), is adaptable to the wet climate and cold winters of Japan and the eastern United States. However, the flesh texture of *V. labruscana* cultivars is not crisp but tough (firm but difficult to masticate) or tender (easily breakable but soft). The low consumption of the *V. labruscana* grape is probably attributed to its texture (Bourne, 1979). Therefore, the National Institute of Fruit Tree Science (NIFTS) has continued breeding for the release of disease-resistant cultivars with a muscat flavor and crisp flesh by crossing among the *V. vinifera*, *V. labruscana* and interspecific hybrids (*V. labruscana* × *V.*

vinifera) cultivars/selections. Moreover, Japanese consumers prefer a large seedless berry weighing more than 10 g. However, it is difficult to obtain hybrids with large, seedless berries in crossing with existing seedless cultivars, such as the ‘Thompson Seedless’, ‘Flame Seedless’ and ‘Himrod’ because they have small berries.

To modify various aspects of the berry characteristics, plant growth regulators have been successfully used in table grape production (Ledbetter and Ramming, 1989). Among plant growth regulators, gibberellic acid (GA₃) has been used extensively to increase berry set and size of seedless cultivars (Weaver and McCune, 1959a, b), and to induce seedlessness in seeded cultivars (Itakura et al., 1965; Kishi and Tazaki, 1960). The conversion of seeded grapes into seedless ones with the application of GA₃ for some table grape cultivars, such as ‘Delaware’, ‘Pione’ and ‘Muscat Bailey A’, is a common practice in grape production in Japan (Okamoto, 1994). Now, GA₃ has been registered under the Agricultural Chemicals Regulation Law as a growth regulator to promote large and/or seedless berries, large cluster, or early ripening of grapes. For these purposes, grape growers use GA₃ routinely on a large scale for the commercial production of table grapes.

The berry texture of a grape is a quantitative trait and varies depending on the cultivar (Sato et al., 1997, 2000), developmental stages (Lee and Bourne, 1980) and environmental factors (Bernstein and Lustig, 1985; Sato et al., 2000). In the sweet cherry, pre-harvest GA₃

Received; February 14, 2003. Accepted; May 23, 2003.

* Corresponding author.

** Present Address: Department of Apple Research, National Institute of Fruit Tree Science, Morioka, Iwate 020–0123.

application increased the firmness of the flesh (Proebsting et al., 1973; Looney and Lidster, 1980). On the other hand, no scientific information is available on changes caused by GA₃ application to the textural properties of grape berry flesh. If the application of GA₃ greatly increases berry flesh firmness, the texture may become crisp in cultivars/selections with soft flesh. The hormone treatment may be useful in the selection process, especially for tetraploid interspecific hybrid breeding, because a tetraploid offspring with a crisp texture is difficult to obtain.

The method for measuring the texture of grape flesh with a rheometer was developed by Sato et al. (1997). According to Sato et al., there were high correlations between the sensory rating of the difficulty to masticate samples and the deformation at the first major peak (DFP), and between the sensory firmness and the maximum force (MF) in a force-deformation curve of a puncture test, so that varietal differences in grape texture could be largely expressed by the DFP and MF. The objective of this study was to determine quantitatively and instrumentally the effect of GA₃ application on the berry flesh texture of 14 *V. vinifera* and interspecific hybrids genotypes.

Materials and Methods

Experiments were conducted at the Department of Grape and Persimmon Research of the National Institute of Fruit Tree Science (NIFTS), Akitsu, Hiroshima, during 1997–2000. Fourteen seeded cultivars/selections (genotypes) were used in the study (Table 1). In table grape breeding at the NIFTS, GA₃ is routinely applied to newly released seeded cultivars and selections to induce seedlessness and/or to enhance berry size. For these purposes, GA₃ was first applied at full bloom to induce

to seedlessness, again 10–16 days later to increase berry size. The treatment consists of dipping clusters on a vine in a 25 ppm solution of gibberellic acid (GA₃) (Gibberellin Kyowa Powder, Kyowa Hakko).

Five GA₃-treated and untreated clusters of each genotype were harvested simultaneously at optimum maturity. Five to 10 berries were sampled from each cluster and the berry weight (BW) was recorded. The soluble solid concentration (SSC) was determined with a calibrated refractometer (N1, Atago) and the titratable acidity (TA) was determined and expressed as grams of tartaric acid per 100ml of juice. For the BW, SSC and TA, the effects due to genotypes and GA₃ treatment were tested by two-way analysis of variance (ANOVA) with genotypes and the treatment as factors. The proportion of seedless berries was determined on 30–50 berries that were sampled randomly from three to five GA₃-treated clusters.

To determine the textural properties, five berries randomly chosen from three clusters of each treatment were cut longitudinally (8 mm thick) and subjected to a puncture test. The sample was mounted on the stage with a 4 mm hole in the rheometer (NRM-2010J-CW, Fudoh) and tested with a 3 mm diameter plunger driven at a rate of 50.0 mm·min⁻¹, according to Sato et al. (1997). The force for compression and the distance from the surface of the sample were assessed from the force-deformation curve. The value of deformation at the first major peak (DFP) and the maximum force (MF) were obtained from the force-deformation diagram. The obtained data were statistically analyzed after transforming logarithmically because the mean and standard deviation were correlated. The ANOVA was performed for the data of the DFP and MF using the model shown below:

$$X_{ijk} = \mu + G_i + T_j + (G \times T)_{ij} + C_{ijk} + B_{ijkl},$$

where μ = the overall mean

G_i = the random effect of the i th genotype

T_j = the fixed effect of the j th treatment

$(G \times T)_{ij}$ = the interaction between the i th genotype and the j th treatment

C_{ijk} = the effect of the k th cluster of the i th genotype and the j th treatment

B_{ijkl} = the effect of l th berry in the k th cluster of the i th genotype and the j th treatment.

Results and Discussion

Significant differences were obtained among the genotypes for both the DFP and MF (Table 2). The mean values in the untreated group were 2.75 mm for the DFP and 0.85 N for the MF, with variations ranging from 1.99 mm (224–49) to 3.77 mm ('Honey Venus') and from 0.38 N ('Sunny Rouge') to 1.44 N (384–25), respectively. The genotypes used in this study include new cultivars and selections from the grape breeding at the NIFTS, which have a lower DFP (easier to break on mastication) with less variation and a slightly higher MF

Table 1. Ploidy level and parentage of 14 grape cultivars/selections used.

Cultivars/selections	Ploidy level	Parentage
Dark Ridge	4x	Kyoho × 301-1 ^z
Honey Venus	4x	Benizuiho × Olympia
Sunny Rouge	4x	Pione × Red Pearl
Akitsu 20	4x	Benizuiho × Hakuho
Akitsu 22	4x	Neo Muscat 4X × Hokuho
Akitsu 23	2x	Akitsu 21 ^y × Hakunan
224–49	4x	Aki Queen selfed
224–56	4x	Aki Queen selfed
364–7	4x	Aki Queen × Beniizu
365–2	4x	Benizuiho × Aki Queen
377–24	4x	Honey Venus × Pione
380–4	4x	Akitsu 20 × Aki Queen
384–25	4x	Dark Ridge × Centennial
638–46	2x	Alphonse Lavallee × July Muscat

^z 301–1 : an F₁ of Kyoho × Niabell.

^y Akitsu 21 : Steuben × Muscat of Alexandria.

Table 2. Effect of GA₃ treatment on the deformation at the first major peak (DFP) and maximum force (MF) of berry flesh texture, and proportion of seedless berry in GA₃-treated clusters for 14 grape cultivars/Selections.

Cultivars/Selections	DFP (mm)		MF (N)		Seedless (%)
	GA ₃ -treated	Untreated	GA ₃ -treated	Untreated	
Dark Ridge	3.38 NS	3.33	0.80 NS	0.82	5
Honey Venus	3.01 *	3.77	0.97 NS	1.00	42
Sunny Rouge	2.66 **	3.39	0.61 **	0.38	100
Akitsu 20	3.41 NS	2.91	1.27 NS	1.09	88
Akitsu 22	3.06 *	2.52	0.42 *	0.63	45
Akitsu 23	2.23 NS	2.26	1.71 *	1.21	97
224-49	1.85 NS	1.99	0.70 **	0.44	62
224-56	2.88 NS	2.55	1.19 NS	1.22	40
364-7	2.32 NS	2.35	0.65 NS	0.52	30
365-2	2.50 NS	3.08	0.90 *	0.65	14
377-24	2.79 NS	2.89	0.86 *	0.63	— ^z
380-4	2.40 **	3.25	0.88 NS	0.68	100
384-25	1.89 NS	2.07	1.07 NS	1.44	90 <
638-46	2.03 NS	2.07	1.68 *	1.14	— ^z
Mean	2.60	2.75	0.98	0.85	
<i>Significance</i> ^y					
Genotype (G)	**		**		
Treatment (T)	NS		*		
G × T	**		**		
Cluster / G × T	*		**		

^z Proportion of seedless berries were not determined but major portion was seeded.^y ANOVA was performed using log-transformed value.NS, *, ** Non significant or significant at $P \leq 0.05$ or 0.01.

(firmer) than the population of the *V. labruscana* cultivars in an earlier report (Sato et al., 1997).

For the DFP, the GA₃ application was insignificant, but the genotype × treatment interaction was significant, indicating that the response to the GA₃ application differed depending on the genotype. The GA₃ treatment significantly reduced the DFP for ‘Honey Venus’, ‘Sunny Rouge’ and 380-4 (Table 2).

On the other hand, the MF in the GA₃-treated berry was significantly higher than that in the untreated one (Table 2). However, the significant genotype × treatment interaction suggests that the magnitude of the effect of the GA₃ to enhance flesh firmness differed, depending on the genotype. GA₃ significantly increased firmness in ‘Sunny Rouge’, Akitsu 23, 224-49, 365-2, 377-24 and 638-96, but unchanged or decreased firmness in ‘Honey Venus’, ‘Dark Ridge’, Akitsu 20, Akitsu 22, 224-56, 364-7, 380-4 and 384-25.

GA₃ treatment after bloom is effective in a duration of several days in increasing berry size. In this study, therefore, the second GA₃ was applied from 10 to 16 days after full bloom. The difference of the timing of second GA₃ treatment may partly account for the genotype × treatment interaction or the effect of the GA₃ treatment on the texture. To determine the relationship

between the timing of the treatment and the textural change, a more rigorous experimental design will be required.

The proportion of seedless berries in the GA₃-treated clusters varied from 5 to 100% (Table 2); the percentage of seedless berries was not related to the effect of GA₃ on the DFP and MF, suggesting that seedlessness induced by GA₃ treatment was independent of berry flesh texture.

The ANOVA showed that the difference between

Table 3. Effects of GA₃ treatment on berry weight (BW), soluble solids concentration (SSC) and titratable acidity (TA) of 14 cultivars/selections.

Treatment	BW (g)	SSC (%)	TA (g/100 ml)
GA ₃ -treated	10.6	20.0	0.47
Untreated	10.6	20.5	0.48
Significance	NS ^z	NS	NS

^z Mean separation by a two-way ANOVA with factors of genotype and treatment. NS, non-significant at $P \leq 0.05$.

Fig. 1. Scatter diagram showing the relationship between the effect of GA₃ on maximum force (MF) and that on soluble solids concentration (SSC) (A) and titratable acidity (TA) (B) in 14 grape cultivars/selections. The effect of GA₃ on MF, SSC and TA were determined by subtracting the mean values of untreated berries from those of GA₃ treated ones in each cultivar/selection.

treated and untreated berries was insignificant for the SSC, TA and BW (Table 3), indicating that significant increase of firmness in GA₃-treated berries cannot be explained by a delay in berry ripening. Furthermore, to determine relationship between the genotype $\times$ treatment interaction in MF and ripeness in each genotype, the effect of the GA₃ on MF, SSC and TA were determined by subtracting the mean values of the untreated berries from those of the GA₃-treated ones in each genotype. The effect of the GA₃ on MF was not correlated to that on the SSC ($r = -0.08^{NS}$) and the TA ($r = 0.02^{NS}$) (Fig. 1). These results substantiate that the effect of GA₃ on firmness is not related to that on ripeness of genotypes. Weaver and McCune (1959) Weaver and McCune (1959a, b) reported that the SSC decreased and TA increased in berries of 'Thompson Seedless' when the application time of GA₃ was delayed. Christodoulou et al. (1968) also reported that, comparison to the untreated berries, the SSC in 'Thompson Seedless' was significantly higher and TA lower when GA₃ was applied at the beginning of berry set. These reports suggested that GA₃ treatment, depending on timing, may lead to a delay of ripening, reduced SSC,

and increased TA at harvest. In this study, slight changes of the SSC and TA were detected between GA₃ treated and untreated berries, suggesting that the timing of the treatment was suitable for maintaining quality in this study.

Significant genotype $\times$ treatment interactions for both the DFP and MF indicate that the effect of GA₃ varied depending on the genotypes. There were no obvious groups among species and parentage in relation to the effects of GA₃. In addition, an increase in flesh firmness occurred irrespective of the ploidy level.

In a previous report, we reported that the DFP and MF were positively correlated in *V. labruscana* cultivars, which resulted in no cultivars with crisp flesh (2.5 mm $\geq$ in the DFP and 0.9 N $\leq$ in the MF) in *V. labruscana* (Sato et al., 1997). In this study, the DFP did not always increase when the MF was increased by GA₃ treatment. For instance, the MF increased from 0.65 N to 0.90 N with GA₃ applications, but the DFP was 3.08 mm (untreated) and 2.50 mm (treated) in 365-2. This indicates that the linkage between the DFP and MF was partly removed by GA₃ applications in 365-2.

The reason why GA₃-treatment resulted in textural changes is unknown, but the content of alcohol insoluble solids in the cell wall of mesocarp was higher in the treated sweet cherry fruits than in the untreated ones (Looney and Lidster, 1980). The GA₃ application in grape may also affect the cell wall composition.

Although the effect of GA₃ on flesh firmness was slight but varied depending on the genotypes, our results revealed that the GA₃ application effectively provided firm flesh. Hence, for those selections with slightly soft flesh, if GA₃ application could possibly make the flesh firmer, it would be a useful procedure for improving flesh texture in interspecific hybrids.

Literature Cited

- Alleweldt, G. and V. Possingham. 1988. Progress in grape-vine breeding. Theor. Appl. Genet. 75: 669-673.
- Alleweldt, G., P. Spiegel-Roy and B. Reisch. 1990. Grapes (*Vitis*). p. 291-337. In: J. N. Moore and J. R. Ballington Jr. (eds.). Genetic resources of temperate fruit and nut crops. Acta Hort. 290.
- Bailey, L. H. and E. Z. Bailey. 1930. Hortus. p.640. The Macmillan Company. New York.
- Bernstein, Z. and I. Lustig. 1985. Hydrostatic methods of measurement of firmness and turgor pressure of grape berries (*Vitis vinifera* L.). Scientia Hort. 25: 129-136.
- Bourne, M. C. 1979. Texture of temperate fruits. J. Texture Std. 10: 25-44.
- Cahoon, C. A. 1986. The Concord grapes. Fruit Var. J. 40: 106-107.
- Christodoulou, A. J., R. J. Weaver and R. M. Pool. 1968. Relation of gibberellin treatment to fruit-set, berry development, and cluster compactness in *Vitis vinifera* grapes. Proc. Amer. Soc. Hort. Sci. 92: 301-310.
- Hedrick, U. P. 1925. Systematic pomology. The Macmillan

- Company. New York.
- Itakura, T., I. Kozaki and Y. Machida. 1965. Studies with gibberellin application in relation to response of certain grape varieties. Bull. Hort. Res. Stn. A4: 67-95 (In Japanese with English summary).
- Kishi, M. and M. Tazaki. 1960. Effects of gibberellin on Delaware grapes. Agric. and Hort. 35: 381-384 (In Japanese).
- Ledbetter, C. A. and D. W. Ramming. 1989. Seedlessness in grapes. Hort. Rev. 11: 159-184.
- Lee, C. Y. and M. C. Bourne. 1980. Changes in grape firmness during maturation. J. Texture Std. 11: 163-171.
- Loony, N. E. and P. D. Lidster. 1980. Some growth regulator effects on fruit quality, mesocarp composition, and susceptibility to postharvest surface marking of sweet cherry. J. Amer. Soc. Hort. Sci. 105: 130-134.
- Okamoto, G. 1994. Grape. In: Organizing Committee XXIVth International Horticultural Congress Publication Committee (eds.). Horticulture in Japan. Asakura Publishing, Tokyo.
- Proebsting, Jr., E. L., G. H. Carter and H. H. Mills. 1973. Quality improvement in canned 'Rainier' cherries (*P. avium* L.) with gibberellic acid. J. Amer. Soc. Hort. Sci. 98: 334-336.
- Sato, A., H. Yamane, N. Hirakawa, K. Otake and M. Yamada. 1997. Varietal differences in the berry texture of grape berries measured by penetration tests. Vitis 36: 7-10.
- Sato, A., M. Yamada, H. Iwanami and N. Hirakawa. 2000. Optimal spatial and temporal measurement repetitions for reducing environmental variation of berry traits in grape breeding. Scientia Hort. 85: 75-83.
- Weaver, R. J. and S. B. McCune. 1959a. Response of certain varieties of *Vitis vinifera* to gibberellin. Hilgardia 28: 297-350.
- Weaver, R. J. and S. B. McCune. 1959b. Effect of gibberellin on seedless *Vitis vinifera*. Hilgardia 29: 247-275.
- Winkler, A. J. 1962. General viticulture. Univ. of California Press. Berkeley and Los Angeles.

ブドウのジベレリン処理による肉質の変化の器械的評価

佐藤明彦・山田昌彦・岩波 宏*・三谷宣仁

農業・生物系特定産業技術研究機構果樹研究所ブドウ・カキ研究部 729-2494 広島県豊田郡安芸津町

摘 要

ブドウ果粒の肉質に対するジベレリン処理の効果を器械的に明らかにするために、欧州ブドウ、米国ブドウおよび種間雑種 14 品種・系統のジベレリン処理果と無処理果の肉質を、レオメーターによる貫入試験によって比較した。用いた 14 品種・系統は遺伝的には有核であり、ジベレリン処理はいずれの品種においても満開期と開花後の 2 回行った。果肉のかみ切れやすさの指標である最初の破断までの変形量（以下、変形量）においてはジベレリン処理による有意な効果は認められなかった。果肉の硬さの指標である最大破断力は、ジベレリン処理果が無処理果よりも有意に大きく、ジベレリン処理によって肉質が硬くなることが器械的指標によって示された。しかし、変形量、最大破断力ともに品種・系統×処理交

互作用が有意であったことから、品種・系統によってジベレリン処理の肉質に対する効果が異なると考えられた。このことは、遺伝的には果肉がかみ切れにくく軟らかい品種・系統であっても、ジベレリン処理によって生食用ブドウの望ましい肉質である、かみ切れやすく硬い肉質が得られる可能性を示唆している。可溶性固形物含量や酸含量は、ジベレリン処理果と無処理果との間に有意な差が認められなかったことから、ジベレリン処理果における硬さの増加は熟期の遅延によるものではなく、肉質が変化したことによるものと考えられた。

現在：果樹研究所リンゴ研究部 020-0123 岩手県盛岡市