

## Response of Muscat of Alexandria table grapes to post-veraison regulated deficit irrigation in Japan

D. O. EL-ANSARY<sup>1</sup>), S. NAKAYAMA<sup>1</sup>), K. HIRANO<sup>2</sup>) and G. OKAMOTO<sup>2</sup>)

<sup>1</sup>) Graduate School of Natural Science and Technology, Faculty of Agriculture, Okayama University, Okayama, Japan

<sup>2</sup>) Laboratory of Pomology, Faculty of Agriculture, Okayama University, Okayama, Japan

### Summary

**The effects of post-veraison regulated deficit irrigation (RDI) on vine water status, ripening, and quality of table grapes, cv. Muscat of Alexandria grown under a polyhouse and root-zone restriction condition were investigated in the Okayama University Experimental vineyard, Japan. From bud break to veraison all vines were irrigated to a soil moisture tension of 3 kPa at a depth of 15 cm, and were re-irrigated when soil moisture tension approached 15 kPa. Starting 10 d after veraison, 3 irrigation regimes were imposed: (1) Control (C): Re-irrigation immediately when soil moisture tension reached 15 kPa; (2) Moderate Deficit Irrigation (MDI): Re-irrigation 2 d after reaching a soil moisture tension of 15 kPa; and (3) Severe Deficit Irrigation (SDI): Re-irrigation 4 d after reaching a soil moisture tension of 15 kPa. Treatments were continued for 6 weeks until harvest. By the end of the experiment, as the vine water status decreased, only SDI vines were wilted or necrotic in the fruit-zone. In SDI vines, the cumulative effect of increased vine water deficit indicated by lower  $\Psi_1$  resulted in berries that were lower in firmness and acidity, with a small increase in aroma, and a higher TSS than control at harvest. The decrease in vine water status in the MDI treatment had a slight effect on berry ripening as compared with control while RDI had no effect on berry weight or juice pH at harvest.**

**Key words:** grape, post-veraison, ripening, deficit irrigation, water potential.

### Introduction

There is a link between water availability and physiological performance of plants which has been well illustrated also for grapevine (LOVEYS and LU 2002). Water deficiency or excess can affect fruit quality: Severe water deficit will reduce yield and quality; mild water deficit reduces yield but may be beneficial for some quality parameters; no water deficit will increase yield but may reduce fruit quality (PRANGE and DEELL 1997). Post-veraison deficit irrigation was shown to lead to successful grape production, though, if not well managed, it may have negative effects on foliage, yield, and quality. CHRISTENSEN (1975) recommended the use of

preharvest deficit irrigation for vineyards of excessive vigor, prone to cluster rot or liable to berry splitting. Working with Cabernet franc, MATTHEWS and ANDERSON (1988) found that deficit irrigation after veraison had no influence on the duration of ripening or juice pH, and had only little effect on total soluble solids (TSS) or titratable acidity. GOODWIN (2002) demonstrated that post-veraison-regulated deficit irrigation in Cabernet-Sauvignon grapes reduced yield, berry size and TSS by 29, 14 and 9 %, respectively. In Chardonnay grapes, early irrigation cut-off after veraison led to severe leaf wilting and berry shrinking and inhibited berry ripening, while a later stop resulted in mild leaf wilting but promoted berry ripening as indicated by increased TSS and amino acids and decreased titratable acidity (OKAMOTO *et al.* 2004). Even today, the effects of various deficit irrigation procedures on ripening processes of grape are not satisfactorily understood as indicated by the considerable controversy in literature (HRAZDINA *et al.* 1984, ESTEBAN *et al.* 2002). This may be due to the interactions of many factors, such as variety, environmental conditions, crop load, and the details of irrigation deficit, *e.g.* timing, duration, degree and rate. Okayama city in the southwestern Honshu Island of Japan is well-known for its production of attractive table grapes. This region is characterized by rainy summer seasons which are unfavorable for grape growing. Thus, viticulture is usually practiced under polyhouses and root-zone restriction conditions to maintain healthy vines, control excessive vegetative growth, and improve berry set and fruit quality (OKAMOTO 2001). However, there is a lack of reliable field data of vine responses to irrigation strategies and scheduling under polyhouse conditions. The purposely imposed moderate stress to achieve certain beneficial results has generally been termed regulated deficit irrigation (JOHNSON and HANDLEY 2000). The aim of our work was to gain more information on the effect of post-veraison regulated deficit irrigation on the vine water status, ripening processes, and quality of Muscat of Alexandria table grapes.

### Material and Methods

**Plant material and growth conditions:** The study was conducted during the 2003 growing season at the Okayama University Experimental vineyard in Okayama city (long. 133.92 °E, lat. 34.66 °N), Japan. Five-year-old grape-

vines (*Vitis vinifera* L., cv. Muscat of Alexandria) grafted on SO4 rootstocks were used. The experimental area was a block of vines grown under a polyhouse, comprising 3 rows of 8 vines each, oriented north-south. Vine spacing was 2 m between rows and 0.6 m within rows. Vines were grown in raised beds (0.3 m high and 0.5 m wide) and under root-zone restriction condition by installing a water-permeable but root-proof polyester sheet (Unitica Co., BDK Lovesheet) below the root-zone. The medium was a mixture of sandy soil, peat moss, and horse manure (4:1:1 vol/vol). Vines were trained to a bilateral cordon and cane-pruned; a vertical shoot-positioning trellis system was used. Water was delivered via dual in-line dripper tubings run down along each bed. Weekly fertigation scheduling of a complete liquid fertilizer (Ohtsuka House Ekihi, No. 1 + No. 2), containing 60 ppm of N was applied, the level of which was reduced to one third at the onset of veraison. A regular pest management program was maintained. Soil moisture tension was monitored by placing tensiometers (DIK-8332, Daiki Rika Kogyo Co. Ltd.) at a depth of 15 cm. From bud break to veraison all vines were irrigated to a soil moisture tension of 3 kPa and were re-irrigated when soil moisture tension approached 15 kPa. Starting 10 d after veraison, 3 irrigation regimes were imposed: (1) Control (C): Re-irrigation immediately when soil moisture tension reached 15 kPa; (2) Moderate Deficit Irrigation (MDI): Re-irrigation 2 d after reaching a soil moisture tension of 15 kPa; and (3) Severe Deficit Irrigation (SDI): Re-irrigation 4 d after reaching a soil moisture tension of 15 kPa. Each vine received 5 l per irrigation. However, irrigation was scheduled on the basis of the 15 cm soil moisture tension; Control, MDI, and SDI vines were irrigated approximately at 3, 5, and 7-day-intervals, respectively. Treatments were continued for 6 weeks until harvesting. In all treatments re-irrigation started at 5 p.m.. Treatments were continued until harvest on 11 September, 12 September, and 13 September 2003 for SDI, MDI, and C, respectively.

**Sampling and analyses:** Sampling and field measurements were conducted just before irrigation at 5 p.m. and/or after irrigation at 8 a.m. Twenty-four berries per bed were randomly sampled and utilized for physical and chemical analyses. For measuring leaf water potential, 6-10 random leaves were taken from the middle part of shoots at 5 p.m. and/or 8 a.m., enclosed in plastic bags and placed in an icebox, and immediately brought to a nearby laboratory. Water potential measurements were conducted by a pressure chamber (Plant Moisture Tension Measuring Instrument, DIK-PC40, Daiki) within 2-3 min after excision. Total soluble solids (TSS) of berry juice were measured using a hand refractometer (Atago ATC-1E), and titratable acidity (% tartaric acid) by diluting the juice with deionized water and titrating with 0.1 N sodium hydroxide to the phenolphthalein end point. Juice pH was measured with a pH meter (Horiba Compact pH Meter B-211). For collecting aroma substances from intact berries, 4 berries were placed into a 0.45 l glass jar (= one replicate); 4 replicates were used per treatment. The jars were then placed in an incubator at 40 °C for 20 min. Then, the headspace aroma was collected by a Solid Phase Microextraction Fiber Assembly (Stationary Phase Polydimethylsiloxane and Film Thickness 100 µm), attached

to a SPME Holder (57330-U), by inserting the SPME needle into the jar and exposing the fiber for 20 min under the same conditions as mentioned above. After aroma collection, the SPME needle was injected into a GC port (Shimadzu GC-14 A) for 2 min. The analytical conditions were as follows: CBJ - WAX Capillary column of 0.5 i.d., length: 30 m; Uniport HP 80/100 mesh; N<sub>2</sub> as a Carrier gas at 30 ml·min<sup>-1</sup>; column temperature was held initially at 70 °C and was programmed at 5 °C·min<sup>-1</sup> to 220 °C and held at the final temperature. Injection temperature was at 170 °C and detector temperature 230 °C. Fruit firmness was measured as the force that provoked 10 % deformation of fruit diameter (30 mm·min<sup>-1</sup>), using a deformation tester (flat steel plate UL-5LK, CAP.: 50 N, Ø 30 mm, Orientec Corp.) mounted on a Tensilon machine (STM-T-50, Toyo Baldwin Co. Ltd.). A one-factor ANOVA was made to determine the effect of treatments. Mean comparisons were performed using Student-Newman-Keuls test to examine differences between treatments. Significance was determined at  $P < 0.05$  or  $P < 0.01$ .

## Results and Discussion

**Vine water status:** The average leaf water potential ( $\Psi_l$ ) at 8 a.m. was -0.44 MPa at the onset of experiment (Tab. 1).  $\Psi_l$  tended to decline in all treatments, but more in MDI and SDI than in C. In the 3<sup>rd</sup> week, before irrigation  $\Psi_l$  was -0.87 MPa in C vines, but was <-1.0 MPa in MDI and SDI; after irrigation  $\Psi_l$  recovered to approximately -0.3 MPa in all vines. As for the 5<sup>th</sup> week, before irrigation  $\Psi_l$  was relatively stable in C vines, but declined significantly ( $P < 0.01$ ) in MDI and SDI vines to about -1.13 MPa. After irrigation,  $\Psi_l$  recovered to approximately -0.4 MPa in C and MDI, but to -0.51 MPa for SDI. MATTHEWS *et al.* (1987) attributed the decline in the vine water status throughout the season despite high soil water contents to increasing transpiration rates exceeding the capacity of the root system to supply water to the leaves. They also reported that withholding water after veraison resulted in a midday  $\Psi_l$  at harvest of 0.35 MPa lower than control.

**Leaf wilting:** By the end of the experiment, as water deficit stress progressed, several basal mature fruit-zone-leaves in the severely stressed vines (SDI) were wilted or necrotic, while in MDI and C vines no symptoms of injury were observed.

**Ripening and fruit quality:** From Tab. 1 it can be seen that in the 3<sup>rd</sup> week of experiment, a significant loss of firmness occurred before irrigation ( $P < 0.05$ ) in SDI-berries compared to MDI- and C-berries, while after irrigation no significant differences were observed among treatments. Fruit continued to soften slowly till the 5<sup>th</sup> week to approximately 4 N for SDI before re-watering; this value was significantly lower ( $P < 0.05$ ) than for MDI- and C-berries. The significant differences among treatments in the 5<sup>th</sup> week did not change after re-watering. At harvest, SDI-berries were still significantly softer than C-berries, whereas MDI-berries did not differ significantly from the other treatments ( $P < 0.05$ ). Decreased firmness of SDI-berries remarkably increased after re-watering in the 3<sup>rd</sup> week, and thus differ-

Table 1

Leaf water potential and berry firmness of Muscat of Alexandria grapes subjected to post-veraison regulated deficit irrigation

Treatment <sup>x</sup>	Onset of RDI 1 <sup>st</sup> week	3 <sup>rd</sup> week		5 <sup>th</sup> week		Harvest 6 <sup>th</sup> week
	After irrigation	Before irrigation	After irrigation	Before irrigation	After irrigation	Before irrigation
	Leaf water potential $\Psi_1$ (MPa)					
C	-0.44±0.07a <sup>y,z</sup>	-0.87±0.08a	-0.33±0.15a	-0.68±0.21B	-0.40±0.06a	-
MDI	-0.44±0.07a	-1.03±0.01a	-0.34±0.14a	-1.12±0.08A	-0.39±0.14a	-
SDI	-0.44±0.07a	-1.01±0.18a	-0.28±0.07a	-1.14±0.08A	-0.51±0.25a	-
	Berry firmness (N)					
C	-	6.16±0.54b	6.11±0.36a	6.09±0.59c	5.78±0.39c	5.47±0.73b
MDI	-	5.85±0.37b	5.69±0.50a	5.04±0.21b	5.16±0.11b	4.99±0.21ab
SDI	-	4.40±0.29a	5.31±0.25a	4.04±0.37a	4.23±0.23a	4.24±0.27a

<sup>x</sup> C =Control; MDI =Moderate deficit irrigation; SDI =Severe deficit irrigation.<sup>y</sup> Means in columns followed by the same letter are not significantly different.<sup>z</sup> Uppercase letters indicate significant difference at  $P < 0.01$ ; lowercase letters indicate significant difference at  $P < 0.05$ .<sup>z</sup> Mean  $\pm$  SD for vines receiving various irrigation treatments (see Material and Methods).

ences among treatments before re-watering were no longer significant as firmness in SDI tended to catch up with those of the MDI and C treatment. The response of water deficient fruit to re-watering was less clear in the 5<sup>th</sup> week of experiment. The temporary dehydration of fruit before irrigation and the compensatory effect after irrigation may be responsible for the changes in firmness in water deficient vines before and after re-watering. Studies on changes of firmness in several grape cvs during maturation showed that deformability increased steadily throughout maturation (LEE and BOURNE 1980). Furthermore, BERNSTEIN and LUSTIG (1981) working on Dattier grapes, stated that water loss from berries to the atmosphere or to the plant results in a decrease of turgor pressure and, consequently, of firmness. This agrees with our results indicating that softening in SDI and MDI treatments was more advanced than that of C. Firmness decreased during maturation and the softening rate increased. The accelerated increase in SDI fruit softening may suggest that the physiological mechanisms of softening were altered. It appears that preharvest-RDI-grapes became physically overmature. However such grapes were still in a healthy and commercially acceptable condition; fruit texture should be carefully considered if the quality at harvest is to be preserved for a long time.

In our study, berry weight did not respond to irrigation deficits. At the onset of treatments, average berry weight was approximately 7.8 g; it increased steadily until ripening (data not shown). At harvest, berry weight was approximately 8.6 g and there was no significant difference among treatments ( $P < 0.05$ ). Previous studies with grape indicated that early season water deficits, *e.g.* after flowering and during stage II, were particularly effective in reducing berry weight rather than late season water deficits (HARDIE and

CONSIDINE 1976, MATTHEWS *et al.* 1987, REYNOLDS and Naylor 1994). The longer the period of water stress the more berry weight was reduced; this reduction is associated with an increase in the number of shriveled berries (REYNOLDS and NAYLOR 1994).

TSS increased from 14.7 % in the first week to 17.5 % in the third week after SDI and MDI treatments (Tab. 2). In the 5<sup>th</sup> week TSS were closed to 18.5 % in all treatments. At harvest TSS in SDI was 19.8 %, *i.e.* was greater than that for MDI and C treatments. The TSS differences were only significant ( $P < 0.05$ ) between SDI and C treatments. Our results are consistent with those of REYNOLDS and NAYLOR (1994) who used glasshouse-grown Pinot noir and Riesling. They also reported higher TSS at harvest as a result of post-veraison water deficit. Generally, TSS in grape berries increased rapidly after veraison and then continued to increase slowly (*e.g.* LEE and BOURNE 1980; HRAZDINA *et al.* 1984). The remarkable increase of TSS as a consequence of irrigation deficits has been reported by several authors. According to REYNOLDS and NAYLOR (1994) there are two likely causes: concentration during berry desiccation, and/or reduction in lateral shoot growth with a concomitant reallocation of carbohydrates to the fruit. On the other hand, YAKUSHIJI *et al.* (1996) suggested that sugar accumulation in Satsuma mandarin fruit was not caused by dehydration under water deficit but rather that sugars accumulated by osmoregulation in response to water deficit. Previous work has shown that, during grape berry ripening, ABA accumulates simultaneously with sugar (DURING *et al.* 1978). Moreover, recent investigations have provided strong evidence that ABA is synthesized in roots in drying soil, and that growth of plants is affected by this hormonal signal (DAVIES and ZHANG 1991). In grapes (OKAMOTO *et al.* 2004) and

peaches (KOBASHI *et al.* 1997, 2000), grown under water deficits during maturation, a remarkable increase of ABA was recorded in fruit. In another study ABA was injected into citrus fruit (KOJIMA *et al.* 1995); it stimulated the increase in glucose and fructose but not in sucrose.

The acidity decreased during ripening from 0.5 to 0.17 % at harvest for SDI-berries; *i.e.* it was slightly lower than in MDI- and C-fruits. These results are consistent with those of REYNOLDS and NAYLOR (1994). As illustrated in Tab. 2, pH of berries increased in MDI- and SDI-vines similar to C-vines.

Deficit irrigation had little effect on aroma, as illustrated in Tab. 3. Although monoterpenes were generally higher in SDI in comparison to MDI and C, most differences among treatments were statistically insignificant. Nevertheless, citronellol increased significantly in SDI-fruit as compared to C- and MDI-fruit ( $P < 0.05$ ). Several studies (*e.g.* OKAMOTO *et al.* 2001) have shown that monoterpenes, especially linalool and geraniol, are the major aromatic fraction in berries of Muscat of Alexandria. They increase during ripening to reach peak levels in overripe fruit (WILSON *et al.* 1984). Up to now, however, the effect of preharvest regulated deficit irrigation on grape aroma is still unclear and further investigations are needed.

## References

- BERNSTEIN, Z.; LUSTIG, I.; 1981: A new method of firmness measurement of grape berries and other juicy fruits. *Vitis* **20**, 15-21.
- CHRISTENSEN, P.; 1975: Response of 'Thompson Seedless' grapevines to the timing of preharvest irrigation cut-off. *Am. J. Enol. Vitic.* **26**, 188-194.
- DAVIES, W. J.; ZHANG, J.; 1991: Root signals and the regulation of growth and development of plants in drying soil. *Ann. Rev. Plant Physiol. Plant Mol. Biol.* **42**, 55-76.
- DÜRING, H.; ALLEWELDT, G.; KOCH, R.; 1978: Studies on hormonal control of ripening in berries of grape vines. *Acta Hort. (ISHS)* **80**, 397-406.
- ESTEBAN, M. A.; VILLANUEVA, M. J.; LISSARRAGUE, J. R.; 2002: Relationships between different berry components in Tempranillo (*Vitis vinifera* L) grapes from irrigated and non-irrigated vines during ripening. *J. Sci. Food Agric.* **82**, 1136-1146.
- GOODWIN, I.; 2002: Water management-a tool for vineyard managers. In: C. DUNDON, R. HAMILTON, R. JOHNSTONE, S. PARTRIDGE (Eds.): *Managing Water*, 19-23. Proc. of ASVO seminar, 12 July 2002, Mildura, Victoria.
- HARDIE, W. J.; CONSIDINE, J. A.; 1976: Response of grapes to water-deficit stress in particular stages of development. *Am. J. Enol. Vitic.* **27**, 55-61.
- HRAZDINA, G.; PARSONS, G. F.; MATTICK, L. R.; 1984: Physiological and biochemical events during development and maturation of grape berries. *Am. J. Enol. Vitic.* **35**, 220-227.

Table 2

Quality components of Muscat of Alexandria grape juice as affected by post-veraison regulated deficit irrigation

Treatment*	Onset of RDI	3 <sup>rd</sup> week	5 <sup>th</sup> week	Harvest
	1 <sup>st</sup> week			6 <sup>th</sup> week
	TSS (%)			
C	14.7±0.97a <sup>y,z</sup>	17.0±1.53a	18.6±1.42a	19.1±0.54b
MDI	14.7±0.97a	17.5±1.56a	18.9±1.75a	19.4±0.49ab
SDI	14.7±0.97a	17.5±1.46a	18.8±1.45a	19.8±0.57a
	Acidity (%)			
C	0.50±0.03a	0.25±0.02a	0.20±0.02a	0.19±0.05a
MDI	0.50±0.03a	0.22±0.01a	0.19±0.02a	0.18±0.05a
SDI	0.50±0.03a	0.25±0.01a	0.17±0.02a	0.17±0.02a
	pH			
C	3.1±0.06a	3.5±0.06a	3.8±0.12a	3.9±0.06a
MDI	3.1±0.06a	3.6±0.06a	3.8±0.15a	4.0±0.17a
SDI	3.1±0.06a	3.5±0.06a	3.8±0.10a	3.9±0.17a

\* For details see Tab. 1.

Table 3

Effect of post-veraison regulated deficit irrigation on major monoterpenes in Muscat of Alexandria grape berries at harvest (ng·100g<sup>-1</sup> FW)

Treatment*	Linalool	α-Terpineol	Citronellol	Nerol	Geraniol
C	1.40±0.62a <sup>y,z</sup>	0.07±0.06a	0.14±0.05b	0.11±0.02a	0.12±0.04a
MDI	2.47±1.49a	0.03±0.05a	0.14±0.03b	0.13±0.04a	0.17±0.05a
SDI	2.88±0.71a	0.12±0.03a	0.32±0.12a	0.22±0.09a	0.21±0.12a

\* For details see Tab. 1.

- JOHNSON, R. S.; HANDLEY, D. F.; 2000: Using water stress to control vegetative growth and productivity of temperate fruit trees. *HortScience* **35**, 1048-1050.
- KOBASHI, K.; GEMMA, H.; IWAHORI, S.; 1997: Effect of water stress on fruit quality and endogenous abscisic acid (ABA) content in peach fruit. *Environ. Control Biol.* **35**, 275-282.
- KOBASHI, K.; GEMMA, H.; IWAHORI, S.; 2000: Abscisic acid content and sugar metabolism of peaches grown under water stress. *J. Am. Soc. Hort. Sci.* **125**, 425-428.
- KOJIMA, K.; YAMADA, Y.; YAMAMOTO, M.; 1995: Effects of abscisic acid injection on sugar and organic acid contents of citrus fruit. *J. Japan. Soc. Hort. Sci.* **64**, 17-21.
- LEE, C. Y.; BOURNE, M. C.; 1980: Changes in grape firmness during maturation. *Journal of Texture Studies* **11**, 163-171.
- LOVEYS, B.; LU, P.; 2002: Plant response to water-new tools for vineyard irrigators. In: C. DUNDON; R. HAMILTON; R. JOHNSTONE; S. PARTIDGE (Eds.): *Managing Water*, 28-31. Proc. of ASVO seminar, 12 July 2002, Mildura, Victoria.
- MATTHEWS, M. A.; ANDERSON, M. M.; 1988: Fruit ripening in *Vitis vinifera* L.: Responses to seasonal water deficits. *Am. J. Enol. Vitic.* **39**, 313-320.
- MATTHEWS, M. A.; ANDERSON, M. M.; SCHULTZ, H. R.; 1987: Phenologic and growth responses to early and late season water deficits in Cabernet franc. *Vitis* **26**, 147-160.
- OKAMOTO, G.; 2001: The physiology of flowering and berry set in grapevines. *Kor. J. Hort. Sci. Technol.* **19**, 605-614.
- OKAMOTO, G.; LIAO, K.; FUSHIMI, T.; HIRANO, K.; 2001: Aromatic substances evolved from the whole berry, skin, and flesh of Muscat of Alexandria grapes. *Sci. Rep. Fac. Agric. Okayama Univ.* **90**, 21-25.
- OKAMOTO, G.; KUWAMURA, T.; HIRANO, K.; 2004: Effects of water deficit stress on leaf and berry ABA and berry ripening in Chardonnay grapevines (*Vitis vinifera*). *Vitis* **43**, 15-17.
- PRANGE, R. K.; DEELL, J. R.; 1997: Preharvest factors affecting postharvest quality of berry crops. *HortScience* **32**, 824-830.
- REYNOLDS, A. G.; NAYLOR, A. P.; 1994: 'Pinot noir' and 'Riesling' grapevines respond to water stress duration and soil water-holding capacity. *HortScience* **29**, 1505-1510.
- WILSON, B.; STRAUSS, C. R.; WILLIAMS, P. J.; 1984: Changes in free and glycosidically bound monoterpenes in developing Muscat grapes. *J. Agric. Food Chem.* **32**, 919-924.
- YAKUSHIJI, H.; NONAMI, H.; FUKUYAMA, T.; ONO, S.; TAKAGI, N.; HASHIMOTO, Y.; 1996: Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. *J. Am. Soc. Hort. Sci.* **121**, 466-472.

*Received June 15, 2004*