Long-term impact of deficit irrigation on the physical quality of berries in 'Crimson Seedless' table grapes

M.R. Conesa(1), J. M. de la Rosa (1), F. Artés-Hernández(2), I. C. Dodd(3), R. Domingo(1), A. Pérez-Pastor(1)

(1) Universidad Politécnica de Cartagena (UPCT). Departamento de Producción Vegetal, Paseo Alfonso XIII, 48, 30203. Cartagena (Murcia) E-mail: charo.conesa@upct.es
(2) UPCT. Departamento de Ingeniería de Alimentos, Paseo Alfonso XIII, 48, 30203. Cartagena (Murcia)
(3) Lancaster University, Lancaster Environment Centre, Lancaster, LA1, 4YQ, UK

Abstract

A 3-year study examined the effects of DI strategies on some physical quality attributes of 'Crimson Seedless' table grape following harvest, after 28 days of cold storage at 0ºC and after an additional shelf life period of 3 d at 15ºC. Control vines were irrigated to ensure non-limiting water conditions (110% of crop evapotranspiration, ETc), whereas RDI and PRD treatments received 35% less water during post-veraison. The null irrigation treatment (NI) only received natural precipitation (72 % less water than the Control). Total yield and physical quality at harvest were not significantly affected by RDI or PRD. Only the NI treatment, with the worst sensory scores, decreased berry size. After cold storage, increased berry shattering within the PRD treatment was correlated with the lower ABA at the time of harvest. Neither RDI nor PRD had a significant effect on berry quality at the end of cold storage and retail period. Sensory results were similar in RDI and PRD, both providing grapes more acceptable to consumers than the control. Thus, it is possible to decrease irrigation amount by ~30 % of table grapes without adversely affecting berry physical quality.

Keywords: *Vitis Vinifera L.*; abcisic acid; firmness; shattering; PRD; storage performance

1. Introduction

Crimson Seedless is a late red-purple seedless table grape widely cultivated for its high export value. The fruit is characterized by excellent eating properties, which include a crisp berry texture and sweet flavor [1]. The most important characteristic in table cultivars for them to be marketed is firmness, since this parameter provides objective information about their physical properties [2]. Moreover, pulp compactness and berry skin consistency are important for customer acceptance of the product while knowledge of any firmness indices like skin thickness might also provide fundamental information about when the grapes can be harvested [3]. From a storage point of view, berry shattering, decay and stem browning are some of the most important factors limiting their marketability [4].

The need to optimize available water resources in Mediterranean areas has led to development of new water saving irrigation techniques, which aim to increase crop water use efficiency. Among them, regulated deficit irrigation (RDI), is based on reducing irrigation during certain periods of the crop growth cycle, when the crop presents little sensitivity to water stress. Partial root-zone drying (PRD) is a technique that requires approximately half of the root system be allowed to dry, while the remainder of the root system is irrigated. The key point behind PRD is to expose part of the root system to drying soil and to let the roots at dry part produce signal of drying, meanwhile the remaining roots in wetted soil can maintain the water supply of the crop [1]. Very few studies about the effects of both techniques are available for table grapes [2]. To our awareness, no information exists concerning the effects of deficit irrigation on the physical properties of the berries of this cultivar at harvest and during storage at different temperatures. On the other hand, ABA is an essential hormone that regulates crop responses to various environmental stresses including drought, salinity and chilling [5]. In grapes, ABA has been considered to promote ripening and also regulate several processes concerning anthocyanin biosynthesis in coloured cultivars. Indeed, both techniques can alter ABA concentrations measured in berries which may alter berry quality [6]. This work aimed to evaluate (i) the effects of both RDI and PRD applied during post-veraison on berry physical quality during cold storage and after a subsequent simulated retail sale period, and (ii) the possible involvement of ABA as a component of fruit quality.

2. Material and Methods

This experiment was carried out in a commercial vineyard located in Cieza (Murcia, Spain) during 2011-2013. The plant material consisted of 10 years-old- vines of 'Crimson' x 'Paulsen 1103', spaced at 4 x 4 m. Four irrigation treatments were imposed: (i) a Control irrigated at 110% of crop evapotranspiration (ETc) to ensure non-limiting soil water conditions; (ii) RDI, irrigated as the Control except during post-veraison (50% of the Control); (iii) PRD irrigated as RDI but alternating (every 10-14 days) the dry and wet sides of the root-zone, and (iv) NI (null irrigated), which received only rain water and occasional supplementary irrigation when the stem water potential (Ψ_s) exceeded -1.2 MPa. Experimental layout and other field conditions have been described in detail in [7].

2.1 Total yield, plant water status and ABA

Total yield was determined as the average cluster weight of 72 vines for each treatment Midday stem water potential (Ψ_s) was monitored weekly with a pressure chamber (Model 3000, Soil Moisture Equipment Corp., USA) on 6 leaves per treatment according to [12]. Xylem sap was collected at predawn and measured following the protocol described by [8]

2.2 Post-harvest experiment

The cold storage and shelf life experiment lasted up to 28 days at 0ºC and 90±2% relative humidity (RH) plus an additional retail shelf-life period of 3 days at 15ºC and 60±5 %.

2.3 Measurements

The area, volume and the ratio area/volume were calculated following the models described by [9] approximating the berries to an ellipsoid. Berry firmness (B_F), pulp firmness (P_F) and skin firmness (S_F) were determined at harvest, after cold storage and at the end of the shelf life, with a texture analyzer LFRA 1500 (Brookfield, USA). Skin firmness (S_F) was calculated as the difference between B_F and P_F. In all cases 20 berries per replicate (60 berries per treatment) were used. The results were expressed in Newton (N). During cold storage and shelf-life, weight losses and decay were recorded using a scale with an accuracy of 0.01 g (Great Accuracy ST, Barcelona, Spain). Decay was mainly identified by the occurrence of *Botrytis cinerea* [10]. To quantify berry shattering, clusters were manually moved for 3 s, and detached berries were weighed and expressed as % of initial fresh weight. All measurements were expressed as % of initial fresh weight and determined in 9 clusters. Sensory evaluation was also performed by a panel consisting of different trained assessors. Visual appearance, flavour, eating texture and overall quality were determined on a 5-point hedonic scale representing acceptance, while stem browning, off-flavours and berry softness were determined by the following 5-point hedonic scale in intensity of disorder [10]. Statistical analyses were subjected to analysis of variance (ANOVA) and differences were separated by Duncan-test at P<0.05 using SPSS (v.9.1).

3. Results and Discussion

The mean annual amount (2011-2013) of water applied in the control was 685 mm year^{-1}, while the RDI, PRD and NI treatments received 35%, 37% and 72% less than the control, respectively. Mean values of Ψ_s in RDI and PRD treatments were close to the control and NI was 0.2 MPa lower. In the post-veraison period, deficit irrigation decreased Ψ_s by around 0.15 MPa in RDI and PRD, and 0.3 MPa in NI respectively, compared to control plants. The same trend was observed in Ψ_{pd} thought the experiment. Similar Ψ_s values for DI strategies were reported by [11] in 'Thomson' cv, with deficit irrigation advancing the date of bud-break compared to well-watered vines. Total yield of RDI and PRD did not differ from the control during the three years However, the yields obtained in the NI treatment were significantly lower (43% and 34%) than the control in the years 2012 and 2013, respectively (Fig. 1). As expected, only severe deficit (NI) decreased berry size. At harvest, the greatest differences among treatments were found for berry firmness (B_F) and for skin firmness (S_F), whereas pulp firmness (P_F) was practically unaffected by moderate (RDI and PRD) and severe (NI) water deficit. After cold storage, the highest mean values of B_F were observed in control berries, whereas RDI, PRD and NI values had decreased by 28%, 9% and 40%, respectively, compared to control values. Increasing temperature to 15ºC, simulating the retail sale period, reduced the differences found at harvest and at the end of cold storage (data not shown). Thus, all firmness parameters decreased at the end of the shelf period. The absolute values of weight loss agreed with the lower values of B_F in RDI treated clusters after cold storage and in control ones at the end of shelf-life, respectively. Berry shattering increased during cold storage

(Table 1) and at the end of this period, the PRD clusters showed the highest rate of berry shattering (≈5 %). High values of berry shattering reached in PRD after cold storage coincided with the lower absolute values of $[ABA]_{xylem}$ at the end of post-veraison (Fig. 2). However, at the end of shelf period, the NI treatment had the highest level of berry shattering, thus other factors such as weight loss should be considered. Decay was higher in the Control clusters during cold storage (Table 1). At the end of the shelf-life, an increased incidence of decay was observed in RDI and NI, while PRD clusters maintained the same low percentages in both storage conditions (≈ 0.20%). Fig. 3 shows the main changes in sensory attributes recorded postharvest. Visually, the grapes of PRD and RDI treatments were more attractive and those of the control and NI less so, probably as a result of the less intense red colour and smaller berry size, respectively. Stem browning increased during cold storage (Fig. 3B), and was higher in the most severe irrigation treatment (NI), probably due to the enzymatic degradation of the stem cell structure caused by the low amount of water received [12]. After cold storage, the grapes from all the irrigation treatments were above the limit of marketability, and NI recorded the lowest berry size and the most dehydrated stems. After shelf period, only RDI and PRD grapes could be regarded as marketable, although very close to the limit of marketability (Fig. 3D), an observation that was crucial for establishing the maximum shelf-life period for this experiment. Indeed, sensory analyses indicated that RDI and PRD treatments performed best

4. Conclusions

PRD and RDI applied 35% less water than Control without compromising total yield or physical berry quality. Berry volume was only affected in the severe deficit treatment (NI) and recorded the worst sensory scores post-harvest. RDI and PRD did not noticeably affect quality after cold storage while the subsequent shelf-life period tended to minimize the differences found at harvest or at the end of cold storage. PRD resulted in the highest percentage of berry shattering, which was correlated with the lower absolute values of [ABA] induced by the grower's irrigation strategy. Generally, most of the physical parameters tested were more affected by pre-harvest irrigation treatment differences than by postharvest storage conditions.

5. Acknowledgements

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Tables and Figures

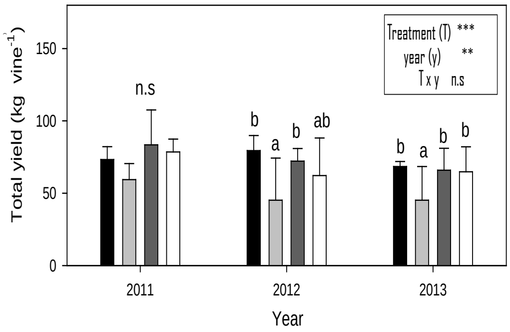

Figure 1. Mean values of the total yield (kg vine^{-1}) at harvest during the experimental period (2011-2013) in Control (▬), NI (▭),RDI (▬, and PRD (▭). Means ± SE (n=18 vines).

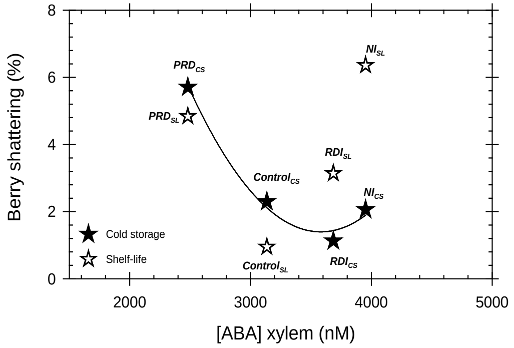

Figure 2. Relationship between xylem ABA concentration and the percentage of berry shattering postveraison at the end of cold storage (✶) and the shelf-life period (☆) in all treatments.

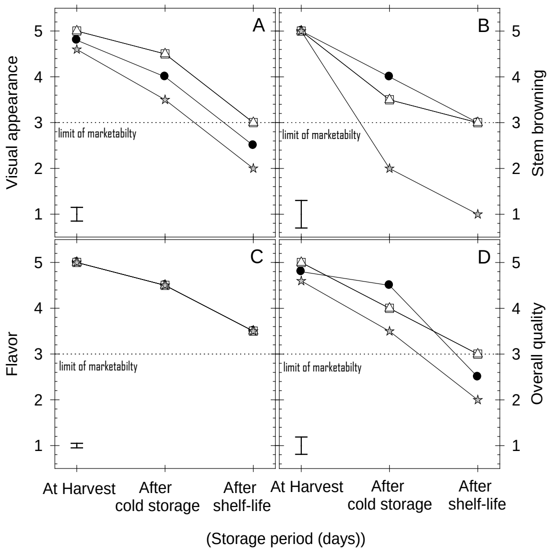

Figure 3. Sensory score for (A) berry visual appearance (B) stem browning, (C) berry flavor and (D) overall quality of clusters stored up to 28 days at 0ºC (cold storage) plus an additional shelf period of 3 days at 15ºC in control (●), NI (☆), RDI (☐)and PRD (Δ). Means ± SE (n=9).

Table 1. Mean values and standard error (n=9±SE) of berry shattering (%); decay (%) and weight loss (%) after a cold storage period of 28 d at 0ºC (CS) and after a subsequent shelf period of 3 d at 15ºC (SL). P-values comparing irrigation treatments within a storage condition are shown.

		Control		NI		RDI		PRD		p-value^z	
	Time	After CS	After SL	After CS	After SL	After CS	After SL	After CS	After SL	After CS	After SL
Berry Shattering (%)	Mean	2.30	0.95	2.06	6.36	1.13	3.14	5.71	4.84	*	*
	SE	0.96	0.55	0.77	0.65	0.45	0.45	0.71	1.43		
Decay (%)	Mean	0.46	1.08	0	1.13	0	0.65	0.21	0.24	*	n.s
	SE	0.28	1.01	0	1.12	0	0.39	0.12	0.12		
Weight loss (%)	Mean	4.44	6.34	4.47	6.18	5.77	5.10	5.29	5.14	n.s	n.s
	SE	0.28	0.58	0.37	0.62	0.53	0.31	0.61	0.36		

^{z} indicates significant effect according to a Duncan multiple range test (P<0.05).