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Preharvest applications of growth regulators and their effect on postharvest quality of table grapes during cold storage

Juan Pablo Zoffoli*, Bernardo A. Latorre, Paulina Naranjo

Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile, Casilla 306-22, Santiago, Chile

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ABSTRACT

Over 54,600 ha of table grapes (*Vitis vinifera*), mainly cvs. 'Thompson Seedless', 'Flame Seedless' and 'Redglobe', are planted in Chile. Almost the entire production is exported to the USA, Europe, Asia, or one of several Latin American countries, which typically requires 15–40 d of maritime transportation. During this period, several physical, physiological, and pathological factors cause table grape deterioration. Because berry size is the main quality factor in international markets, farmers often overuse the growth regulators, gibberellic acid (GA_3) and forchlorfenuron (CPPU), in an effort to increase berry size. We examined the effect of preharvest growth regulators on seedless ('Thompson Seedless', and 'Ruby Seedless') and seeded ('Redglobe') table grape cultivars during cold (0 °C) storage plus a shelf life period of 3 d at 20 °C. The overuse of GA_3, eight instead of two GA_3 applications on Thompson Seedless, and the use of one GA_3 application on Redglobe and 'Ruby Seedless', increased berry pedicel thickness and lowered cuticle content but induced shatter and predisposed grapes to gray mold caused by *Botrytis cinerea*. In contrast, CPPU increased berry pedicel thickness and cuticle content but did not increase shatter or gray mold incidence. Clusters that were subjected to overuse of combined GA_3 and CPPU were highly sensitive to shatter, had the thickest pedicel, and developed a high gray mold incidence during cold storage. Hairline, a fine cracking developed during cold storage, was induced on 'Thompson Seedless' and 'Ruby Seedless' by growth regulators, but no hairline occurred on 'Redglobe' table grapes. Therefore, berry quality during cold storage is greatly influenced by growth regulator management in the vineyard.

1. Introduction

Table grapes (*Vitis vinifera* L.) are the main fruit crop produced in Chile with over 54,600 ha. In 2005, over 823,000 t were produced, mainly consisting of 'Thompson Seedless', 'Flame Seedless', and 'Redglobe' table grapes, which were exported to the USA, Europe, Asia, or one of several Latin American countries. High yields of high quality grapes are the main objectives of the Chilean table grape industry.

Postharvest grape deterioration can be due to physical, physiological, or pathological factors that may occur in the vineyard (preharvest) or after harvest. For example, rachis dehydration is a physical deterioration associated with high vapor pressure deficit between the rachis and the environment during pre- and postharvest periods (Nelson, 1985). Skin browning is the main physiological problem associated with an excessively mature Princess table grape cultivar (Vial et al., 2005). Ammonium toxicity, because of excessive nitrogen fertilization, has been associated with physiological waterberry disorder on 'Thompson Seedless' berries (Christensen and Boggero, 1985). Hairline cracking and bleaching develop under high SO_2 postharvest management (Gao et al., 2003; Zoffoli et al., 2008). *Botrytis cinerea* Pers. ex Fr. can infect during berry development, remaining latent until harvest, or appearing during storage (Holz et al., 2003; Latorre, 1986). Therefore, the integration of canopy management and fungicide treatments before harvest with the use of SO_2 and cold storage (−0.5 °C) after harvest are the commercial strategies implemented to control this disease (Gubler et al., 1987; Luvisi et al., 1992; Marois et al., 1992; Esterio et al., 1996; Latorre et al., 2001).

Micropore density on the surface of the berry has been highly correlated with *B. cinerea* infection on table grapes (Blaich et al., 1984; Mlikota Gabler et al., 2003). Similarly, decay incidence increases as cuticle content decreases in the contact zone of touching berries (Marois et al., 1986; Percival et al., 1993). Preharvest grape management that enhances shading (Thomas et al., 1988; English et al., 1989) and cluster tightness (Vail and Marois, 1991) increases decay susceptibility in berries of table grapes. Therefore, grape berry resistance to decay is related to the morphological features of the berries, which are genetically determined and affected by preharvest crop management in the vineyard.

* Corresponding author. Tel.: +56 26864159; fax: +56 25534130.
E-mail address: Zoffolij@uc.cl (J.P. Zoffoli).

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Berry size is the main quality factor affecting sales of table grapes in international markets. Berry size is genetically predetermined among cultivars, but it can be considerably increased by adjusting the crop load (Kliewer and Weaver, 1971; Dokoozlian and Hirchfelt, 1985; Kington and Van Epenhuijsen, 1989; Dokoozlian et al., 1994a), by employing cluster and berry thinning (Sharples et al., 1955), trunk girdling (Dokoozlian et al., 1994b), and with the use of growth regulators. Gibberellic acid (GA_3) is applied to 'Thompson Seedless' table grapes and other stenospermocarpic grape cultivars during the fruit set stage in order to increase berry size and achieve commercially acceptable fruit quality. At least two GA_3 applications (40 $\mu L\,L^{-1}$) are commercially recommended on 'Thompson Seedless' table grapes under Chilean conditions (Perez, 1994). However, growers often overuse GA_3 in order to achieve the berry size required by international markets. These applications delay fruit ripening and increase berry shatter in 'Thompson Seedless' (Retamales and Cooper, 1993; Ben-Tal, 1990). Early work has demonstrated that rates of GA_3 application during berry set (from 39.5 to 152.2 g ha^{-1}) resulted in a 40% increase the berry weight of 'Flame Seedless' table grapes but reduced harvestable fruit by 30% due to inadequate color development (Bianchi et al., 1991). Production of 'Thompson Seedless' with over applications of GA_3 increase bud mortality the following growing season (Jawanda et al., 1974; Collins and Rawnsley, 2005). As a result, no more than three GA_3 applications to increase berry size, have been recommended under South African conditions (Mariette, 2007). Although overexposure of GA_3 affects fruit quality and productivity, there are few reports that have demonstrated detrimental effects during storage.

Alternatively, forchlorfenuron (CPPU) was introduced to increase berry size. CPPU stimulates periclinal cell division in the berry, leading to more round or oval shaped berries compared with GA_3 application alone. This compound has strong cytokinin activity, but it also delays maturity and red color development, and increases rachis size and pedicel thickness (Reynolds et al., 1992; Retamales et al., 1995). CPPU also increases berry shatter during storage (Navarro et al., 2001). In an effort to understand the significance the morphological changes produced in the berry, the purpose of this study was to examine the effect of preharvest growth regulators on decay and berry deterioration during cold storage.

2. Materials and methods

2.1. Table grapes

This study was conducted on 5-year-old table grapes, cvs. 'Redglobe' (seeded) and 'Thompson Seedless' (seedless), in a commercial vineyard located in the Central Valley near Santiago, Chile. 'Redglobe' table grapes were supported on an overhead arbor 2 m high (pergola), spaced at 3.5 m × 3.5 m (816 plant ha^{-1}) with 35 canes per vine and three buds per cane. 'Thompson Seedless' table grapes were spaced at 4 m × 4 m (625 plant ha^{-1}) with 27 canes per vine and 8–10 buds per cane. One cluster per shoot was left after cluster thinning just before flowering when inflorescences were fully developed, and a total of 30 and 40 clusters per plant were left as the final crop loads with 'Redglobe' and 'Thompson Seedless', respectively. This experiment was repeated in 'Redglobe' and 'Ruby Seedless' table grapes in Rancagua, Central Valley. The latter cultivar was included because of its high susceptibility to decay.

2.2. Growth regulator treatments

Clusters of 'Thompson Seedless' table grapes were subjected to the following growth regulator treatments: (1) clusters were sprayed until run-off twice with 40 $\mu L\,L^{-1}$ gibberellic acid (GA_3, Pro-Gibb 20% Valent Biosciences Chile S.A., Santiago, Chile) ($2xGA_3$) at fruit set and 7 d later when berries were 4 and 5 mm respectively, as it is customarily done for berry growth on 'Thompson Seedless' table grapes (Jensen et al., 1994); (2) in addition to the above $2xGA_3$ spray applications, clusters were over-treated with GA_3 by dipping them in 20 $\mu L\,L^{-1}$ GA_3 for 30 s ($8xGA_3$). These dipping treatments were applied on six occasions, on berries 5.5, 7.2, 11.5, 12.6, 13.2 and 14.1 mm in width, until 55 d after full bloom (DAFB). (3) Clusters were dipped in 6 $\mu L\,L^{-1}$ forchlorfenuron (*N*-(2-chloro-4-pyridyl)-*N*-phenylurea (CPPU) (Sitofex KT-30 EC, 0.1% BASF, Santiago, Chile) when berries were 4.7 mm in diameter and (4) clusters were treated as described for treatments 2 and 3 ($8xGA_3$ + CPPU), respectively.

Clusters of 'Redglobe' table grapes from a commercial vineyard in Santiago were subjected to the following treatments: (1) dip application in 30 $\mu L\,L^{-1}$ GA_3 ($1xGA_3$) for 30 s when berries were 15 mm in diameter; (2) a single dip in 8 $\mu L\,L^{-1}$ CPPU for 30 s when berries were 8 mm in diameter; (3) a single dip application of GA_3 and CPPU as indicated above ($1xGA_3$ + CPPU), and (4) an equal number of non-treated berries, dipped in distilled water for 30 s, were left as control. This protocol was repeated on 'Redglobe' in Rancagua. In addition, 'Ruby Seedless' table grapes were included and treated as above. GA_3 application was not included in the control treatment. Therefore, clusters received a single dip GA_3 application.

2.2.1. Effect on berry size and maturity

Berry growth development was monitored on attached berries every 10–20 d. With this purpose, three clusters per vine were selected, and berry width and berry length were determined on 10 berries per cluster starting at 29 DAFB until 123 DAFB. 'Thompson Seedless' table grapes in Santiago were harvested at 103 DAFB, when the ratio between total soluble solid (TSS) content and titratable acidity (TA) was at least 20 or otherwise the TSS ≥ 16%. In Santiago, 'Redglobe' was monitored from 22 DAFB until 135 DAFB, and grapes were harvested at 111 DAFB. Firmness was determined using Durofel with a 3-mm tip (Copatechnology, France,). Durofel values were converted to Newtons ($N = 9.8\{\exp[(\text{Durofel value} - 59.32)/14.89]\}$) (Polenta et al., 2005). Firmness, berry weight, TSS (thermo-compensated refractometer, Atago, Italy), TA (titrated with 4 g L^{-1} NaOH until pH 8.2), and the ratio between width and length were determined for a 10-berry sample in each of five replicates. These measurements were performed every 1–2 weeks from 50 or 60 DAFB for 'Thompson Seedless' or 'Redglobe', respectively. At harvest, the pedicel thickness was determined at the insertion of the berry, and the diameter of the main and lateral stems of the rachis was determined. Red color intensity of the berries was measured according to the CIE scale (Commision Internale de l'Eclairage) using a Minolta colorimeter (Minolta, CR-200 Japan) with 1: (red, H°: 71.6; *C*: 7.3; *L*: 34%), 2: (purple, H°: 194.3; *C*: 5.1; *L*: 31.9%), and 3: (dark red, H°: 328.9; *C*: 3.1; *L*: 31%). In Rancagua, the effect of growth regulators on 'Redglobe' and 'Ruby Seedless' was determined only at harvest, 121 DAFB, and 108 DAFB, respectively.

2.2.2. Cuticle content, microcracks and micropore number

To determine the possible effect of growth regulators on cuticle content, microcracks, and micropore number, fruit were assessed 48, 60, 76, 88, 103 and 123 DAFB for 'Thompson Seedless' and 49, 64, 83, 111, 135 DAFB for 'Redglobe' in Santiago. In 'Redglobe' and 'Ruby Seedless', from Rancagua, these parameters were characterized only at harvest (121 and 108 DAFB, respectively). With this objective, 70 disks (50 mm^2) of berry skin were removed from the outer layer of 35 berries in each of five replicates (two disks per berry). Disk samples were taken in the middle portion of the berry. The cuticle proper/epicuticular wax layer was then separated from