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Gibberellic Acid Bloom Sprays Reduce Fruit Set and Improve Packable Yield of 'Autumn Royal' Table Grapes

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Abstract

A three-year study (1997-1999) examined the effects of gibberellic acid (0, 5, 10, 15 or 20 g•ha^{-1} GA_3) applied at bloom (approximately 80% capfall) on the berry growth, fruit composition and productivity of 'Autumn Royal' table grapes (*Vitis vinifera* L.). The results indicate that 5 g•ha^{-1} GA_3 was the optimum treatment for this cultivar, significantly reducing berry set and cluster compactness, as well as the amount of fruit per vine with bunch rot, compared to the control. This treatment also increased berry length and reduced the number of seed traces per berry, but had no effect on berry weight or diameter. The packable yield of vines treated with 5 g•ha^{-1} GA_3 were either similar to or significantly greater than the control, while rates ≥ 10 g•ha^{-1} reduced vine productivity and fruit growth, and were therefore unacceptable.

'Autumn Royal,' a late-maturing black table grape released by the USDA Horticultural Crops Research Laboratory (selection #A97-68) in Fresno, CA in 1996, is a cross of 'Autumn Black' x USDA unreleased selection #C74-1 (10). Its parentage includes 'Blackrose,' 'Calmeria,' 'Flame Seedless' and 'Ribier.' 'Autumn Royal' produces large (6 to 9 g), ovoid-shaped berries which are dark purple to black in color and ripen in late-September to mid-October in California. The commercial appeal of this cultivar is due to its naturally large berry size and late maturity, and the fact that relatively few inputs are required for its production compared to other seedless cultivars. For example, trunk girdles and other berry sizing treatments used on 'Thompson Seedless' are not normally applied to this cultivar (5). Although 'Autumn Royal' is considered seedless, in some years prominent seed traces (remnants of seeds aborted during stenospermocarpic fruit set) may be present. While the traces are relatively small (typically ≤ 10 ug) compared to those in some stenospermocarpic cultivars (2), they are often detectable and can negatively impact consumer acceptance.

The primary problems associated with the production of 'Autumn Royal' include variable bud fruitfulness and productivity, a relatively weak rachis and excessive berry set. The latter results in tight, compact clusters prone to bunch rot during inclement weather. This is a significant concern, particularly since the cultivar is harvested in mid- to late-fall when the chances of pre-harvest rains are likely. Gibberellic acid (GA_3) is commonly applied during bloom to reduce the fruit set and cluster compactness of seedless table grapes (3, 8, 11). This application also increases berry size, and may reduce the number and size of seed traces in stenospermocarpic cultivars (3, 4). The optimum amount of GA_3 required for berry thinning varies significantly among cultivars, requiring that specific recommendations be developed as new cultivars are released (5). For example, 'Thompson Seedless' is commonly treated with GA_3 twice during bloom using 30 to 40 g•ha^{-1} per application (5). In contrast, optimum

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thinning of 'Crimson Seedless' is achieved with a single application of 2.5 g•ha^{-1} GA_3 (6). GA_3 rates below optimum result in inadequate berry thinning (3), while above optimum rates may cause excessive thinning, the formation of shot berries and reductions in budbreak and vine fruitfulness the following year (6, 12).

Our preliminary observations suggested that a single application of 5 to 15 g•ha^{-1} GA_3 during bloom was effective for reducing the fruit set and cluster compactness of 'Autumn Royal.' The purpose of this study was to determine the long-term effects of GA_3 bloom applications on the berry growth, fruit composition and productivity of this cultivar.

Materials and Methods

Vineyard and cultural practices. The experiment was initiated in 1997 in a commercial vineyard located near Fresno, CA. Own-rooted vines, planted in 1994 in a sandy loam soil, were used in the study. Vineyard rows were oriented east-west, and plant spacing was 3.6 m between rows and 2.4 m between vines within the row (plant density = 1121 vines.ha^{-1}). Vines were trained to the quadrilateral cordon system, with fruiting zones spaced 80 cm apart and located 1.2 m above the vineyard floor. The vines were trellised to the open gable system (9). Twenty eight, two-node spurs (7 per cordon arm) were retained on each vine at pruning each winter. In the first year of the trial (1997), all vines were adjusted to 24 clusters following fruit set. In 1998 and 1999, the number of clusters per vine was not adjusted so that yield data would reflect treatment effects on return fruitfulness. All clusters were tipped to a length of approximately 25 cm immediately following fruit set. The vineyard was drip irrigated, and standard disease and pest control practices for the region were followed.

Treatments and experimental design. Vines were treated with 0, 5, 10, 15 or 20 g•ha^{-1} GA_3 at approximately 80% bloom. (i.e. 80 % flowers open per vine). Application dates were 8 May, 30 May and 27 May, respectively, in 1997, 1998 and 1999. Applications were made at a spray volume of 1800 L.ha^{-1} using a hand-held spray wand. Control vines were treated with water. Each treatment was replicated 8 times using 3-vine plots arranged in a randomized complete block design. Treatments were repeated on the same vines for three consecutive years, with the middle vine in each plot used for data collection.

Fruit set, berry growth and compositional analyses. Four apical shoulders from eight randomly selected clusters (2 clusters per cordon arm; total of 32 shoulders per vine) were selected from each data vine following fruit set. The number of berries per shoulder and total shoulder length were recorded, and used to calculate the number of berries per cm shoulder length. This parameter was used to estimate berry set and cluster compactness (8). One-hundred berries were randomly selected from each data vine at harvest for growth and compositional analyses. The berries were weighed, then placed in a trough with their equators gently touching and the combined diameter recorded. Combined berry length (with stylar and receptacle ends gently touching) was recorded in a similar manner. These data were used to calculate mean berry diameter and length. In 1998 and 1999 the berries were then sliced longitudinally, and all visible seed traces were removed. The number and weight of the traces was recorded. The berries were then macerated in an electric blender, filtered and allowed to settle for 30 min. Aliquots of the clear juice were used to determine soluble solids and titratable acidity. Soluble solids were determined using a hand-held, temperature compensated refractometer (American Optical, Buffalo, NY). Titratable acidity was determined by titrating a 5 ml aliquot of juice with 0.1 N NaOH to a pH endpoint of 8.2 using a automatic titrator (Radiometer America Inc., Westlake, OH). An additional 50-berry sample was randomly collected from each plot at harvest, placed in sealed plastic bags, and stored at –15 °C until analyzed for skin anthocyanins. One 10 mm skin disk was removed from the equator of each frozen berry using a cork

Table 1. Influence of GA_3 applied at bloom on the shoulder length, berries per shoulder and berries per cm shoulder length of 'Autumn Royal' table grapes. 1997-1999.

GA_3 applied at bloom ($g \cdot ha^{-1}$)	1997			1998			1999		
	Shoulder length (cm)	Berries per shoulder	Berries per cm shoulder length	Shoulder length (cm)	Berries per shoulder	Berries per cm shoulder length	Shoulder length (cm)	Berries per shoulder	Berries per cm shoulder length
0	14.8 a[z]	29 a	2.0 a	15.2 a	24 a	1.6 a	14.8 a	28 a	1.9 a
5	15.5 a	25 b	1.6 b	15.6 ab	21 b	1.3 b	14.7 a	24 b	1.6 b
10	17.3 b	24 b	1.4 bc	16.4 b	20 b	1.2 b	15.0 a	23 b	1.5 bc
15	17.2 b	22 c	1.3 c	17.3 bc	20 b	1.1 bc	16.5 b	22 bc	1.3 c
20	17.0 b	21 c	1.2 c	18.1 c	16 c	0.8 c	16.9 b	20 c	1.2 c

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT).

borer and forceps. Care was taken to remove only berry skin and not pulp. The disks were placed in clear polystyrene tubes containing 50 ml of acidified methanol (1% HCl by volume), and extracted in darkness at 25 °C. After 48 hours the samples were removed from the darkness, mixed for 5 s using a vortex mixer, and settled for 30 min. The absorbance of a diluted 5 ml aliquot from each sample was determined at 520 nm using a spectrophotometer (Milton Roy Co., Rochester, NY). Acidified methanol served as the blank for the measurements. Anthocyanin content was expressed as mg anthocyanins/cm^{-2} berry skin, and calculated using a molecular weight of 529 and the molar absorbance value for malvidin-3-glucoside, the dominant pigment in black grape cultivars (1).

Budbreak and yield components. Prior to bloom in 1998-2000, the numbers of shoots and clusters on each data vine were recorded in order to determine potential treatment carry-over effects on vine budbreak and fruitfulness the year after GA_3 application. Budbreak was expressed as the percentage of nodes retained at pruning with shoots emerging in the spring. The experiment was harvested in the last week of October in all three years. All clusters were removed from the data vines and assigned a visual quality grade (packable or cull due to rot) based on standard commercial standards. Clusters were graded cull or unpackable due to rot if ≥ 25% of their berries were infected with rot, or if the decayed portion of the cluster could not be easily removed by trimming. The weight of packable and rotten fruit was recorded separately. No other fruit defects (i.e. poor color, poor cluster form, etc.) were present in the vineyard.

Statistics. Statistical analyses of all data were performed using analysis of variance and mean separation procedures in SAS (SAS Institute, Cary, N.C.)

Results and Discussion

GA_3 significantly decreased the number of berries per cm shoulder length compared to the untreated control, with mean

Table 2. Influence of GA_3 applied at bloom on the berry size of 'Autumn Royal' table grapes. 1997-1999.

GA_3 applied at bloom ($g \cdot ha^{-1}$)	1997			1998			1999		
	Berry weight (g)	Berry diameter (mm)	Berry length (mm)	Berry weight (g)	Berry diameter (mm)	Berry length (mm)	Berry weight (g)	Berry diameter (mm)	Berry length (mm)
0	6.5 ab[z]	19.7 a	26.1 c	6.4 a	20.0 a	25.3 b	6.6 a	20.2 a	24.9 b
5	6.8 a	20.1 a	26.8 a	6.6 a	19.3 b	25.8 a	6.4 a	19.7 b	26.5 a
10	6.2 c	19.1 b	26.4 b	5.7 b	18.8 b	25.5 ab	6.0 b	19.3 c	26.5 a
15	6.3 bc	18.8 b	26.3 bc	5.5 b	18.7 b	24.0 c	6.0 b	19.4 c	24.3 c
20	6.1 c	19.2 b	26.0 c	4.9 c	18.8 b	24.2 c	5.9 b	19.3 c	24.2 c

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT).

Table 3. Influence of GA_3 applied at bloom on the composition of 'Autumn Royal' table grapes. 1997-1999.

GA3 applied at bloom ($g \cdot ha^{-1}$)	1997			1998			1999		
	Soluble solids (°Brix)	Titratable acidity (g/L)	Anthocyanins ($mg \cdot cm^{-2}$)	Soluble solids (°Brix)	Titratable acidity (g/L)	Anthocyanins ($mg \cdot cm^{-2}$)	Soluble solids (°Brix)	Titratable acidity (g/L)	Anthocyanins ($mg \cdot cm^{-2}$)
0	18.6 bc[z]	2.7 a	0.48 c	18.1 c	3.1 a	0.55 c	19.1 d	2.8 a	0.49 c
5	18.8 bc	2.6 a	0.57 b	20.8 b	3.1 a	0.70 b	20.5 c	2.9 a	0.66 b
10	19.0 b	2.6 a	0.66 b	21.1 ab	3.1 a	0.82 a	20.8 bc	2.9 a	0.75 b
15	19.8 a	2.6 a	0.75 a	21.4 ab	3.1 a	0.82 a	21.4 b	2.9 a	0.85 a
20	19.9 a	2.5 a	0.80 a	22.3 a	3.0 a	0.88 a	22.4 a	2.8 a	0.88 a

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT).

reductions over the three years ranging between 18% (5 $g \cdot ha^{-1}$) and 42% (20 $g \cdot ha^{-1}$) (Table 1). All GA_3 treatments decreased berry number per shoulder, while rates ≥ 15 $g \cdot ha^{-1}$ significantly increased shoulder length compared to the control. Based on visual assessments, optimum fruit set for this cultivar is considered approximately 1.5 berries per cm shoulder length. Using this criteria, applications of 5 and 10 $g \cdot ha^{-1}$ GA_3 resulted in optimum levels of berry thinning.

The berry weight of control vines and vines treated with 5 $g \cdot ha^{-1}$ GA_3 were similar, while vines treated with ≥ 10 $g \cdot ha^{-1}$ GA_3 produced lower berry weights than the control (Table 2). Berry diameter was greatest for the control, and generally declined with increased GA_3 concentration. Berry length was increased when vines were treated with 5 $g \cdot ha^{-1}$ GA_3, and reduced in 1998 and 1999 when vines received ≥15 $g \cdot ha^{-1}$ GA_3. GA_3 altered natural berry shape slightly, increasing the berry length:diameter ratio. Mean berry length:diameter ratios over the three years were 1.24 for the control and 1.35 for vines treated with 5 $g \cdot ha^{-1}$ GA_3. Fruit soluble solids and skin anthocyanins improved as the amount of GA_3 applied at bloom was increased, while titratable acidity did not vary significantly among the treatments (Table 3). Changes in berry composition were at least partially related to the reductions in crop load per vine observed as GA_3 was increased. In both 1998 and 1999, GA_3 treated fruit produced significantly fewer seed traces per berry compared to the control (Table 4). In 1998, GA_3 also reduced mean seed trace weight.

All GA_3 treatments significantly reduced mean cluster weight compared to the control (Table 5), reflecting their decreased berry set and, in the case of vines treated with ≥ 10 $g \cdot ha^{-1}$ GA_3, lower berry weights. Packable yields for vines treated with 5 $g \cdot ha^{-1}$ GA_3 were similar to the control in 1997, while in 1998 and 1999 these vines produced significantly greater yields than the control. In contrast, the packable yields of vines treated with ≥ 10 $g \cdot ha^{-1}$ GA_3 were lower than the control. Averaged over the three years of the experiment, packable yields were 9.8 kg per vine for the control and 10.9 kg for vines treated with 5 $g \cdot ha^{-1}$ GA_3. The packable yields of vines treated with 10, 15 and 20 $g \cdot ha^{-1}$ GA_3 averaged 6.6, 5.1 and 4.3 kg, respectively. Due to their lower fruit set and reduced cluster compactness, GA_3 treated vines also produced significantly less rotten fruit (expressed as either the total weight of rotten fruit per vine or as a percentage of total yield) than the control.

Table 4. Influence of GA_3 applied at bloom on the number and size of seed traces in 'Autumn Royal' table grapes. 1998-1999.

GA_3 applied at bloom ($g \cdot ha^{-1}$)	1998		1999	
	Seed trace number per berry	Mean seed trace wt. (μg)	Seed trace number per berry	Mean seed trace wt. (μg)
0	2.4 a[z]	10.0 a	5.1 a	6.8 a
5	2.1 b	8.1 b	4.6 b	7.6 a
10	1.9 bc	7.2 b	4.3 bc	7.8 a
15	1.9 bc	5.3 c	4.2 c	7.8 a
20	1.6 b	4.1 c	4.0 c	6.9 a

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT).

Table 5. Influence of GA_3 applied at bloom on the mean cluster weight and yield of 'Autumn Royal' table grapes. 1997-1999.

GA_3 applied at bloom ($g \cdot ha^{-1}$)	1997			1998			1999		
	Mean cluster wt (g)	Packable yield per vine (kg)	Rotten fruit per vine (kg)	Mean cluster wt (g)	Packable yield per vine (kg)	Rotten fruit per vine (kg)	Mean cluster wt (g)	Packable yield per vine (kg)	Rotten fruit per vine (kg)
0	0.62 a[z]	12.6 a	3.0 a	0.58 a	6.6 b	3.8 a	0.68 a	10.2 b	4.4 a
5	0.58 b	11.9 a	1.5 b	0.49 b	8.0 a	1.7 b	0.58 b	12.6 a	1.3 b
10	0.42 c	9.4 b	0.4 c	0.39 c	4.6 c	0.5 c	0.40 c	5.8 c	0.6 c
15	0.40 c	9.3 b	0.2 c	0.38 c	2.3 d	0.2 d	0.38 c	3.8 d	0.2 d
20	0.38 c	8.9 b	0.2 c	0.38 d	2.2 d	0.2 d	0.35 c	2.0 e	0.3 d

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT)

Over the three years, the weight of rotten fruit per vine averaged 3.7 kg for the control and 1.5, 0.5, 0.2 and 0.2 kg for vines treated with 5, 10, 15 and 20 g. ha^{-1} GA_3, respectively. It should be noted that in 1997 all vines were adjusted to similar cluster numbers following fruit set (24 clusters per vine), thus yield differences among treatments reflect current year effects on fruit development (fruit set and berry weight). Yield differences in 1998 and 1999 reflect current year effects on fruit development, as well as carry-over effects on budbreak and vine fruitfulness (number of clusters per vine and cluster size) from applications made the previous year (Table 6). Budbreak and number of clusters per vine the year following GA_3 application were similar for the control and vines treated with 5 g GA_3. ha^{-1}, but significantly reduced when GA_3 applications were $\geq$10 $g \cdot ha^{-1}$.

The results of this study indicate that 5 $g \cdot ha^{-1}$ GA_3 applied at 80% bloom is effective for berry thinning 'Autumn Royal' table grapes. This treatment significantly reduced berry set and mean cluster weight, increased berry length and reduced the number of seed traces per berry compared to the control. Vines treated with 5 $g \cdot ha^{-1}$ GA_3 had packable yields that were either similar to or significantly greater than the control, reduced cluster compactness and less rotten fruit per vine at harvest. GA_3 rates $\geq$ 10 $g \cdot ha^{-1}$ produced unacceptable results because they significantly reduced vine productivity and in some cases decreased berry growth. GA_3 applied to grapevines in the spring and early summer can reduce budbreak, cluster number and cluster size the following year (12). However, seedless cultivars vary significantly in their rate sensitivity. Bloom applications ranging from 20 to 100 $g \cdot ha^{-1}$ GA_3 have relatively minor effects on the budbreak and return fruitfulness of 'Thompson Seedless' and 'Flame Seedless' (5, 12), while applications $\geq$ 6.25 $g \cdot ha^{-1}$ GA_3 severely reduced the budbreak and return fruitfulness of 'Crimson Seedless' (6).

Over the three years of this study, 5 $g \cdot ha^{-1}$ GA_3 applied during bloom reduced the fruit set (or number of berries per cm shoulder length) of 'Autumn Royal' ap-

Table 6. Influence of GA_3 applied at bloom on the subsequent budbreak and fruitfulness of 'Autumn Royal' table grapes the following year. 1998-2000.

GA_3 applied at bloom ($g \cdot ha^{-1}$)	1998		1999		2000	
	Total budbreak (%)	Clusters per vine	Total budbreak (%)	Clusters per vine	Total budbreak (%)	Clusters per vine
0	69 a	26 a	75 a	18 a	85 a	22 a
5	72 a	24 a	75 a	19 a	80 a	24 a
10	68 a	18 b	60 b	13 b	55 b	16 b
15	54 b	8 c	48 c	6 c	48 b	11 c
20	43 c	6 c	45 c	7 c	47 b	6 d

[z]Numbers followed by the same letter within columns are not significantly different at 5% level (DMRT).

proximately 18% compared to the untreated control. Similar efficacy has been reported for GA_3 bloom applications on other seedless cultivars. Christodoulou et al. (3) and Lynn and Jensen (8) reported that 12 to 90 $g \cdot ha^{-1}$ GA_3 applied at bloom reduced the number of berries per cm shoulder length 20 to 25% on 'Thompson Seedless' compared to the untreated control. Similar levels of berry thinning (20% to 25% reduction in the number of berries per cm shoulder length compared to the control) have been obtained on 'Flame Seedless' with 5 to 20 $g \cdot ha^{-1}$ GA_3, and on 'Crimson Seedless' with 2.5 $g \cdot ha^{-1}$ GA_3 (5, 6).

Compared to some stenospermocarpic cultivars (2, 4), seed traces in Autumn Royal berries are relatively small. Nevertheless, in some years they can be detected and detract from eating quality. In this study GA_3 applied at bloom reduced the number of seed traces per berry in both years that it was measured, although seed trace weight or size was reduced in only one year. These results are consistent with previous studies, which indicated that GA_3 applied near bloom reduced both seed trace size and number per berry in stenospermocarpic cultivars (4, 7). It should be noted that, compared to the rates reported previously for other cultivars, relatively low rates of GA_3 were effective for reducing seed trace development in 'Autumn Royal' (4, 7). This may be due to differences in initial seed trace size, as well as differences in GA_3 sensitivity among cultivars.

While GA_3 bloom sprays are a useful tool for reducing the cluster compactness and improving the packable yield of 'Autumn Royal' table grapes, the potentially low and variable productivity of this cultivar remains a concern. The highest yielding treatment (5 $g \cdot ha^{-1}$ GA_3) averaged approximately 11 kg of packable fruit per vine over the three years of the experiment. This is equivalent to a yield of 1,235 10-kg boxes per ha, which is well below the minimum production level (2,000 10-kg boxes per ha) considered necessary for economic viability in the California table grape industry. However, the vines in this study were in their early years of production (years 4-6), thus yield evaluations will continue as the vines mature to determine the potential productivity of this cultivar.

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