PLANT GROWTH REGULATOR USE FOR TABLE GRAPE PRODUCTION IN CALIFORNIA

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There are currently three plant growth regulators (PGR's) registered for use on table grapes in California - gibberellic acid (GA_3), ethephon and hydrogen cyanamide (H_2CN_2). These compounds have played a major role in the development of the modern California table grape industry. Prior to the introduction of GA_3 in the 1960's, seeded cultivars dominated production - primarily due to their naturally large berry size. GA_3 allowed seedless grapes to be produced with similar berry size and quality as seeded cultivars. Seedless cultivars now dominate table grape production in most regions of the world. Ethephon and H_2CN_2 have also made major contributions toward improving production efficiency and fruit quality. In addition, it appears likely that a new plant growth regulator, a synthetic cytokinin known as forchlorfenuron or CPPU, may be registered in California for use on table grapes in the next few years.

The purpose of this presentation is to briefly summarize the current plant growth regulator use on table grapes in California, with emphasis on recent results from our ongoing research.

Gibberellic Acid (GA_3)

The primary use of GA_3 is to reduce the fruit set and increase the berry size of seedless table grape cultivars. Treatment rates and timings for these applications are quite specific, depending upon the region, cultivar and desired effects on berry growth and fruit quality. Due to the variability among table grapes in their response and tolerance to GA_3, specific guidelines must be developed for each cultivar.

Seedless Table Grapes

<u>Cluster elongation</u>

GA_3 may be applied to seedless table grapes several weeks prior to bloom to elongate the cluster stem or rachis. Common use is to apply one or two treatments ranging between 20 and 40 g/ha. However, nearly all replicated studies show no significant benefit for this treatment. The studies reported that prebloom GA_3 applications initially accelerate cluster growth, but have no effect on either cluster length or compactness at harvest. While this treatment is used commercially, it is generally not recommended for this reason.

Berry thinning

Fred Jensen, UC Extension Viticulturist Emeritus, and Curtis Lynn, Fresno County Viticulture Farm Advisor and Tulare County Extension Director Emeritus, pioneered the use of GA_3 for berry thinning in the mid-1960's. Their guidelines on optimum application timings and rates for bloom sprays remain in use throughout California today. They found applications of 10 to 20 mg GA_3/l (ppm) applied between 30 and 80% bloom were generally most effective. These applications reduce the berry set of most cultivars 10% to 30%, allowing fruit sizing manipulations (such as the use of GA_3 and girdling to increase berry size) to be performed without resulting in excessive cluster compactness. Higher rates of GA_3 applied at bloom generally do not improve thinning, but can significantly increase the number of shot or parthenocarpic berries per cluster. Single sprays produce similar levels of thinning as multiple sprays, but multiple sprays often produce larger berries at harvest.

GA_3 application rates and timings commonly used for berry thinning seedless table grape cultivars in California are presented in Table 1. While up to three bloom applications are allowed under the current registration, it is most common to use two on both 'Thompson Seedless' and 'Flame Seedless'. Most studies indicate that single and multiple applications result in similar levels of fruit thinning. However, multiple applications may produce larger berries at harvest compared to single applications due to their effects on berry cell division and elongation. Multiple applications are typically performed near 50% and 85% bloom. Bloom stage is estimated by determining the percentage of total open (exposed) flowers per vine. In the case of both 'Crimson Seedless' and 'Ruby Seedless', a single application near full bloom is generally recommended to avoid excessive thinning and/or abnormal fruit development.

Studies have shown that the effects of GA_3 on fruit thinning are generally similar when applications are performed between 25% and 100% bloom. However, applications made during late bloom increase the length and weight of ellipsoidal or cylindrical shaped berries (such as 'Thompson Seedless') more than early bloom applications. If a single application for thinning is used on 'Thompson Seedless', it is normally performed near full bloom for this reason.

In the central and northern regions of California, as well as in many other table grape growing regions of the world, GA_3 applied at bloom often provides inadequate levels of berry thinning. This results in the need for manual berry thinning, in order to reduce cluster compactness, at a cost of up to US $1,500 per ha in California. Unfortunately, the mechanism by which GA_3 works as a fruit thinning agent is one of the least understood aspects of table grape physiology. Exploring these questions has been a major focus of our laboratory during the past decade.

Many theories have been proposed regarding the mechanisms responsible for GA_3-induced berry thinning of seedless grapes. The theories listed below are among the most common hypotheses:

- Pollenicide hypothesis. This hypothesis states that GA_3 acts as a pollenicide, interfering with pollen germination or pollen tube growth. The theory was promoted by early workers who showed that pollen viability in both seeded and seedless cultivars was reduced by GA_3. This concept spread rapidly among both scientists and growers, and was previously the most widely accepted theory for the mechanism of GA_3-induced thinning. However, work in both Chile and California over the past decade showed that pollen germination is not reduced by GA_3 concentrations normally applied for commercial berry thinning. Based on these results, the pollenicide theory should now be eliminated from consideration.

- Hormone balance hypothesis. Some have suggested that GA_3 applied at bloom alters the natural or endogenous balance of hormones in the berry, causing flower or fruit abscission to occur. The theory suggests that relative hormone concentrations, for example GA_3:auxin or GA_3:cytokinin, regulate fruit set. Proponents of the hypothesis argue that elevated GA_3 levels promote thinning, while cytokinins and GA_3 synthesis inhibitors promote fruit set. Since little is known about how the concentrations of various hormones in the berry change during set, direct evidence in support of this hypothesis is not readily available.

- Growth or nutrient competition hypothesis. The hypothesis suggests that GA_3 induces nutrient competition between flowers and shoots, or among flowers within a cluster. One version of the theory is based on the idea that GA_3 stimulates the shoot apex to grow, thereby diverting nutrients away from developing berries to the apex. Thinning is caused due to a reduction in the amount of nutrients available for berry growth. Another version of the theory suggests that GA_3 stimulates nutrient competition among berries within the cluster by stimulating rapid cell division and expansion at set. Physiologically advanced berries, or berries from strong or early blooming flowers, become strong sinks or users of nutrients. Weaker berries, or berries from late blooming flowers, are unable to effectively complete against the stronger berries for nutrients and abscise. Again, little direct information in support of this theory is available at this time.

At present, our ongoing work in this area is focusing on reproductive events prior to fruit set to determine how GA_3 affects early berry growth, as well as to determine if GA_3 induced abscission differs from natural abscission. We hope that this work will provide insight regarding the elucidation of the mechanisms responsible for GA_3-induced berry thinning. This work is important, as it is unlikely that treatment efficacy can be improved until the mechanisms responsible for GA_3-induced berry thinning are better understood.

Natural berry set is significantly reduced when warm temperatures (>33 C) persist during bloom. Warm temperatures inhibit pollen germination and pollen tube growth, and reduce ovule fertilization. Perhaps because natural berry set is reduced, we feel that GA_3 efficacy is often better when warm temperatures are experienced during the bloom period. In contrast, temperatures between 25 and 30 C are ideal for berry development and fruit set and likely result in reduced shatter. However, a recent study examining the interaction between temperature and GA_3 on berry set found that GA_3 had similar effects on fruit set across a wide range of temperatures.

If the shoot-cluster nutrient completion hypothesis were true, vigorous, rapidly growing vines should set fewer berries per cluster than vines of moderate vigor. Relatively little documentation on the relationship between vine growth and the efficacy of berry thinning sprays is available. During the past few years we have conducted a variety of trials to examine this relationship, and the results from one experiment are presented in Figure 1. The figure indicates that, while GA_3 treated shoots generally set fewer berries than untreated shoots, a poor correlation exists between shoot vigor or shoot growth rate and berry set.

Based on the shoot-cluster nutrient completion hypothesis, one might also expect clusters borne on vigorously growing, vertically erect shoots to set fewer berries than clusters on less vigorous, horizontally oriented shoots. However, we found shoot direction had no consistent effect on the berry set of Thompson Seedless (Figure 2). Shoot orientation and shoot growth rate were not closely related, nor were shoot growth rate and berry set. GA_3 increased the growth rate of shoots oriented upward and horizontally, while a positive relationship between shoot growth rate and berry set was observed. The data indicate that, while GA_3 may increase shoot growth rate, increased growth rates are not correlate with decreased berry set.

In an attempt to alter vine vigor or shoot growth rate via irrigation levels, another study examined the effects of vine water status on the efficacy of GA_3 thinning sprays. Despite slight differences in leaf water potential at bloom, irrigation amounts had little effect on the efficacy of GA_3 applied for berry thinning. Mid-day leaf water potential at 100% bloom was -0.85, -0.89, -0.90, -1.0 MPa for the 1.2, 0.8, 0.4 and 0% ET treatments, respectively. GA_3 decreased the berry set of all irrigation treatments approximately 20%, and berry set decreased only slightly as applied water increased.

Are other fruit thinning agents effective on table grapes? When applied during bloom, nitrogen-based flower desiccants (such as ammonium nitrate and Armothin, a amine-based surfactant) reduce the fruit set of many deciduous fruit crops. In some cases these compounds have showed promise as thinning agents for table grapes. Unlike GA_3 applied at bloom, these materials do not increase berry size or elongate the rachis. They must therefore be used in conjunction with GA_3 to achieve optimum efficacy for berry thinning. If not applied carefully, these compounds cause erratic berry thinning and unacceptable fruit scarring. At this point it appears doubtful that treatment combinations which provide effective and consistent thinning without berry scaring or other detrimental effects to fruit appearance or quality will be developed.

Recent work in California indicated that the non-ionic surfactant Laytron improved the efficacy of GA_3 berry thinning applications on both Thompson Seedless and Flame Seedless table grapes. In three out of four trials, the addition of 0.25% to 0.50% (v/v) Laytron to GA_3 thinning sprays decreased fruit set, or the number of berries per centimeter shoulder length, an additional 8% to 24% compared to GA_3 applied alone. Fruit growth and berry composition and were similar among the treatments at all sites, and the addition of Laytron did not increase spray-induced berry scarring. Similar results were found when Laytron was added to either the first (50% bloom) or second (80% bloom) bloom spray. While the addition of 0.25% to 0.50% Laytron significantly increased the efficacy of GA_3-induced berry thinning in this and other studies, the improvement was often insufficient to result in economic benefit for Thompson Seedless. Our earlier work indicated that berry set must be decreased an additional 20% or more, compared to GA_3 applied alone, in order to achieve a significant reduction in cluster compactness and reduce or eliminate the need for manual berry thinning. During a three-year period, this level of improvement was achieved in only 6 out of 12 trials (50%) with Thompson Seedless. In contrast, this level of improvement was achieved in 4 out of 5 trials

(80%) with Flame Seedless. At present, the addition of 0.25% to 0.50% Laytron to GA_3 bloom sprays is not allowed in California.

Lastly, a brief view of the literature indicates that the efficacy of GA_3 thinning sprays has not changed since the mid-1960's. When a series of experiments conducted on Thompson Seedless over a 30 year period were examined, comparing similar rates and application timings, the results were similar. Why do some growers feel that treatment efficacy is declining? Perhaps our standards or perceptions for adequate thinning have changed as berry size has increased. During the past two decades, improved cultural practices and greater rates of GA_3 applied for fruit sizing have nearly doubled the average weight and size of commercial Thompson Seedless table grape berries in California, from about 4 to 8 grams. As berry size increases, and the level of berry thinning remains constant, cluster compactness and our standards for successful thinning increase.

Berry sizing

GA_3 is applied to seedless table grapes near fruit set to increase berry size. Standard treatment regimes for the major cultivars grown in California are presented in Table 1. Berry growth is stimulated as a result of increased cell division (increasing the total number of cells per berry) and cell elongation (producing larger cells in the berry). These treatments increases berry size at harvest 50% or more, depending upon the cultivar, rate and the number of applications performed.

Application timing has a major impact on the efficacy of GA_3 applied at fruit set (Figure 1). For most seedless cultivars, including 'Thompson Seedless' and 'Perlette', the treatment window for the maximum sizing response is quite narrow (4 to 5 mm berry diameter), while 'Flame Seedless' has a relatively broad window for maximum response (4 to 9 mm).

While the berry size of most seedless cultivars continues to improve as the amount of GA_3 applied at fruit set is increased, the response generally saturates between 200 and 300 g GA_3 per ha. Several problems are common as the amount of GA_3 used for berry sizing is increased. First, GA_3 decreases berry attachment to the capstem or pedicel, resulting in significant berry shatter (berries separate from the cluster) during harvest and the postharvest period. Second, GA_3 delays fruit maturity and reduces berry color (ex.' Flame Seedless'), causing harvest to be extended and/or the total amount of harvestable fruit to be reduced. Third, high rates of GA_3 are generally associated with decreased vine fruitfulness the following year. Growers must therefore compromise between achieving maximum berry size and the potential detrimental effects on fruit quality and vine productivity when selecting application rates.

Previous studies indicated that GA_3 molecules enter leaves and other plant tissues more efficiently when applied in solutions of low pH (pH 3 to 4) compared to neutral (pH 6 to 7) or high pH (pH 8). This is because neutral GA_3 molecules (GA_3 has no charge if solution pH is < 4) move through the surface waxes of plant tissues and penetrate epidermal cells more readily than negatively charged GA_3 molecules. Based on this information, it seems that solution acidification would improve GA_3 uptake into berries and the efficacy GA_3 applications on table grapes. In fact, work performed in Israel showed that solution acidification improved the efficacy of relatively low concentrations of GA_3 (10 to 15 ppm) on citrus fruit and grape berries. Several years ago we examined the effects of solution pH and acidifying agents on the efficacy of GA_3 applications made at rates similar to those commonly used in California. Clusters of Thompson Seedless were dipped in unbuffered (pH 7.0) or buffered (pH 3.0) solutions containing either 20, 40, 60, or 80 ppm GA_3. Two different buffers, phosphoric acid and citrate, were used to adjust solution pH to 3.0. We found no significant difference in berry weight at harvest was found among fruits treated with buffered and unbuffered solutions at the same GA_3 concentration.

Another study performed in Israel showed that urea phosphate, a commonly used buffer in spray solutions, enhanced GA_3 uptake and response in grape berries. We also examined the effects of urea phosphate on GA_3 efficacy on Thompson Seedless. GA_3 solutions of 20, 40, 60, and 80 ppm were prepared with either 0, 500, 1000, or 2000 ppm urea phosphate. We found that the addition of urea phosphate dropped the pH of GA_3 solutions substantially. For example, the addition of 500 ppm urea phosphate to 80 ppm GA_3 dropped solution pH from 7.0 to 3.0. However, urea phosphate did not improve the response of grape berries to GA_3 sizing applications in our study. Berry weight at harvest was similar for fruit treated at a given GA_3 concentration, regardless of the urea phosphate concentration in the solution. Although previous work had found urea phosphate improved the efficacy of relatively low GA_3 concentrations (15 ppm), we concluded that it did not improve the efficacy of GA_3 concentrations commonly used for berry sizing in California.

In California, GA_3 solutions applied to clusters with commercial spray equipment typically dry within 30 minutes (day) to 90 minutes (night) after treatment. Close examination of GA_3 treated clusters indicated the presence of spray residue on the berry surface, after the berries were dry. We therefore wished to determine the extent to which GA_3 residue on the berry surface stimulated berry growth. Thompson Seedless clusters were treated with 40 ppm GA_3, then washed with water at various intervals following treatment to remove GA_3 residues from the berry surface. We found that GA_3 had no effect on berry weight when clusters were washed immediately after treatment. Berry weight was 33% and 57% greater than the untreated control, respectively, when clusters were washed 30 and 60 minutes after treatment. The berry weight of fruits washed 24 hours after treatment were 81% greater than the berry weight of untreated fruits. When GA_3 residue was retained on the berry surface 6 days following treatment, berry weight was approximately equal to the berry weight of unwashed, GA_3 treated fruits. The results indicated that GA_3 residue on the berry surface continued to stimulate berry growth up to 6 days after the initial application. These results were surprising, indicating that approximately 40% of the berry sizing response associated with GA_3 treatment was attributed to the biological activity of surface residues.

One hypothesis that resulted from the above experiment was that GA_3 residues on the surface of the berry became rehydrated by dew in the early morning, resulting in further uptake into berries. To test this hypothesis we treated two sets of Thompson Seedless clusters with 80 ppm GA_3. One set of clusters remained untouched following treatment (control), while the other half were re-wet each morning for a week following the initial GA_3 application. The clusters were re-wet by applying a fine mist of distilled water (no excess moisture or run-off). We found that the weight of berries from control and re-wet clusters was similar. This indicates that free moisture on the berry surface does not increase the biological activity (or perhaps the uptake) of GA_3 residues on the berry surface.

We also conducted experiments to determine if prolonged cluster exposure to GA_3 solutions increased berry growth. Clusters were immersed in either 20, 40, or 80 ppm GA_3 for 1 minute, or 1, 2, or 4 hours. We found a significant increase in berry weight at harvest when cluster exposure to 20 ppm GA_3 was increased from 1 minute to 1 hour. However, longer exposures to 20 ppm GA_3 yielded no additional increase in berry weight. Berry weight at harvest was similar among fruits immersed in 40 ppm GA_3, regardless of incubation period. Similar results were found for fruits immersed in 80 ppm GA_3. We concluded that berry growth was not greatly stimulated when clusters were incubated for prolonged periods in GA_3 solutions.

California table grape growers commonly attribute the decline in vine fruitfulness over time, particularly in Thompson Seedless, to continued or long-term GA_3 use. GA_3 applied for berry sizing is believed responsible for reducing vine fruitfulness, primarily because of the high rates applied for this purpose. However, previous studies indicate that the effects of GA_3 applied at fruit set on bud fruitfulness are variable and highly dependent upon both cultivar and season. We recently examined the relationship between GA_3 application timing and bud fruitfulness more closely, particularly since the amounts of GA_3 used for both berry thinning and sizing have increased significantly during the past 10 to 15 years. We found that stretch applications were significantly more detrimental to the fruitfulness of Thompson Seedless and Flame Seedless compared to bloom or berry set applications. Compared to the untreated control, stretch applications reduced bud viability, the number of viable buds with clusters, budbreak and shoot and cluster numbers per vine in all three years of the study. Berry set applications significantly reduced the size or dry weight of Thompson Seedless clusters, while all GA_3 applications reduced the size of Flame Seedless clusters. However, when Thompson Seedless canes were exposed to full sunlight, even high rates of GA_3 had no significant effect on bud fruitfulness or cluster size the following year.

Seeded Table Grapes

The use of GA_3 on seeded table grapes is limited, primarily due to its phyotototoxic effects on vine growth and productivity. It is generally accepted that seeded grapes are more sensitive to GA_3 applications than seedless grapes because their natural or endogenous gibberellic acid levels are greater. This may also explain why GA_3 is much less effective for increasing the berry size of seeded grapes compared to seedless grapes, particularly since seeds provide a source of GA_3 for the berry. Most seeded grapes are quite sensitive to foliar applied GA_3, and irregular leaf and shoot growth characteristics are commonly observed even at low rates. Foliar applications performed in the spring result in severe reductions in bud fruitfulness the following year, and may also cause bud death. GA_3 applied prior to or during bloom causes abnormal cluster stem and berry development, and leads to the formation of shot berries. Shot berries are small, underdeveloped berries without seeds that must be removed prior to packing.

GA_3 is commonly used to increase the berry size of 'Redglobe' and other seeded cultivars in California. This application is particularly effective on berries that contain only one or two seeds, although most 'Redglobe' berries contain three or four seeds. Due to the phytotoxicity problems associated with foliar applications, only the clusters are treated. This is done by manually immersing each cluster, or by spraying individual clusters using hand-held spray wands and foliage shields that prevent the solution from reaching developing buds. These applications are allowed under a Special Local Needs Permit in several counties in the San Joaquin Valley. These treatments are typically performed two weeks following berry set at rates between 40 and 50 mg GA_3/L. These treatments typically increase the average diameter and weight of 'Redglobe' berries 5 to 10% compared to untreated berries.

GA_3 is also applied to the seeded cultivar 'Emperor' approximately two weeks after fruit set to reduce berry shrivel, a physiological disorder which causes the cluster stem to dry and the berries to soften and often raisin prior to harvest. This application also increases berry size. In this case the entire vine is treated, approximately two weeks following fruit set, at rates up to 40 grams GA_3 per ha.

Ethephon (2-chloroethylphosphonic acid)

Ethephon (2-chloroethylphosphonic acid; trade name = Ethrel) enhances pigment (anthocyanin) or color accumulation in the skin of grape berries. While this effect is most visible in red cultivars, the color of black cultivars is also improved. In many cases ethephon is applied to advance the date of harvest, particularly for early-ripening cultivars such as Flame Seedless. In other cases it is applied to improve production efficiency by increasing the amount of fruit that can be harvested in the first picking, and/or reduce the total number of pickings necessary. The application of ethephon partially overcomes the effects of berry sizing manipulations, such as GA_3 and trunk girdles applied at fruit set, which are generally detrimental to fruit color. The specific mechanisms involved with ethephon induced color and ripening enhancement in grape, a non-climacteric fruit, are unknown but believed related to the compound's ethylene evolving properties.

For best results on early or mid-season ripening cultivars, such as 'Flame Seedless', ethephon should be applied shortly after berry softening or the initiation of fruit ripening. This is defined as the moment when 5 to 10% of the berries appear colored. In early-ripening districts, such as the Coachella Valley, trunk girdles are often applied at berry softening in conjunction with ethephon to further hasten fruit coloration and maturation. Ethephon may be applied to late ripening cultivars, such as 'Crimson Seedless' or 'Christmas Rose', immediately after berry softening as described above (5% to 20% of the berries showing color). If late harvest or delayed fruit coloration is desired, ethephon may be applied to these cultivars as late as 4 to 6 weeks prior to anticipated harvest date. The application rate on table grapes in California is 500 to 1000 mL of formulated product (21.7% a.i.) per ha.

Ethephon reduces berry firmness, particularly when it is applied near fruit softening. This reduction is rate dependent and most noticeable on cultivars in which natural berry firmness is low, such as 'Ruby Seedless' or 'Redglobe'. Fruit soluble solids are typically not affected or increased only slightly, while acidity is usually reduced.

Hydrogen Cyanamide (H_2CN_2)

The commercial use of hydrogen cyanamide (H_2CN_2; trade name = Dormex) in California is generally limited to early season table grapes grown in the Coachella Valley of Riverside County. Grapevines grown in this region receive inadequate winter chilling for optimum budbreak in the spring. This causes budbreak to be delayed and erratic, as well as shoot and cluster numbers per vine to be reduced. When treated with H_2CN_2 after pruning, vines overcome the effects of inadequate winter chilling. Total budbreak is increased and growth uniformity improved. Depending upon the date of pruning and H_2CN_2 application, the budbreak and harvest are significantly advanced. For best results winter pruning should be delayed as long as possible in order to maximize chilling exposure. However, in many cases vines must be pruned and treated with H_2CN_2 in early winter in order initiate budbreak and advance harvest date into the desired market window. Depending upon temperatures following application, budbreak typically occurs 20 to 30 days after H_2CN_2 treatment. Harvest date may be advanced by two to three weeks or more compared to untreated vines, depending upon temperatures during the growing season.

In the Coachella Valley vines are usually treated with a 2% (v/v) solution of active ingredient (4% Dormex) within 72 hours after pruning. Safety precautions must be followed carefully. H_2CN_2 is a restricted use material and requires a closed system for mixing. Care should be taken to avoid spray drift from reaching surrounding crops. H_2CN_2 drift causes significant defoliation and potential crop losses to lemons.

This compound is also registered for use on table grapes in the southern and central portions of the San Joaquin Valley. However, because the region receives ample winter chilling (600 hours or more < 7 C) for normal budbreak, there is no economic benefit for its use. Erratic or incomplete budbreak on grapevines in the San Joaquin Valley is not believed to be due to inadequate winter chilling. While vines treated with H_2CN_2 initiate growth sooner than untreated vines, studies indicate that the application does not advance fruit maturity. This is due to the lower rate of degree accumulation in the early spring in this region compared to the Coachella Valley.

We examined the interaction between chilling accumulation (0, 50, 100, 200, 400, and 800 hours at 3 C) and hydrogen cyanamide (H_2CN_2) concentration (0, 1.25% and 2.50% v/v) on the budbreak of dormant grapevine cuttings in controlled studies over a two-year period. Cuttings used in the study were collected prior to onset of temperatures $\leq$ 12°C from a commercial Perlette table grape vineyard in the Coachella Valley. After receiving the appropriate treatment, the cuttings were placed in distilled water and allowed to grow under continuous light at 22° C. Budbreak was most rapid for cuttings which received 800 hours of chilling, and poorest for cuttings which received no chilling. The budbreak of cuttings receiving 50 to 200 hours of chilling was similar, and lagged behind that of cuttings exposed to either 400 or 800 hours of chilling. Total budbreak after 60 days was 95, 83, 55, 46, 47, and 35 percent, respectively, for cuttings exposed to 800, 400, 200, 100, 50 and 0 chilling hours. Hydrogen cyanamide hastened and increased the budbreak of all chilling treatments, and generally reduced differences in budbreak due to chilling accumulation. With respect to chilling treatment, little difference was observed in the budbreak of cuttings treated with 1.25% or 2.50% H_2CN_2. The number of days required to reach 50% budbreak declined linearly as chilling accumulation increased from 0 to 400 hours, while the rate of budbreak advanced only slightly when chilling accumulation increased from 400 to 800 hours. The number of days required for 50% budbreak was similar for all chilling treatments when cuttings were treated with either 1.25% or 2.50% H_2CN_2.

We have also examined the efficacy of alliterative dormancy treatments in the Coachella Valley. A series of field experiments conducted over a five-year period indicated that surfactants may significantly reduce the concentration of Dormex required for optimum budbreak. Compared to the industry standard treatment in California, 4% Dormex, budbreak was improved when 1% Dormex was added to 3 or 4% surfactant, or when 2% Dormex was applied with 2 or 3% surfactant. Several non-ionic and paraffin based surfactants, including Agridex, Armobreak and Activator 90, were equally effective in improving the efficacy of Dormex applications. We have also examined the effects of other alternative chemical treatments, such as fertilizers and nitrogen-based chemicals, on budbreak. The compounds we tested generally showed reduced efficacy compared to Dormex, while their performance is highly sensitive to vine chilling status at the time of treatment. For example, in years with high levels of chilling (> 200 hrs at 7 C), 35% CAN-17 (calcium ammonium nitrate - a common N fertilizer used in California) + 2% surfactant provided similarly budbreak as 4% Dormex. In low chill years (< 100 hrs at 7 C), 35% CAN-17 + 2% surfactant were ineffective compared to 4% Dormex. The results with fertilizers and other nitrogen-based chemicals suggest that, in order to better match chemical treatments with specific environmental conditions, vine chilling status must be carefully considered.

CPPU (Forchlorfenuron)

CPPU (forchlorfenuron or N-(2-chloro-4-pyridyl)-N'-phenylurea) is a synthetic cytokinin which has significant physiological activity on many fruits, including grapes. The compound was originally formulated in the mid-1980's, and has been tested and registered for use on a variety of fruit crops throughout the world during the past two decades. In the early to mid 1990's, CPPU was registered for use on table grapes in Chile, Mexico, South Africa and Italy. In 1998, Abbott Laboratories (now Valent BioSciences) purchased the US marketing and distribution rights for this compound. EPA registration of CPPU for table grapes in California is currently pending, with approval expected in 2001 or 2002.

The primary physiological effects of CPPU on grapevines involve the regulation of fruit set, berry growth and development. When applied immediately prior to anthesis or bloom, 10 to 20 g/ha CPPU typically increases the fruit set of both seedless and seeded grape cultivars. When applied shortly after fruit set, 5 to 40 g/ha CPPU stimulates both cell division and cell elongation, resulting in significant increases in berry size. CPPU applied at fruit set also delays fruit maturation, slowing the accumulation of sugar and color, as well as the respiration of acids. High rates ($\geq$20 g/ha) applied at fruit set may permanently retard color development, particularly on sensitive cultivars such as Flame Seedless and Redglobe, and have also been reported to alter berry flavor and texture. CPPU does not reduce the fruitfulness of either seedless or seeded table grape cultivars the year following its application.

Due to its high physiological activity, the amount of CPPU required for enlarging the berries of seedless table grapes is much lower compared to GA_3. Our previous work showed that a single application of CPPU (25 grams per ha) provided similar efficacy for increasing the berry size of Flame Seedless as 2, 100 g per ha GA_3 applications. Previous studies have also reported that combined applications of CPPU and GA_3 have synergistic effects on berry growth. For example, our recent work showed a 16% increase in berry weight in Thompson Seedless when GA_3 and CPPU were combined, compared to either material applied alone.

In addition to potential benefits related to its fruit sizing effects, the ability of CPPU to delay fruit maturity may be promising to growers in late districts. In California, CPPU delayed the harvest of Thompson Seedless approximately one week or more when applied at either berry set or during the initial stages of berry softening. However, fruit maturation was most delayed when CPPU was applied in combination with GA_3 at fruit set. These results indicated that the addition of CPPU can delay the harvest of Thompson Seedless table grapes two weeks or more, depending upon rate. While CPPU increases cluster stem or rachis size and dry weight, and in some cases increases the force required to remove berry from the capstem, studies generally show that it has little effect on postharvest water loss or quality. In many cases CPPU may also alter fruit quality or flavor. Trained sensory panels, comparing treated and untreated Thompson Seedless berries at similar soluble solids and titratable acidity levels, indicated that CPPU treated fruit tasted "green or less mature" compared to untreated (GA_3 only) fruit. Panelists also noted that CPPU treated fruit was "more firm and less juicy" compared to untreated fruit. Consumer acceptance of CPPU treated fruit remains a concern, particularly when high rates are used.

Previous work with CPPU has focused on traditional seedless table grape cultivars, and treatment responses for both Thompson Seedless and Flame Seedless are well described in the literature. These studies indicate that CPPU should be used in combination with GA_3 in order to achieve synergistic effects on berry growth and fruit maturation. When used in conjunction with GA_3, optimum rates for CPPU on Thompson Seedless and Flame Seedless range between 10 and 30 g/ha and 5 and 20 g/ha, respectively. Lower rates are generally suggested for Flame Seedless and other red cultivars due to potential detrimental effects on color development. In general, little response is seen if < 4 g/ha is applied at fruit set. Rates between 4 and 12 g/ha increase berry and capstem size, and may reduce color on red cultivars, but generally do not have a great impact on ripening. In contrast, in addition to increasing berry and stem size, rates > 12 g/ha retard ripening and greatly inhibit color accumulation. Because CPPU increases fruit set, it is generally applied in combination with the second GA_3 sizing application or well after the completion of shatter.

As the registration of this compound nears in California, further work is needed to examine treatment timing x rate interactions for other prominent table grape cultivars. A major objective of our current work is to evaluate the effects of CPPU berry sizing treatments on seeded cultivars (ex. Redglobe), or GA_3 sensitive seedless cultivars (ex. Crimson Seedless, Melissa), where whole-vine sprays of GA_3 at fruit set may are generally detrimental to either fruit quality or vine fruitfulness. For example, for Redglobe and other seeded cultivars, whole-vine sprays of CPPU may be an effective alternative to treating individual clusters with GA_3. Due to the detrimental effects of this compound on fruit color, we are currently examining CPPU x ethephon rate interactions on the major red cultivars grown in California.

Thidiazuron (N-phenyl-N-1,2,3-thiadiazol-5-urea) is another synthetic cytokinin exhibiting significant biological activity on table grapes. It is currently registered in the US as a cotton defoliant, marketed under the trade name Dropp. Our preliminary work indicates that, when applied at similar rates and treatment timings, thidiazuron generally provides similar effects on berry growth and development as CPPU. Expanded registration for the use of this compound on table grapes is not being pursued at this time.

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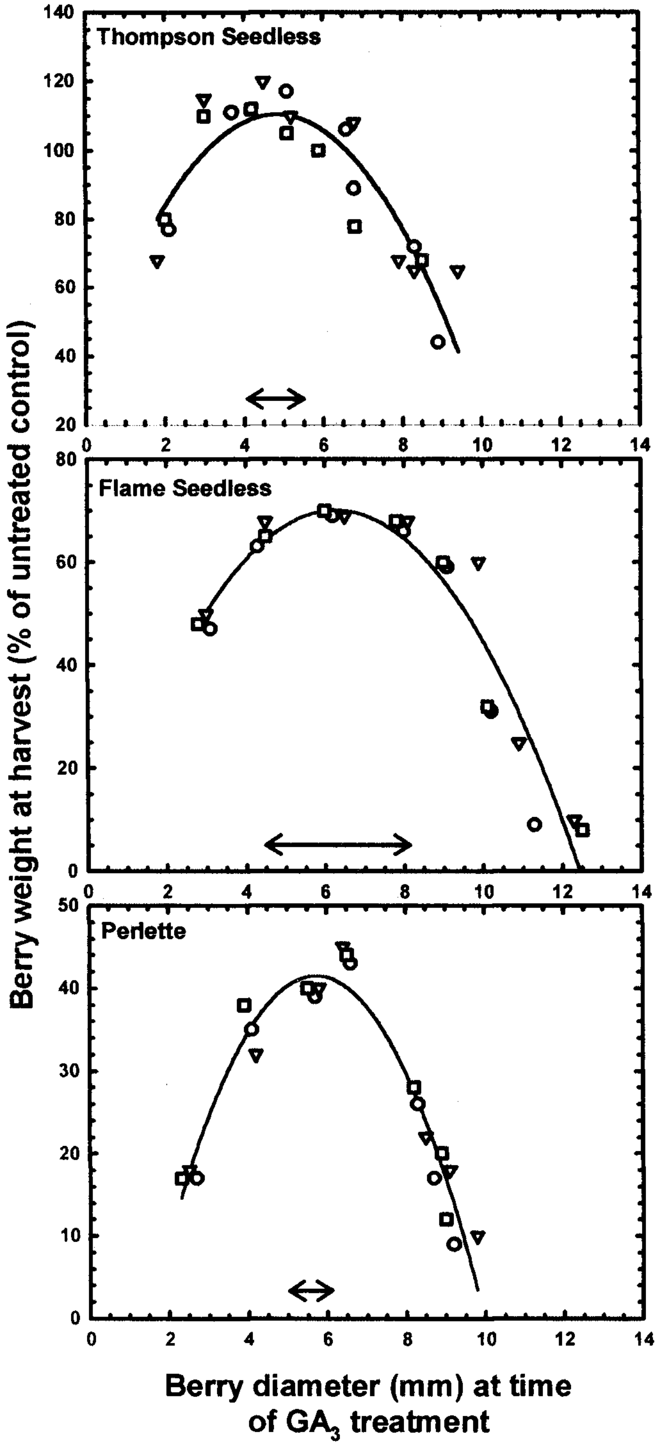

Figure Legend

Figure 1. Influence of berry diameter at the time of initial GA_3 treatment on the final berry weight of Thompson Seedless (upper graph), Flame Seedless (middle graph) and Perlette (lower graph) table grapes. Data is expressed as a percentage of the untreated control. Vines were not girdled.

Table 1. Standard GA_3 treatment regimes for some commercially important table grape varieties of California[1].

Cultivar	Berry Thinning			Berry Sizing			Comments
	Rate (g GA_3/ha)	Number of applications	Application timing (% bloom)	Rate (g GA_3/ha)	Number of applications	Timing of first application (berry diameter)	
<u>Seedless Cultivars</u>							
'Crimson Seedless'	2.5	1	90% bloom				Sizing sprays not generally recommended
'Flame Seedless'	10-20	1 or 2	50% and 85% bloom	80 to 100	2 to 3	6 to 7 mm	Higher rates at sizing delay or reduce berry color.
'Perlette'				100 to 150	2 to 3	4 to 5 mm	Manual brushing required to reduce fruit set.
'Ruby Seedless'	2.5	1	85% bloom	30- to 40	1	8-10 mm (Berry set + 2 weeks)	Higher rates at bloom may result in shot berries, reduced fruitfulness the following year.
'Thompson Seedless	30-40	2 to 3	50% and 85% bloom	100 to 150	2 to 3	4 to 5 mm	
<u>Seeded Cultivars</u>							
'Emperor'				40	1	12-15 mm (Berry set + 2 weeks)	Sizing application also reduces berry shrivel. Applied to clusters and foliage.
'Redglobe'				40 ppm	1	12-16 mm (Berry set + 2 weeks)	Sizing treatment applied directly to clusters (do not treat foliage)

[1] Total GA_3 use cannot exceed 510 grams a.i./ha per growing season (all uses combined).