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Effect of Hydrogen Cyanamide on Flower Production of 'AU Golden Sunshine' and 'AU Gulf Coast Gold' Kiwifruit

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Abstract

The *Actinidia chinensis* cultivars, 'AU Golden Sunshine' and 'AU Gulf Coast Gold' produce heavy crop loads of large, commercially acceptable kiwifruit in central Alabama. However, due to fluctuations in annual winter temperatures, these vines may not always receive sufficient amounts of chilling hours or units or portions they require to break bud and flower effectively. When these vines do not receive 700–900 chilling hours, they can exhibit nominal and intermittent bud break and flowering. This leads to insufficient cropping and negative economic impacts for growers. Experiments were conducted over 2 years on 'AU Golden Sunshine' and 'AU Gulf Coast Gold' to determine the effectiveness of the dormancy breaking chemical, hydrogen cyanamide (HC). Applications of HC were made ~28 (1 Feb.) and ~14 (15 Feb.) days before natural bud break to assess the effect on timing of application. Bud break was advanced in response to HC applications, with earlier applications causing bud break to occur earlier. In year one, vines receiving applications ~14 days before natural bud break showed increased bud break and flowering intensity as well as a reduction of lateral flower buds over the vines treated at ~28-day before natural bud break. The nontreated controls had the fewest lateral buds throughout the study. During year two, all vines were injured by a late frost event that occurred 7 Mar. 2019. Vines receiving the earliest HC applications were damaged the most, followed by the vines receiving the second HC application, which led to reduced flower production compared to nontreated vines. Control vines had the greatest number of floral shoots after the frost event because they were the last to experience bud break. Hydrogen cyanamide may be a beneficial tool to growers experiencing lower than normal chilling, however caution is advised due to the possibility of late spring frost.

Introduction

The Southeastern United States experiences inadequate chilling some years due to milder winter temperatures in the region. This can limit production of perennial fruiting plants grown there and can reduce profitability of producers. Green kiwifruit (*Actinidia deliciosa* C.F. Liang et A.R. Ferguson) was introduced to the region in the mid-1980's by a commercial nursery in South Carolina (Powell et al., 2000). Later, plantings were established in Central and Southern Alabama to be trialed for a possible commercial industry. These plantings were mostly unsuccessful due to the high chilling requirement of the green kiwifruit cultivar 'Hayward' (Powell et al., 2000). Investigations with golden kiwifruit (*A. chinensis* Planch) began in the 1990's. Two cultivars with commercial potential in the region are 'AU Golden Sunshine' and 'AU Gulf Coast Gold' (Spiers et al., 2018). The chilling requirement for 'AU Golden Sunshine' is thought to be between 700-900 h for optimal bud break and flowering, while chilling is not yet known for 'AU Gulf Coast Gold' (Dozier et al., 2011; Wall et al., 2008).

Southeast Kiwi Farming Cooperative, a 180-acre commercial orchard, was established in 2014 near Reeltown, Alabama, USA

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and began growing 'AU Golden Sunshine' and 'AU Gulf Coast Gold'. The potential to utilize hydrogen cyanamide (HC) to encourage fruit production of these new cultivars warranted research. During years with low chill hour accumulation, vines can exhibit sporadic bud break and insufficient flower production, leading to very few saleable fruit (Brundell, 1976). Hydrogen cyanamide has been extensively researched as a tool to overcome insufficient chill accumulation for kiwifruit in temperate zone regions. Not only was HC researched to overcome lack of chill, but also as a means to advance and consolidate bud break and bloom. Flower numbers were also increased when the product was used appropriately (Costa et al., 1997; Erez, 1995; Hernández et al., 2015; Inglese et al., 1998; McPherson et al., 2001; Nee, 2012; Powell et al., 2000; Shuck and Petri, 1995; Walton et al., 1991; Walton et al., 1997). Research on the effects of HC on *A. chinensis* cultivars is lacking and a better understanding of the effects of HC on these cultivars of golden kiwifruit is needed before it can be recommended to growers of the commodity.

Timing and concentration of applications play a critical role in efficacy of products containing HC. Hernández and Craig (2011) determined that applications made 45 to 25 d before natural bud break advanced bud break on *A. deliciosa* 'Hayward'. These findings agreed with research addressing effects of HC application timing on green kiwifruit varieties conducted by others (Erez, 1995; Shuck and Petri, 1995; McPherson et al., 2001; Powell et al., 2000). However, Hernández et al. (2015) showed that applications of HC at a rate of 3% on *A. chinensis* 'Gold3', applied 17 d before natural bud break, were comparable to those made 33 d before natural bud break in regards to bud break intensity. Importantly, lateral flower bud (LB) development of 'Gold3' was reduced when applications were made closer to anticipated bud break (Hernández et al., 2015). Incidence of lateral flower buds also decreased when applications of 3% HC were made on green kiwifruit, which could lead to lower pollination and thinning expenses for growers (Erez, 1995; McPherson et al., 2001). This reduction in lateral flower development is thought to be related to chilling and timing of HC application. Sites receiving less chilling will have fewer inflorescences than sites with higher chilling when HC is used (McPherson et al., 2001). Applications of HC made closer to natural bud break reduced lateral flowers due to controlled damage of lateral flowers when adequate chilling was accumulated (Hernández and Craig, 2011; Hernández and Craig, 2015). Lateral bud break was advanced when HC was applied to 'Gold3' 25 or more days before anticipated bud break (Hernández et al., 2015). Concentrations at or below 2% HC decreased the risk of phytotoxicity associated with higher concentrations and later application times (Erez, 1995; Shuck and Petri, 1995; Costa, 1997; Powell et al., 2000). When HC was used properly, flowering was increased because more buds arose before floral suppression began (Shuck and Petri, 1995). This is because effective applications of HC compressed bud break and flowering (Engin et al., 2010; Inglese et al., 1998; Hernández et al., 2015; McPherson et al., 2001; Shuck and Petri, 1995). Applications to vines ~14 d before natural bud break increased flower production over earlier applications on *A. deliciosa* (Inglese et al., 1998).

The objectives of this research were to determine the effectiveness of HC on bud break and flower development of 'AU Golden Sunshine' and 'AU Gulf Coast Gold'. Timing of application of HC and the influence of chilling were also studied.

Materials and Methods

All experiments were conducted over 2 years (2018-2019) at Southeastern Kiwi Farming Cooperative in Reeltown, Alabama. Vines chosen were 4 to 5 years of age at initiation and were managed according to the best management practices recommended for commercial production of the commodity

(Hasey, 1994). Two studies were conducted to determine the efficacy of 2% HC applied approximately 28 or 14 d before natural bud break, as compared to nonsprayed (control) vines. Each of the studies were arranged in a randomized complete block design with one vine per treatment replication.

Study one was conducted on 'AU Golden Sunshine' while study two was conducted on 'AU Gulf Coast Gold'. Both cultivars were grafted onto *A. deliciosa* 'Hayward' seedlings. During year one (2018), there were 15 blocks with three vines per block (one vine/treatment), whereas in year two (2019) there were 10 blocks. To reduce variability, four canes, two on either side of the cordon were chosen per vine for flowering and bud break data collection in all fields. These canes were in various locations along the cordon and were marked using flagging tape.

Treatments were randomly applied in each block. Three treatments were applied to better understand application timing impact on uniformity of bud burst and bloom period. Hydrogen cyanamide was applied at a concentration of 2% to the experimental vines during both years of the study. In 2018, the first treatment of HC was applied approximately 28 days before anticipated natural bud break on 1 Feb. The second treatment of HC was applied approximately 14 days before anticipated natural bud break on 15 Feb. The third treatment remained nontreated and was used as a control. A total of 1198h below 7.2 ˚C accumulated at the orchard during 2018, with 1013h on 1 Feb. and 1079h on 15 Feb. In 2019, the first treatment of HC was applied on 31 Jan. and the second treatment was applied on 14 Feb, when total accumulated chilling hours was 891 h below 7.2 ˚C. Chill hours of 749 h and 806 h had accumulated by the time of the first and second applications, respectively. Hydrogen cyanamide was applied via backpack sprayer (Solo 475-B Backpack Sprayer, Solo Inc. Newport News, VA, USA) to entire vines until wet.

Cane diameter and cane length were measured on each of the four canes used per vine. Dormant buds were counted prior to bud break as a basis to determine king flower to dormant bud (KFl/DB) ratios. This ratio can be used by growers to make crop estimations during the growing season. Bud break was assessed twice weekly and each emerging bud was counted when it reached the dome shape described by Brundell (1975a). Bud break counts ceased when buds were no longer breaking. After bud break, floral and vegetative shoots were counted to calculate a floral shoot percentage. Shoots were considered to be floral if flower buds were present on the shoot and considered vegetative if no flower buds were observed on the shoot. These counts continued until flowering occurred. Flower counts were made every 3 d and flowers were considered open when the petals permitted easy access to bees (Hernández and Craig, 2011). Flower counts began upon opening of the first bloom until all blooms had successfully opened. Vines had reached full bloom when 95% of flowers had opened.

An analysis of variance was performed for each cultivar on all response variables using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was a randomized complete block with canes as subsamples, block was a random factor and treatment was a fixed factor. We recorded number of king flowers (#KFl), number of lateral flower buds (# LB), king flower to dormant bud ratio (KFl/DB), lateral bud to king flower ratio (LB/KFl), total number of shoot, number of vegetative shoots, KFl/shoot, percent floral shoots, and number of floral shoots. To compare the treatments, we used Tukey test (α=0.05).

Results

Study 1: 'AU Golden Sunshine'. The date of natural bud break varied by year and cultivar. During the 2018 season, natural bud break occurred on 2 March for 'AU Golden Sunshine' on 'Hayward' seedling rootstocks. The 1 Feb. treatment commenced bud break 23 d after application and advanced bud break by ~7 d in comparison to natural bud

Table 1. Effects of hydrogen cyanamide (2% a.i.) applications on bud break, flowering, and lateral bud development of 'AU Golden Sunshine' *Actinidia chinensis* grafted on seedling *A. deliciosa* rootstock during 2018 and 2019.

Year	Treatment timing	Chilling (<7.2°C)	Chilling (0°C-7.2°C)	BB[z] (%)		KFl/DB[y]		KFl/Shoot[x]		LB[w] (%)		Floral Shoots[v] (%)	
2018	Feb. 1	1013	575	57.1	B[u]	1.10	B	2.0	B	16.5	A	77.5	B
	Feb. 15	1079	639	70.7	A	1.72	A	3.0	A	2.9	B	84.4	A
	Control	1198	718	56.4	B	0.67	C	1.0	C	0.5	B	62.0	C
2019	Jan. 31	749	588	41	A	0.10	B	0.24	B	0.0	A	9.7	B
	Feb. 14	806	634	41.9	A	0.16	B	0.38	B	0.0	A	16.1	B
	Control	891	691	42.8	A	0.39	A	0.90	A	0.1	A	27.6	A

[z] %BB = Percent bud break = Percentage of total dormant buds that broke dormancy
[y] KFl/DB = Number of king flowers per dormant bud
[x] KFl/Shoot = Number of king flowers per shoot
[w] LB (%) = Lateral flower bud percentage = total number of lateral flowers divided by total number of flowers present × 100
[v] % Floral Shoot = Percent floral shoots based on number of shoots with flowers over total number of shoots
[u] Least square means with the same letter are not significantly different according to the Tukey test (α=0.05).

break. The 15 Feb. treatment advanced bud break by ~5 d when compared to natural bud break, or bud break occurred 12 d after HC application. Though vines treated on 1 Feb. broke bud prior to the 15 Feb. treated plants, the 15 Feb. application resulted in a greater bud break percentage (Table 1). The 15 Feb. treatment had a higher percentage of total bud break over other treatments.

During the 2019 season, the region experienced a spring frost event that occurred on 7 March with temperatures getting as low as -3.3 ˚C. This had a negative impact on any bud that broke before 7 March 2019, causing death. Secondary buds did arise and were vegetative. Nevertheless, natural bud break occurred on 25 Feb. 2019. The first HC application (31 Jan.) advanced bud break 8 days earlier than the later application (14 Feb.) and nontreated vines. Bud break percentage was highest among the vines that received the first application of HC and though the second application did not break bud before nontreated vines, it did cause higher bud break percentage before the frost event. After the frost event, all buds that had broken were killed, however, bud break resumed with no difference in advancement or bud break percentage between treatments.

'AU Golden Sunshine' showed promise during the 2018 season when 2% HC applications were made, with heavy flower loads and ample vigor. Flowers for this cultivar first emerged during the first week of April (~60 d after application) for vines receiving the early application (1 Feb.) which was two full weeks earlier than the controls, which first flowered on 16 April. The later application (15 Feb.) of HC also advanced flowering on 'AU Golden Sunshine' over nontreated vines with the first flowers opening on 10 April, 8 d after vines receiving the early application began to bloom. The later application had the greatest number of KFl/shoot with ~3x the number of KFl/shoot on nontreated vines (Table 1). King flower to dormant bud ratios for this cultivar were highest on vines receiving the later application having a ~2.5x greater than control vines. Control vines and vines receiving 2% HC on 15 Feb. had relatively few LB compared to vines treated on 1 Feb. Vines sprayed on 15 Feb. had the highest percentage of floral shoots and control vines had the lowest percentage of floral shoots (Table 1).

During the 2019 season, 'AU Golden Sunshine' flowered at approximately the same time for all treatments. Treatments did not affect %BB, KFl/DB, KFl/shoot, or %LB however, floral shoots were greater on control vines than on vines receiving 2% HC (Table 1). Blooms began to appear on 15 April for all treatments. This was due to the late spring frost which caused shoots to die back and re-emerge as vegetative shoots. The vines most affected by the late freeze were vines receiving the early applications of 2% HC because they were far more advanced. Control vines, though also injured by the frost event, had a greater percentage of floral shoots, followed by vines receiving the 14 Feb. application (Table 1).

Study 2: 'AU Gulf Coast Gold'. Natural bud break for grafted 'AU Gulf Coast Gold' vines also occurred on 2 March during 2018. Compared to the control, the early application advanced bud break by ~7 d, whereas the later application was ~5 d advanced. Bud break occurred 23 d after application for the early treatment and 12 d after application for the later treatment. Again, both treatments were more advanced than control vines. The later application had a higher bud break percentage than the early application and the control (Table 2).

Natural bud break for 'AU Gulf Coast Gold' plants occurred on 18 Feb. during 2019. Bud break advanced by ~5 days for the early application which occurred 14 d after application. Time of bud break was similar for the later application and the control. The early application had a higher bud break percentage than the later application and control before the frost event, however, all buds were killed and secondary growth resumed, equalizing bud break percentage across treatments (Table 2).

Flowering for 'AU Gulf Coast Gold' began on 30 March (~58 d after application) for vines receiving the early application of 2% HC in 2018. This was followed by vines that received the later application, which began to bloom on 2 April. Control vines did not flower until 14 April and bloom duration was longer than the other two treatments. Vines receiving the later application had the highest KFl/DB (Table 2). Both treatments had higher KFl/DB than the control. The percentage of LB were similar to that of 'AU Golden Sunshine' (Tables 1 and 2). The early application had the highest LB percentage at 9.5% and control vines had the least LB (1.5%). More floral shoots emerged on vines receiv-

Table 2. Effects of hydrogen cyanamide (2% a.i.) applications on bud break, flowering, and lateral bud development of 'AU Gulf Coast Gold' during 2018 and 2019.

Year	Treatment timing	Chilling (<7.2˚C)	Chilling (0˚C-7.2˚C)	BB[z] (%)		KFl/DB[y]		KFl/Shoot[x]		LB[w] (%)		Floral Shoots[v] (%)	
2018	Feb. 1	1013	575	46.8	B[u]	0.88	B	1.7	B	9.5	A	81.9	B
	Feb. 15	1079	639	60	A	1.35	A	2.1	A	6.2	AB	90.8	A
	Control	1198	718	47.7	B	0.56	C	1.1	C	1.5	B	69.4	C
2019	Jan. 31	749	588	71.3	A	0.18	A	0.24	B	7.6	A	9.2	B
	Feb. 14	806	634	72.1	A	0.29	A	0.43	A	1.8	A	16.8	A
	Control	891	691	67.5	A	0.32	A	0.46	A	0.3	A	16.6	A

[z] %BB = Percent bud break = Percentage of total dormant buds that broke dormancy
[y] KFl/DB = Number of king flowers per dormant bud
[x] KFl/Shoot = Number of king flowers per shoot
[w] LB (%) = Lateral flower bud percentage = total number of lateral flowers divided by total number of flowers present × 100
[v] % Floral Shoot = Percent floral shoots based on number of shoots with flowers over total number of shoots
[u] Least square means with the same letter are not significantly different according to the Tukey test (α=0.05).

ing the later application of HC (90.8%). During 2019, the frost event limited flower production of these vines. There were no differences among treatments for 'AU Gulf Coast Gold' in 2019 (Table 2).

Discussion

Recommendations for HC use to advance bud break in selected gold kiwifruit cultivars can be risky and vary from season to season depending on a number of factors. Our results for 2018 show that applying HC ~14-16 d before natural bud break on 'AU Golden Sunshine' and 'AU Gulf Coast Gold' may provide the highest amount of bud break percentages and the least percentage of lateral flower buds which agrees with the findings of Inglese et al. (1998) and Hernández et al. (2015). More chilling could have helped accelerate bud break for the 15 Feb. (2018) application (Erez, 1995).

Bud break was advanced with all treatments of 2% HC over nontreated vines during 2018 and this supports results of many other authors (Costa et al., 1997; Erez, 1995; McPherson et al., 2001; Powell et al. 2000; Shuck and Petri, 1995). Vines receiving the early application (1 Feb. 2018) were most advanced but had lower KFl/DB and greater %LB than vines receiving the late application (15 Feb. 2018), which could increase the amount of effort required for fruit thinning. Flowering was advanced on all vines receiving HC in 2018, though the late application (15 Feb. 2018) had the highest KFl/DB and fewer LB than the early application. These findings agree with those of Hernández and Craig (2015) and Hernández et al. (2015) who found that applications made closer to natural bud break decreased the amount of LB observed on *A. chinensis* 'Gold3'.

In 2019, the most advancement in bud break resulted from the early application (31 Jan. 2019), however, this treatment also had the most damage from the late spring frost event. Shoots were mostly vegetative on vines receiving the early application (31 Jan. 2019) which is directly associated with the frost event. There were no signs of phytotoxicity caused by HC throughout the two-year study.

Flowering was significantly advanced when HC was applied during 2018 across both cultivars. Applications made ~14 d (15 Feb.) before natural bud break had higher KFl/DB and lower %LB than the other treatment. 'AU Golden Sunshine' had the highest KFl/DB when HC was applied 2 weeks before natural bud break. 'AU Gulf Coast Gold' had a lower KFl/DB than 'AU Golden Sunshine', however, 'AU Gulf Coast Gold' had the highest percentage of floral shoots. This indicates that 'AU Golden Sunshine' produced more vegetative shoots than did 'AU Gulf Coast Gold'.

Conclusion

Based on results from 2018 in the absence of frost injury, 2% HC may be used to enhance bud break and flowering of these female cultivars with optimum applications being applied ~14-16 d before anticipated bud break. Vines receiving HC applications ~2 weeks before natural bud break had greater numbers of KFl/DB, KFl/Shoot, and percentage of floral shoots when frost injury did not occur (2018). Applications made too early can lead to fewer flowers and increase the amount of unwanted LB. This could lead to higher thinning costs to growers. The risk of frost injury increases with an advancement in bud break. Though even nontreated vines experienced significant frost injury in 2019, flower production was reduced to a greater extent on vines treated with HC due to advanced bud break.

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