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Winter Shading of Blueberry Plants in the Southeastern United States

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Abstract

In central Florida, southern highbush blueberries (*Vaccinium corymbosum* hybrids) are often treated with hydrogen cyanamide (HC) to replace lack of chilling and enhance flowering and fruiting. Experiments were conducted to determine the effects of repeated applications of a processed-kaolin particle film product (PKPF) and a flat-top shade structure on blueberry plants during the fall and winter months as an alternative to spraying HC on bud viability, flowering, and fruit set. Both methods were effective in lowering the bud or air temperatures and increasing plant yield or fruit set compared with the control plants (e.g., not treated with HC) in some years. Results from this study suggest that weekly application of PKPF for eight weeks from October to December or shading the plants from November to onset of bloom in mid-January may reduce, eliminate, or enhance the use of HC in some southern highbush blueberry (SHB) cultivars. Shade structures were also useful in reducing damage to flowers and green fruit during radiation frost events in late winter and early spring.

Southern highbush blueberry acreage and production have greatly increased in Florida during the last decade. During April to early May, Florida has become the primary producer of fresh blueberries in the northern hemisphere. Research and breeding efforts in Florida include: 1) increasing early-season fruit production with the introduction of early flowering cultivars; 2) developing production practices for non-traditional blueberry soils using pine bark incorporated in beds; 3) utilizing evergreen cultural practices for growing blueberries in high tunnels and in areas with < 100 h of chill-hour accumulation; and 4) application of plant growth regulators to mitigate insufficient chilling (Williamson et al., 2001).

Like all deciduous fruit crops, blueberry plants must be exposed to a period of cool temperatures in winter before they break dormancy and grow normally in spring. In central and south Florida, blueberry acreage is increasing although chill-hour accumulation is inadequate for satisfactory growth and development in many years. Temperatures needed to satisfy the chilling requirement

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are generally considered to be between 0 and 7°C. Exposure to temperatures above the optimum chilling temperatures can result in partial chill accumulation. Loss of recently acquired chilling can occur with exposure to temperatures > 18°C, which is common throughout the winter in the region (F. Takeda, unpublished data). When blueberry plants are not fully defoliated in winter, chill hour accumulation may be reduced.

Currently, many growers in these areas apply HC to low-chill requiring cultivars such as 'Primadonna' and 'Jewel' blueberry in mid- to late-December to induce defoliation and insure adequate leaf development and rapid blooming of plants so that fruit can be harvested in late March and early April. When HC is applied, a high efficacy is not always realized because of cultivar sensitivity, poor application timing and rate, or poor weather conditions (Williamson et al., 2001). Hydrogen cyanamide (H_2CN_2) is a plant growth regulator that is classified as a restricted use pesticide and is extremely toxic to humans for a short time after application (CDC, 2005). Organic blueberry production, concern over crop loss due to HC injury, and an increasing number of small acreage farms near residential areas necessitates the development of alternative, non-chemical, or organic-certified practices to satisfy chill requirements of blueberry plants.

Cooling of plant tissues during winter is a matter of increasing interest for growing blueberries under subtropical or tropical conditions. Various methods can be used to cool plants, such as evaporative cooling, application of PKPF (Surround WP, Tessenderlo Kerley, Inc., Phoenix, AZ), or shading to decrease radiation and concomitant energy load during warm periods. A PKPF product is approved for use in certified organic production (OMRI, 2014). Repeated application of PKPF leaves a protective, powdery, white residue on leaves, fruit, and branches, which acts as a broad spectrum protectant for preventing pest and heat damage. PKPF applications in summer resulted in apple leaf temperatures as much as 7°C cooler at mid-day than those of untreated trees (Glenn et al., 2003).

Shade nets lower ground and plant temperatures as much as 2°C as compared with those in non-shaded sites (Shahak et al., 2008; Rajapakse and Shahak, 2007). Modifications in microclimate during winter could enable season extension and improve production of deciduous fruit crops in areas with high and fluctuating winter temperatures; or where insufficient chilling of deciduous fruit crops results in delayed and erratic budbreak (Darnell and Davies, 1990; Gilreath and Buchanan, 1981). Inadequate winter chilling in some blueberries leads to reduced fruit set because of poor spring floral and vegetative growth (Lyrene and Crocker, 1983).

In addition to winter chilling problems, late winter and early spring freezes occur in central Florida and are a threat to SHB blueberry production. Flowers and young fruit are highly susceptible to freeze and freeze injury after exposure to -1 or -2°C. Overhead irrigation is commonly used to reduce blueberry fruit losses to freezes in Florida. Due to expected fresh groundwater shortages in central and south Florida by 2050, there is a high probability that further restrictions on its use for agriculture and crop protection will be imposed by counties and water management districts in this area (Spencer and Altman, 2010).

In this paper, we report the results from studies conducted to determine the effects of shading SHB blueberries in winter on bud viability, fruit set, and yield. Treatments included: 1) multiple applications of PKPF from late October to late December; 2) shading of blueberry plants from November to January with or without HC application in mid-December; and 3) shading of plants during late winter and spring frost events.

Materials and Methods

Shade study. Flat-top modular shade structures (MoSS) (60 m-long x 15 m-wide x 2.4 m-tall) covering ≈ 0.10 ha were established on two commercial SHB blueberry farms in central Florida and south Georgia. At Woodbine, Georgia (lat. 31°N, long. 81.7°W), the MoSS was erected on 30 Nov. 2011 and covered three rows of 3-year-old 'Emerald', two rows of 'Sweetcrisp', and one row of 'Farthing' SHB blueberry established at ≈ 3,690 plants/ha. Rows of 'Emerald' and 'Sweetcrisp' located ≈ 20 m from the other plants served as unshaded control plots. Half of the MoSS was covered with 40% shade cloth and the other half was covered with 60% shade cloth (DeWitt Co., Sikeston, MO). The Florida site located at Homeland, FL (lat. 27.7°N, long. 81.9°W) had an uncovered control row, as well as rows covered with a 60% shade fabric on a MoSS erected on 2 Dec. 2011. At this site, the MoSS covered three rows of 'Jewel' and three rows of 'Primadonna' SHB blueberry plants.

At both locations, the MoSS consisted of a series of 5 cm-square, protruded reinforced fiberglass posts (Bedford Reinforced Plastics, Bedford, PA) spaced 6 m apart within every other 3 m-spaced row (Fig. 1). The bottom of the post was slipped over and bolted to a welded eye on the earth anchor in the ground. Six m-long (0.6 cm-diameter) steel wire rope lanyards with a swage-less eye or loop fitting at each end (McMaster-Carr, Robbinsville, NJ) were slipped onto a bolt (1.3 cm-diameter) fastened at the top of each post. All perimeter posts were then pulled outward by tensioning the cable attached to top of each perimeter post and earth anchor 0.3 m away until the posts were angled perpendicular to the ground and the cable lanyards between the posts were taut. A shade cloth panel (6 m-long x 3 m-wide) was secured to the cables on three sides by an aluminum hog ring through the grommets on the cloth. This allowed each shade panel to be deployed in winter and during periods of spring frost and then retracted once blueberry plants began to bloom.

Temperature data loggers (Watchdog A150, Spectrum Technologies, Aurora, IL) were placed 1 m above ground on a post facing north (out of direct sunlight) in open (e.g., unshaded) and shaded rows. Temperatures were recorded at 15 min intervals. Data were downloaded to a computer and a spreadsheet was created for data processing. At the central Florida site, open rows and half of the rows under the shade structure were treated

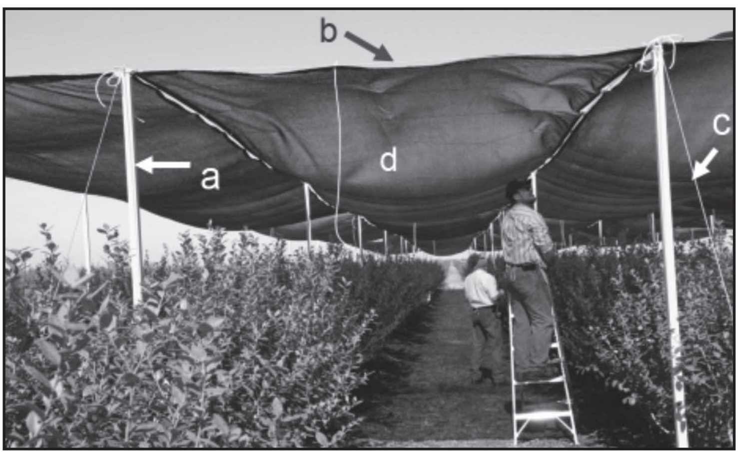

Fig. 1: Installation of a flat-top modular shade structure at a blueberry farm in Homeland, FL. Five-cm square, protruded fiberglass posts (a) were installed 6 m apart in 3 m spaced rows. Tops of these posts were connected with steel rope lanyards (b). All perimeter posts were pulled outward to be 90° upright by tensioning the cable (c) anchored 3 m away and the lanyards between the posts were taut. A shade-cloth panel (d) (6 m-long x 3 m-wide) was secured to the cables with hog rings. Note the amount of shading provided by 60% shade cloth as indicated by darkened ground under the shade structure.

with HC (Dormex, Dormex Comp., Fresno, CA) at 1% (v/v) concentration and applied with an air-blast sprayer.

Ten to 20 shoots were tagged in each of four 10-plant sections under shaded and non-shaded areas in early January and then flower buds on tagged shoots were counted. In February and early March, flowers and green fruit were counted on tagged shoots to determine fruit set. Fruit set was calculated by determining the mean number of flowers per flower bud (100 flower bud sample) for each cultivar and counting the number of flower buds per shoot. This produced a close estimate of the total number of flower buds per tagged shoot. By counting green fruit well after bloom, an estimated percent fruit set value was determined. Also, the number of leaf buds with emerging leaves was counted on 20 Feb. using 50 shoots each from HC-treated and untreated plants of 'Jewel' and 'Primadonna' blueberry to assess the effect of HC application and shading on vegetative growth.

In south Georgia, on several occasions when a frost event was predicted, the top and side panels of the shade structure were pulled to enclose the blueberry plants. Within the 2 ha blueberry planting, some sections were protected with an overhead irrigation system (R33 rotator sprinkler heads, Nelson Irrigation, Walla Walla, WA) and the remaining sections were not protected. The following day, flower and fruit samples were collected from plants in each section of the field to assess freeze damage.

Processed-kaolin particle film application. This study was performed during the 2011-2012 season at the University of Florida Gulf Coast Research and Education Center in Balm, FL (lat. 27.7°N, long. 82.4°W) with 'Jewel' SHB established in 2008 at ≈ 3,690 plants/ha in pine bark beds. Plants had been grown without HC application. Processed-kaolin particle film was applied from 15 Sept. to 15 Dec. either at one or two week intervals at 28 kg·ha^{-1} in a 935 L·ha^{-1} water volume. Fruit were harvested eight times beginning in early March. Fruit samples were weighed to determine early-season and annual yield. Data were analyzed separately for each location by ANOVA, with all percentage values transformed by arcsine square root transformation before analysis using the MIXED procedure of SAS (SAS Institute, 2010). Mean separation was performed using the DIFF option of SAS with $P \leq 0.05$.

Results and Discussion

Central Florida. Winter chilling was low in 2011-2012 with only 30 h below 7°C recorded before HC application in mid-December and 130 h by mid-January. Hydrogen cyanamide is normally applied after ≥ 50 chill-hours have accumulated or by mid-December to partially substitute for lack of winter chilling. Shading lowered the daily maximum temperatures on most days. Compared to the control (open) plots, leaf and bud temperatures were ≈ 5°C cooler under the MoSS at mid-day during sunny days (data not shown). Mean air temperature at mid-day was 1.3°C cooler under the MoSS compared to that of open plot in early and mid-December (data not shown). From October to mid-January, the MoSS decreased the hours >24°C by more than 150 h (Fig. 2). Extremely high temperatures (≥29°C) were reduced by ≈ 30 h. Temperatures between 13.1 to 26.8°C were increased by nearly 200 h by shading. Such differences in air temperatures over two to three months during winter may affect chill-hour accumulation in SHB blueberries and their growth in early spring.

Most blueberry cultivars require more chilling for vegetative than for reproductive budbreak (Williamson et al., 2002). If the reproductive requirement is met, but not the vegetative requirement, floral and fruit development may be adversely impacted because there is insufficient leaf carbohydrate content to support fruit growth. This situation may occur during mild winters and in areas with subtropical climatic conditions. A routine strategy used by conventional blueberry growers is application of hydrogen cy-

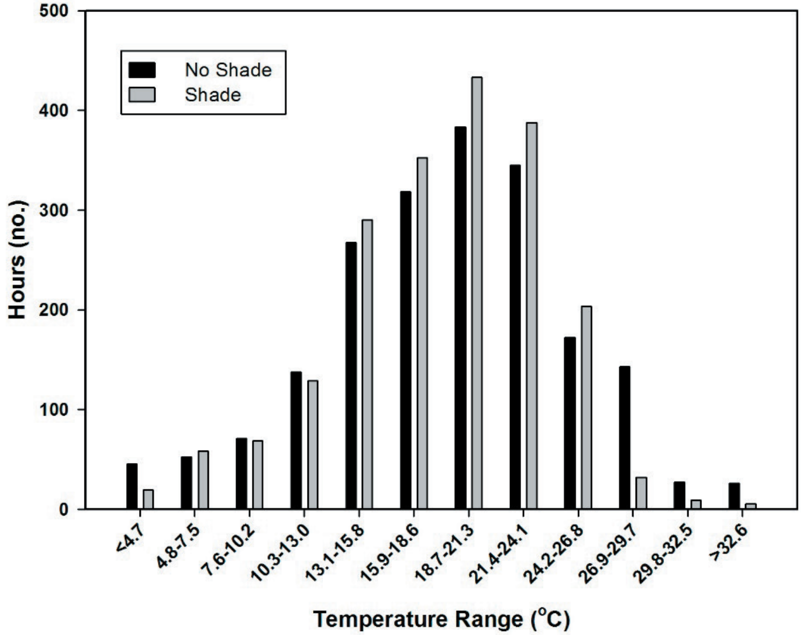

Fig. 2: Distribution of temperatures in the open and under the shade structure. Temperatures were recorded from 25 Oct. 2012 to 16 Jan. 2013 in Homeland, FL.

anamide to partially substitute for a lack of winter chilling.

Some SHB cultivars do not respond favorably to HC in years with warm winters. In January 2012 and 2013, flower buds of 'Primadonna' and 'Jewel' were examined at the onset of anthesis. Results from these years indicated that neither cultivar responded to the shading nor HC application as flower bud retention (e.g. buds/shoot) number was not enhanced (Table 1). Although 18% of flower buds on HC-treated 'Primadonna' plants in open rows were completely uninjured (no damaged flowers in the cluster) compared to 40% of flower buds on HC-treated plants under the MoSS, the difference was not significantly different. Later in spring, fruit count per flower bud indicated that shading improved fruit set in 'Primadonna' but not in 'Jewel' SHB blueberry. Fruit set count in 'Primadonna' plants that were under the MoSS was nearly doubled that of plants in the open (Table 1). HC application had no effect on fruit set in 'Jewel' blueberry in 2012 and 2013.

From October to December 2013 in the third year of this study, less than 20 chill-hours had been recorded by the time HC application was made on 'Jewel' blueberry. Data on flower count and berries per shoot or bud indicated that HC had an effect on flower retention with the fewest flowers present on plants that appeared to have received an excessive amount of HC (G. Krewer, personal observation) as indicated by the amount of defoliation and excessive bud abscission. Flower number per shoot was more numerous on plants that were sprayed with the proper amount of HC as determined by leaf retention (Krewer, personnel observation). The highest flower count was on plants that were in the open and received the standard volume of HC. By March when many green berries were about 5 mm size, it was quite noticeable that excessive HC application reduced and/or delayed foliation compared to

Table 1: The influence of shade and hydrogen cyanamide (HC) on the number of flower buds and berries per shoot for 'Primadonna' southern highbush blueberry in 2012 and for 'Jewel' SHB in 2012 and 2013 in Homeland, Florida.

	Buds/shoot (no.)			Berries/shoot (no.)		
	Primadonna	Jewel		Primadonna	Jewel	
Treatment	2012	2012	2013	2012	2012	2013
No shade, no HC	5.0	5.0	3.5	8.8 bc	9.7	12.5
No shade, with HC	5.7	5.0	3.4	6.9 c	11.5	12.3
Under shade, no HC	5.0	4.9	3.6	12.7 ab	8.2	13.5
Under shade, with HC	5.6	4.0	2.8	15.9 a	11.5	13.1

[z] Means followed by different letters are significantly different ($P \leq 0.05$).

non-sprayed plants under the MoSS. Berry number per bud for shaded plants recorded in early March was slightly greater than that for unshaded plants (Table 2).

Shading also advanced leaf emergence in 'Jewel' blueberry (data not presented). The percentage of shoots with visible leaves on 22 Jan. ranged from a low of 8% in open plots to a high of 32% under the MoSS. Leaf bud development is a problem on 'Jewel' blueberry during warm winters. The 60% shade treatment increased leaf emergence by 24% in 'Jewel' and 36% in 'Primadonna'.

During the radiation freeze that occurred on 5 Jan. 2012, temperatures under the MoSS remained higher than in the open (data not presented). On hill-top sites in central Florida, usually only a 0.4 to 1.8°C elevation in temperature is needed to protect blueberry flowers from freeze damage. Results from our study indicate that the 60% shade cloth on the MoSS may be sufficient to replace overhead irrigation for freeze protection in most years. This would constitute a major advancement in water management in an area where water is becoming limited for blueberry production. For example, the area just west of Clear Spring near Plant City, FL currently has serious problems with sinkhole formation due to over pumping of the aquifer. As a result, water management districts could limit the use of groundwater for frost protection. Also, high winds often occur at the location used for the shade study. How-

Table 2: The influence of shade and hydrogen cyanamide (HC) application on the number of berries per shoot and flower buds in 'Jewel' blueberry in an ultra-low chilling year.[z]

Treatment	No. flower buds/shoot	No. berries/shoot	No. berries/bud
No shade, no HC	5.6 b[y]	21.0 a	4.0 b
Under shade, no HC	4.5 c	21.4 a	5.0 a
Standard HC application	7.4 a	21.2 a	3.0 c
Excessive HC application	4.0 c	4.2 b	1.1 d

[z] Hydrogen cyanamide was applied in mid-December when < 20 chill-hours had accumulated. Bud and fruit counts were recorded in early March 2014.
[y] Means followed by different letters are significantly different ($P \leq 0.05$).

ever, the MoSS survived many wind storms without damage. Unlike normal rigid shading, the system flexes and wind rolls over the shade panels.

***South Georgia**.* Sufficient chilling occurred in South Georgia in October and November followed by unseasonable heat such that 25% 'Emerald' blueberry flowers had opened by early January (about one month earlier than in normal winters). On sunny days, bud temperature measured with a hand-held narrow-beam infrared thermometer (Model OS535E, Omega Engineering, Stamford, CT) was 4°C cooler under the 40% shade and 5.8°C cooler under the 60% shade (data not presented). However, there was no apparent effect of treatments on early bloom date.

A radiation freeze of -5.9°C occurred on 4 Jan. 2012. In open plots, flower buds had 76% flower damage (e.g. completely dead or some flowers dead), while flower buds on plants under the 40% and 60% shade panels had only 52 to 46% damage. We observed that frost formed on top of the shade cloth, but rarely under the shade. Before this freeze event, air temperatures at night averaged 0.7°C warmer under the 60% shade than in the open plots. Another unexpected freeze occurred on 2 Feb. Two days later, 50 flowers at stage 4, 5 or 6 (Spiers, 1978) were collected from each of the treatments. Flowers were then sorted based on live or dead (brown) ovules. Mean dead ovules for the control were 46%, 24% for the 40% shade, 16% for the 60% shade, and 40% for the overhead irrigated area. Damage was high in the irrigated portion of the field because the water was turned on when the temperature at plant height was already down to -2°C.

A windy freeze of -3.9°C occurred on 12 Feb. followed by a radiation freeze of -8.3°C the following day. By this time, 'Emerald' was at about 60% bloom. Overhead irrigation was attempted in one section of the field, but windy conditions were extreme. About 2,342,250 $L \cdot ha^{-1}$ of water were pumped during the two freeze events. Tagged lateral flowers on 'Emerald' blueberry in open plots had 1.7% fruit set while the two shade treatments had 4.5% fruit set. Estimated percent of full crop (including late blooming fall growth) was 25% for control plants, 31% for those under 40% shade, 35% under 60% shade, and 40% in irrigated section, although much of the fruit on plants that received overhead irrigation were scarred.

In early March 2014, a radiation freeze occurred at -3°C. Fruit diameter of 'Primadonna' was about 8 mm at this time. Freeze injury ratings of berries indicated that overhead irrigation was most effective in preventing freeze damage (Fig. 3). Examination of fruit showed no freeze damage on plants protected by overhead irrigation. Under the shade structure, the percentage of fruit with no damage and minor injury to ovule were 75% and 23%, respectively. More than 75% of fruit on plants in the open exhibited injury to the ovule. Fruit with damaged ovules continued to grow, but usually did not attain full size at maturity.

The only negative effect of the shade cloth treatment was an increase in *Botrytis* flower blight developing on frozen flowers in one section that was under a 60% shade after a period of foggy weather in February. Organic-approved fungicides (Regalia, Marrone Bio Innovations, Davis, CA and Serenade, AgraQuest, Inc., Davis, CA) were used on all the treatments to control *Botrytis* infection. The shade cloth was pulled back on March 1 after the danger of frost had passed. A few unexpected benefits of shading were observed. There was almost no cedar waxwing (*Bombycilla cedrorum*) bird damage on fruit inside the "pulled back" MoSS, while damage occurred on fruit on plants outside the structure despite an aggressive bird control program with noise makers and firing of a shotgun. Also, when the temperature reached 33°C, the 60% shade was closed for the benefit of the pick-your-own customers, especially the elderly and small children. The shade cloth appears to be enormously strong. During the 12 Feb. freeze, two sprinkler deflectors in the overhead irrigation section came off during

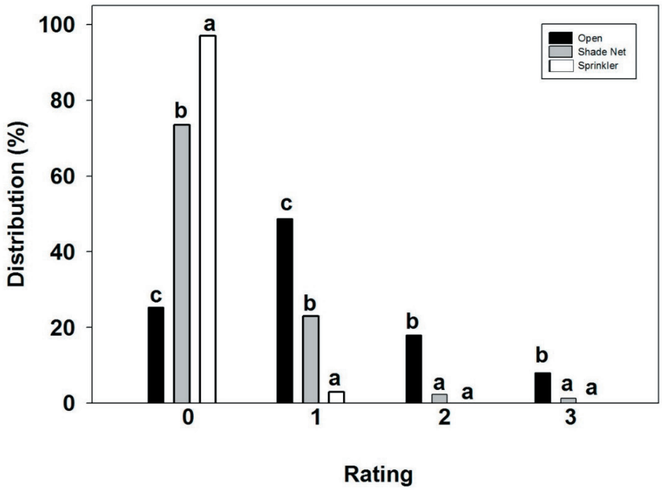

Fig. 3: Distribution of blueberry fruit samples from 'Emerald' blueberry plants in open rows, under the shade structure, and in open rows protected by a sprinkler system. The following scale was used to visually rate sliced fruit tissues for oxidative browning: 0 = no freeze injury; 1 = minor injury to ovule; 2 = >50% of ovules injured; and 3 = browning of all ovules and mesocarp tissues.

the night causing a heavy ice build-up on one edge of the MoSS. This caused the cables and shade fabric to sag with the weight of ice, but they did not break and no significant damage occurred. A few aluminum "hog rings" opened and disengaged from the grommets or cables. After the ice melted they were easily installed.

Repeated applications of PKPF lowered tissue temperatures and increased early-season yield in 'Jewel' blueberry following a mild winter (Table 3). Bud temperatures were ≈1.7 to 2.2°C cooler in plants that received weekly applications of PKPF (data not shown). Bi-weekly applications had no effect on reducing bud temperature or yield. Weekly applications of PKPF from September to December increased the early-season yield of 'Jewel' SHB blueberry by 29%, but not the total yield, following a mild winter. Biweekly application of PKPF had no effect on early-season or total yields. Weekly application of PKPF was sufficient to maintain a white, reflective particle layer on the plant which was sufficient for reducing the solar heat load.

Conclusions

Changes in the climate are likely to impact the vegetative and reproductive development of SHB blueberries in central and south Florida where chill-hour accumulation is already marginal. Winters are projected to be warmer and the time needed to meet winter chill requirements will increase. Warm winters with low chill accumulation will cause erratic flo-

Table 3: Effect of weekly and biweekly applications of a processed-kaolin particle film product from October to December 2012 on early season and total yields of 'Jewel' southern highbush blueberry.

	Yield ($T \cdot ha^{-1}$)	
Treatment	Early season	Total
None	3.0 b[z]	5.0
Weekly	3.9 a	5.7
Biweekly	3.0 b	5.1

[z] Means followed by different letters are significantly different ($P \leq 0.05$).

ral bud break, delayed flowering, and sparse foliage, which will contribute to decreased yields. Adapting blueberry culture in Florida to projected climate changes is a challenge. Some adaptive options to alleviate the negative consequences of warm winters currently include breeding cultivars with low chilling requirements (Olmstead et. al., 2015) and the application of hydrogen cyanamide to break dormancy (Williamson and Krewer, 2015). Overhead sprinklers may be used to reduce temperatures by as much as 4°C (Gilreath and Buchanan, 1981) and has increased chill accumulation in stone fruits (Erez and Couvillon, 1983). This study investigated two other management strategies for reducing temperatures during winter. Processed-kaolin clay particle application and use of a shading structure reduced canopy temperatures during the mid-day. Shading reduced hours above 25°C by more than 100 h over the 3 month period before bloom in mid-January. Both treatments advanced bloom and improved bud viability. These production options may offer blueberry growers in the region a method of producing blueberries without HC or improve production with HC during the lucrative marketing period in March and April. Both treatments are a viable option for organic blueberry production and small blueberry farms, especially those that are in close proximity to residential areas.

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Inhibitory effect of chlorogenic acid on fruit russeting in 'Golden Delicious' apple

Abstract

Analysis of the secondary metabolites in apple peels showed that the levels of total flavonoids and chlorogenic acid (CA) during 15–60 days after full bloom (DAFB) were significantly higher in cultivar 'Feng Shuai', a spontaneous non-russeting mutant of 'Golden Delicious' apple, than in its maternal plant, which indicated higher level of endogenous CA may be associated with the inhibition of russet formation. Application of 0.5 mmol L−1 exogenous CA solution to 'Golden Delicious' fruits at 30 DAFB effectively inhibited fruit russet formation. It also increased the levels of CA and total flavonoids in fruit peels at the 7th day after treatment, but depressed the lignin content. Furthermore, CA treatment induced the activity of phenylalnine ammonialyase (PAL) and cinnamate-4-hydrolase (C4H), but depressed activity of polyphenol oxidase (PPO) and peroxidase (POD). These effects were further supported by RT-PCR, where the expressions of PAL, C4H, 4CL, CHS, and CHI were up-regulated while those of CAD, POD and PPO were down-regulated by CA treatment. Interestingly, the up-regulated genes are involved in the biosynthesis of chlorogenic acid and flavonoids while the down-regulated ones are involved in lignin biosynthesis. Therefore, it can be deduced that the inhibition of russet formation in 'Golden Delicious' apple by CA is associated with the inhibition of lignin biosynthesis, not the enhancement of total flavonoids biosynthesis.

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