Determining the Effective Pollination Period and Effects of Crop Load Reduction on AU Kiwifruit Cultivars

by

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Abstract

The objectives of this research were to determine the effective pollination period (EPP) of ‘AU Golden Sunshine’ (*Actinidia chinensis*) and ‘AU Fitzgerald’ (*A. deliciosa*), and to determine effectiveness of lateral bud or fruit removal on marketable yield of ‘AU Golden Sunshine’. For the first study, we tested the EPP of ‘AU Golden Sunshine’ and ‘AU Fitzgerald’. Flower buds were bagged one day prior to anthesis and hand pollinated either 1, 2, 3, 4, or 5 days after anthesis for ‘AU Golden Sunshine’. Flowers were hand pollinated 1, 2, 3, 4, 5, or 6 days after anthesis on ‘AU Fitzgerald. Flowers were re-bagged directly after hand pollination to prevent subsequent pollination. ‘AU Golden Sunshine’ showed no significant drop in fruit set or size within the 5-day period, and thus, appears to have an EPP ≥ 5 days after anthesis. Further testing will be performed extending the days tested. Fruit set was reduced on ‘AU Fitzgerald’ starting 5 days after anthesis. Fruit size, weight, and seed number were reduced on day 5, and the EPP of ‘AU Fitzgerald’ appeared to be 4 days for this study. The second study was conducted to determine the effects of lateral bud removal and fruit thinning on marketable yield of ‘AU Golden Sunshine’. Bud thinning treatments consisted of removing, by hand, all lateral buds and leaving only the “king” bud. Fruit thinning treatments consisted of lateral fruit removal by hand. Fruit from un-thinned vines were significantly different in soluble solids content, internal color and external color compared to both thinning treatments. Lateral bud removal resulted in the greatest total marketable yield. Total fruit yield was not significantly different amongst the three treatments, however; cull number was smallest for bud thinning. Lateral bud removal also

resulted in the most fruit ≥ 88 g when compared to the other treatments. Marketable yield was similar among fruit thinned vines and un-thinned vines.

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List of Abbreviations

°C	Degrees Celsius
AU	Auburn University
cv.	cultivated variety
DAA	Days After Anthesis
DMC	Dry Matter Content
DW	Dry Weight
EPP	Effective Pollination Period
FW	Fresh Weight
g	Gram
GDH	Growing Degree Hours
GI	Growth Index
h	hours
ha	Hectare
IHA	Internal Color
EHA	External Color
kg	Kilogram
L	Liters
m	meter
SSC	Soluble Solids Content

CHAPTER ONE

Introduction

The profitability of kiwifruit orchards is directly related to fruit size (Lahav et al., 1989). Larger fruit command higher prices which in turn lead to increased revenue for the orchardist (Atkins, 1990). Various studies have indicated that consumers prefer kiwifruit with high soluble solids content (SSC) and dry matter content (DMC) (Burdon et al., 2004; Crisosto and Crisosto, 2001; Harker, 2004; Harker et al., 2009; Jaeger et al., 2011). Recent consumer preference studies indicate DMC was considered to be the most critical determinant of consumer purchase likelihood/choice for the consumers (Jaeger et al., 2011). Kiwifruit management techniques should consider these consumer trends to promote fruit size and fruit quality.

Optimal kiwifruit production is highly dependent on pollination because fruit size is closely related to the number of seeds; however, pollination of kiwifruit is impaired by the dioecious nature of the species (Pyke and Alspach, 1986) and low or no nectar in flowers, hence, limited attraction of flowers to pollinators (Palmer-Jones and Clinch, 1974). Additionally, various cultivars of kiwifruit are prolific fruit bearers and have the tendency to overbear, that leads to the production of smaller fruit (Thakur and Chandel, 2004).

Actinidia chinensis 'AU Golden Sunshine' and *A. deliciosa* 'AU Fitzgerald' are two kiwifruit cultivars that perform well in the relatively lower chill environments of the southeastern United States. Both cultivars are currently planted in central Alabama at the Chilton Research and Extension Center in Thorsby, Alabama, USA (lat. 32º 55' N; long. -86º 40' W).

The purpose of this research was to determine methods to enhance marketable yield of these new AU kiwifruit cultivars. The objectives of the first study were to determine the effective pollination period (EPP) for *A. chinensis* 'AU Golden Sunshine' and *A. deliciosa* 'AU

Fitzgerald'. Developed by Williams (1965), the effective pollination period (EPP) concept indicates the number of days that pollination is effective in producing fruit and is determined by the longevity of the ovules minus the time lag between pollination and fertilization (Sanzol and Herrero, 2001). Effective pollination in kiwifruit is important because successful pollination results in more seeds, and seed number directly correlates with fruit size (Hopping, 1976; Ferguson, 1990). There are various factors that may affect the EPP. It was shown that the EPP can be affected by temperature, flower quality, and chemical treatments (Sanzol and Herrero, 2001). The EPP was determined for *A. deliciosa* 'Hayward' by Gonzalez et al. (1995), but has not been reported for any other kiwifruit cultivars or species.

The objective of the second study was to determine the influence of fruit thinning and/or lateral bud removal on marketable yield and fruit quality of 'AU Golden Sunshine'. Fruit thinning is not always needed in commercial kiwifruit production; however, 'AU Golden Sunshine' is a prolific fruit bearer and has a tendency to over-crop. It was shown that thinning *A. deliciosa* 'Bruno' and 'Hayward' at the bud swell stage proved to be more advantageous to produce marketable sized fruit than thinning after fruit set (Lahav et al., 1989; Antognozzi et al., 1991). Fruit thinning has also shown to be an effective method for controlling fruit number and manipulating fruit size of *A. deliciosa* 'Hayward' by Richardson and McAneney (1990).

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CHAPTER TWO

Literature Review

Kiwifruit Cultivars

Actinidia deliciosa

Actinidia deliciosa (A. Chev.) C.F. Liang et A.R. Ferguson var *deliciosa* cv. Hayward is the most widely grown *Actinidia* crop (Ferguson, 1991; Nishiyama et al., 2004). 'Hayward' is chosen based on its large fruit production and long storage life (Ferguson, 1999). Kiwifruit seeds were first transported to New Zealand for commercial cultivation in 1904 and planted in 1906. Less than 50 years later, in 1953, kiwifruit were exported worldwide. Soon, around 1970, commercial cultivation spread to California, France, Italy and Japan (Ferguson, 1990). By 1988 New Zealand was host to about 16,500 ha of kiwifruit with total production around 200,000 tonnes (Ferguson, 1991).

One new cultivar of *A. deliciosa*, 'AU Fitzgerald', has been developed with efforts from Auburn University, Auburn, Alabama, USA. 'AU Fitzgerald' was officially named in 2010 and is considered a distinct species of *A. deliciosa* (Dozier et al., 2010b). The male pollinizer for 'AU Fitzgerald' is 'AU Authur' that is also *A. deliciosa* (Dozier et al, 2010a*).* These new cultivars were discovered in Mrs. A.A. Fitzgerald's backyard in Summerdale, Alabama, USA. Her vines were grown from seeds she obtained from kiwifruit purchased from a local grocery store. It is assumed that the fruit purchased were from the 'Hayward' cultivar. 'AU Fitzgerald' produces cylindrical shaped fruit covered in brown skin with medium length hairs and green pericarp (Dozier et al., 2010b).

Actinidia chinensis

Originally deemed as the Chinese gooseberry, *Actinidia chinensis* Planch., is native to China and was introduced to New Zealand in 1906 (Schroeder and Fletcher, 1967). The primary difference between *A. chinensis* and *A. deliciosa* is the color of the pericarp with *A. chinensis* being golden and *A. deliciosa* being green. The golden color in *A. chinensis* is because of an absence of chlorophylls in the pericarp. When compared to *A. deliciosa* cv. Hayward, *A. chinensis* showed similar carotenoid content but differing chlorophyll content, thus relating chlorophyll content to pericarp color (McGhie and Ainge, 2002).

One new cultivar of *A. chinensis*, 'AU Golden Sunshine', has been developed with contributions from Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Hubei province, P.R. China. 'AU Golden Sunshine' was officially named in 2011 and is considered a distinct cultivar of *A. chinensis* (Dozier et al., 2011b). The male pollinizer for this cultivar is 'AU Golden Tiger' (Dozier et al., 2011a). 'AU Golden Sunshine' was selected from seeds of a fruit collected in an open pollinated seedling orchard in Chongyang County of Hubei Province of P.R. China. This cultivar produces cylindrical, uniform shaped golden-fleshed fruit. The skin is brown with short tomentose hairs (Dozier et al., 2011b).

Producing Marketable Fruit

Soil Type and Training Methods

Kiwifruit prefer to be planted in well drained soils, as an abundance of soil moisture retention can lead to the spread of pathogens like *Phytophthora* root rot disease. This fungal disease may be identified on root systems of necrotic vines that eventually die. This disease

inhibits the flow of nutrients and water from the roots by blocking the xylem (Latorre et al., 1991; Baudry et al., 1991; Ferguson, 1990).

Kiwifruit are often trained to a winged t-bar or pergola trellis. Both trellis systems target good support of naturally unsupportive vine canes as well as promoting light interception. Fruit on kiwifruit vines add an immense amount of weight to the vine and additional support is necessary (Ferguson, 1990). Studies have been performed on other upright trellis options like the Y-trellis with inferior results. It has been shown that lowering the cane angle increases flowering and production of marketable fruit thus supporting the use of the winged t-bar and pergola trellis systems (Snelgar and Manson, 1990). As vines fill their allotted block of trellis space, cane tips are pinched or headed to deter apical dominance and encourage lateral, bushy, vegetative growth (Himelrick and Powell, 1998).

Climatic Requirements

Kiwifruit are considered to be a temperate crop. In New Zealand, where kiwifruit are the country's top export horticultural crop, their climate serves as a good foundation for best conditions for commercial kiwifruit production. In Te Puke in the Bay of Plenty district of New Zealand, the mean annual temperature is 14.0 °C. The mean minimum and maximum temperatures during their summer months are 13.7 °C and 23.7 °C, respectively. Similarly for their winter months, maximum and minimum mean temperatures are 13.7 °C and 4.8 °C. They receive about 1725 mm of rain each year with a relative humidity around 80%. It has been reported that a single mature kiwi vine can transpire up to 100 liters of water on an average summer day (Ferguson, 1990).

Wall et al. (2008) determined that ‘AU Golden Sunshine’ has a lower vegetative chilling requirement than ‘AU Fitzgerald’. ‘AU Golden Sunshine’ requires 700 h. A chilling hour is typically defined as 1 hour within 0 ºC to 7 ºC. ‘AU Fitzgerald’ has a vegetative chilling requirement of 800 h. It was shown as well that the number of flowers to develop increased with chilling for both cultivars. ‘AU Golden Sunshine’ reached a maximum flower count at 900 h chilling. ‘AU Fitzgerald’ reached its maximum flower count at 1100 h chilling. Chilling hours and heat units, or growing degree hours (GDH), both fill a requirement for initial bud break. If there is an abundance of chilling hours, first bud break will happen earlier given adequate heat units in the spring. ‘AU Golden Sunshine’ requires 15,000 GDH for bud break at the desired 700 h mark of chilling hours. ‘AU Fitzgerald’ requires 10,000 GDH for bud break at 800 h chilling. There have been various chilling hour requirements reported for ‘Hayward’. ‘Hayward’ was reported to need 750 to 800 h chilling for satisfactory flower count by Ferguson (1990). Caldwell (1989) found ‘Hayward’ vines planted in South Carolina require 900 h chilling for satisfactory vegetative bud break and 1150 h chilling for maximum flowering. Powell et al. (2000) studied test plots of ‘Hayward’ that were installed in southern and central Alabama, USA, starting in 1987. Winter chilling ranged from 500 to 1000 h but was as low as 500 to 800 h about 50% of the time in the years between 1990 and 2000. It was shown that vegetative chilling requirements were being met but not flowering requirements, and fruit set was minimal.

Kiwifruit vines are susceptible to frost damage, especially when plants are exiting dormancy in the spring. Temperatures reaching -1.5 ºC were determined to either kill or severely damage young actively growing shoots of ‘Hayward’ (Pyke et al., 1986). Temperatures of -0.5 ºC damaged 60% of actively growing shoots. Vines were shown to die at a winter temperature of -9 ºC or lower and bud break was reduced by 70% with temperatures of -7 ºC. Dozier et al.

(1992) performed an experiment on four pistillate cultivars (*A. deliciosa*) of 4-year-old kiwifruit vines. They found trunk wraps and microsprinkler irrigation to be effective means to protect the vines from freeze damage. Overhead irrigation is more effective than under-vine sprinklers. Irrigation works well because when 1 g of water freezes, 80 calories of heat energy are released (Perry, 1998). The release of this heat, heat of fusion, protects the vines from freeze damage. Snyder (1994) gives sprinkler rates for overhead irrigation frost protection. He states proper management must be employed to ensure successful protection. If sprinkler rates or timing of irrigation is off, more harm can be introduced to the vines than what would have been present without the use of protective irrigation. The wet bulb temperature must be observed when using overhead irrigation as freeze protection. The wet bulb temperature is calculated in relation to air temperature and dew point temperature. The wet-bulb temperature is useful because it is essentially what the plant temperature will be once the irrigation is started and evaporative cooling has taken place. The dew point is the temperature at which the relative humidity reaches 100% as the air cools. If the dew point is below freezing, so that condensation and heat release do not take place until below freezing, temperatures can drop to damaging levels extremely rapidly. If dew point is below freezing, irrigation must be turned on before air temperatures reach 0 ºC.

Pollination of Kiwifruit

Pollination can be impaired in kiwifruit based on its dioecious nature. Male and female flowers of kiwifruit are borne on separate plants. For fruit to be produced, a female vine must first be pollinated by a male pollinizer that should be within close proximity to the female

vine. Wilbur (1994) suggests to plant at least one male vine for every eight female vines in the orchard with 4.5 - 5 m spacing.

It has been shown that wind pollination alone is insufficient. Gonzalez et al. (1998) found 12% and 37% (first year, second year) fruit set on adult vines of 'Hayward' with wind as the only pollination vector and 80% and 83% with wind and insects. Fruit were also smaller with wind pollination exclusively (39, 29 g) compared to open pollination (106, 102 g). Quality of the yield was determined in categories: extra (fruits greater than 110 g), first (fruits 80-110 g), second (fruits 65-80 g), third (fruits less than 65 g) and marketable (fruits higher than 80 g). Fruit quality was improved with hand pollination when compared to mechanical or open pollination with average fruit weights being 114, 77, and 87 g (hand, mechanical, free, respectively). The average fruit produced with hand pollination was included in the extra category. They state that the benefit of fruit production within the extra category could increase the final value of the crop by 10%. Only 50% of the increase in final crop value is needed to pay the cost of hand pollination. The remaining benefit serves as extra income for the producer.

Presently, honey bees appear to be the most important measure of pollen transfer (Clinch, 1984; Ferguson, 1990). Palmer-Jones and Clinch (1974) found that honey bees provide a distinct advantage for pollination of kiwifruit; however, honey bees are easily lured away to other pollen sources. Kiwifruit flowers contain dry and unattractive pollen with no nectar. Severe competition came from white clover, citrus trees, and honeysuckle; as these species produce nectar that is highly attractive to bees. They noticed that bees visited kiwifruit flowers more in the mornings than in the afternoons. The bees were observed to visit kiwifruit flowers in the afternoons following an early rain event while the flowers were still damp. The bees appear to prefer damp flowers because the pollen can be gathered more readily from the flowers.

Goodwin et al. (2013) found that bees have a floral sex preference. They observed 393 honey bee visits but only 2.8% were to the 'Sparkler' staminate flowers. They observed 180 honey bee visits in another treatment but only 2.2% of the visits were to 'Meteor' staminate flowers. The remaining visits in both treatments were to pistillate flowers. They also reported an average increase in seed number per bee visit. In the single bee visit, each visit produced an average of 51 seeds. They exposed 21 pairs of flowers one pair at a time, and re-bagged them once a bee had visited one of them. None of the 21 unvisited flowers produced fruit. They also performed a multiple bee visit study in which they video-recorded 126 flowers and subsequently counted bee visits. Each bee visit increased fruit weight by 10.8 g and increased seed number by 77.8 seeds up to a total of 5 visits. Flowers received an average of 5.1 visits each day and the length of the visits averaged 12.2 s. They determined the effect of staminate vine distribution as well. They removed all the flower buds from four staminate vines at the north end of their block. This left the pistillate flowers at the end of that block between 34 and 54 m from the closest staminate vines in that same row. These pistillate vines were divided into 2 m sections. Honey bees were captured on pistillate flowers and the section where captured was recorded. Pollen carried by the bees in their corbicula was analyzed and the number of staminate pollen grains was determined. They found a reduction of 0.8% in staminate pollen carried by the bees for every additional meter from a staminate vine. Seed number decreased with each additional meter from a staminate vine by 0.75% or 3.5 seeds. They also determined the importance of wind pollination at night. Each day they enclosed flowers at 0700 h and removed the pollen exclusion bags at 1900 h starting when the flower buds were in "soft bud stage" just prior to opening. They found that out of 25 flowers, only 2 produced fruit of which both weighed 20 g.

Pollination vectors for *A. chinensis* have not been studied extensively. Goodwin et al. (2013) performed a study on wind and honey bee pollination of *A. chinensis* 'Hort16A', that made up 23.1% of New Zealand's kiwifruit crop at the time of the study. Flowers produced by *A. chinensis* are similar to *A. deliciosa* in that the female flowers do not produce nectar and bees simply scurry across anthers and move on. Open pollinated flowers (wind and insects) were shown to have a 92.3% fruit set as compared to 16.6% from wind pollination only. It was noted in this study that pistillate flowers from *A. chinensis* dehisced their petals after 2 days while *A. deliciosa* typically hold their petals for 5 d. Flowers that have undergone dehiscence of petals are less likely to be visited by honey bees as Free (1964) found for apple trees. Free (1964) emasculated (stamens, petals and sepals removed leaving the stigmas intact) 8 trees. These trees were left open for insect pollination and none of these trees set fruit. Goodwin et al. (2013) discovered stigma receptivity to be closely related to anther dehiscence. Stigma receptivity for *A. chinensis* 'Hort16A' was highest during the first 2 days after anthesis and anther dehiscence occurred just after this period. Anthesis was described as the day the flower opens.

Because of the variability of effectiveness in relying solely on natural pollination from honey bee activity in a kiwifruit orchard, many growers will also apply supplemental pollen in their orchard. Various factors can be synchronized if an effective pollination period is determined for kiwifruit. Male vines can be properly distributed, proper timing of bee hive placement can be achieved, and growers can optimize their supplemental pollen applications. The effective pollination period (EPP) concept was developed by Williams (1965). EPP is defined as the number of days following anthesis during which pollination is effective in producing marketable fruit. Proper timing of supplemental pollen application is important because supplemental pollen is expensive. In February 2012, kiwi pollen from Pollen Collection

& Sales, Inc., Lemon Cove, CA. sold at $1.55 / g and recommended application rate is 500 g/ha and there are often multiple applications.

Gonzalez et al. (1995) found the EPP for *A. deliciosa* 'Hayward' to be 4 d. For this study, they pollinated using pollen collected from dried male flowers collected one day prior to anthesis. Pollen was applied by hand using a camel brush to 25 isolated pistillate flowers at 1, 2, 3, 4, 5, 6, and 7 days after anthesis. Fruit set was recorded 30 d after pollination. They obtained ≥ 80% fruit set during the first 4 days following anthesis. By day 5 fruit set reached 36% and by day 7 fruit set was almost 0%. When plotted, Gonzalez et al. (1995) found that stigmatic receptivity closely fit the curve of fruit set ($r^2 = 0.99$). Hence, they concluded that EPP is limited by stigmatic receptivity. Goodwin et al. (2013) conducted a similar study with *A. chinensis* 'Hort16A'. To determine stigma receptivity, they isolated 150 flowers using pollen-proof bags. They hand-pollinated 20 pistillate flowers per day by direct flower-to-flower contact using two stigmatic flowers for each pistillate flower. Following pollination, they re-bagged the flowers to prevent open pollination. They found stigma receptivity to be highest during the first 2 days after anthesis. Stigma receptivity can range from no more than an hour in *Avena* or *Dactylis* to more than a week in *Eucalyptus* (Heslop-Harrison, 2000).

Goodwin et al. (2013) also isolated flowers (*A. chinensis* 'Hort16A') with pollen-proof bags that were hand pollinated at anthesis and observed pollen tube growth using fluorescence and scanning microscopy. Pollen tubes reached the stylar transmitting tissue 1 d after pollination and ovules were fertilized 3 d after pollination. The mean temperature was 15 ºC with a mean maximum of 20 ºC. These temperatures are considered optimal for pollen tube growth. Hopping and Jerram (1979) studied temperature and pollen tube growth of *A. chinensis* Planch. The greatest pollen tube growth rate was recorded with a maximum and minimum field

temperature of 24.6 °C and 8.3 °C, respectively, at an average rate of 0.21 mm/hr, enabling most of the pollen tubes to reach the style base in 31 h. Pollen tubes continued to grow and reach the ovaries as late as 74 hr after pollination. Pollen adhesion and germination varies depending on species. For sweet cherry (*Prunus avium* L.), pollen tube growth rates were greatest at 10°C and least at 30°C (Hedhly et al., 2003). Germination and adhesion was found to be greater at 22 °C than 15 °C in almond (Vezvaei, 1997). For avocado, germination and pollen tube penetration was greater at 25/20 °C day/night and 33/28 °C than at 17/12 °C (Sedgley and Annells, 1981).

Fruit Quality and Profitability

Profitability of a kiwifruit orchard was once strongly based on total crop load. That trend has shifted to promote emphasis on production of specific kiwifruit sizes for consumer markets. As an individual factor, total crop load no longer determines profitability of an orchard. The number of marketable fruit now primarily determines orchard profitability (Atkins, 1990).

One key difference between *A. chinensis* and *A. deliciosa* other than pericarp color is their ripening physiology. *Actinidia chinensis* ripens on the vine while *A. deliciosa* must be stored cold for the fruit to ripen (Ben-Arie et al., 1982). Total soluble solids content (SSC) is the primary determinant for ripeness in kiwifruit. *Actinidia deliciosa* fruit are often harvested when SSC reaches a minimum of 6.2% (Ben-Arie et al., 1982; A.R. Ferguson, 1990). *Actinidia chinensis* are typically harvested when SSC is between 9 and 14% (Clark et al., 2004)

Dry matter content (DMC) and SSC are directly related to orchard profitability. Burdon et al. (2004) conducted a study on consumer evaluations of quality based on SSC and DMC on *A. deliciosa* ‘Hayward’. Fruit (115-127 g) were gathered from orchards in the Bay of Plenty, New Zealand in 1998. They separated the fruit into 8 DMC categories ranging from a

lowest rating of <14% up to >20% in 1% increments. The fruit were held for 9 days storage at 0 ºC, treated with ethylene for 16 h at 20 ºC, and presented to a panel of 72 untrained Japanese consumers for sensory evaluation. Forty five percent of the panelists were between the ages of 31 and 60 years with 64% female. They found that overall liking of kiwifruit was different between DMC of <14% and 14-15%. Fruit with a DMC of <14% were liked less than fruit with a DMC of 14-15%. Once the fruit reached a DMC of 15-16% or greater, there was no effect of DMC on overall liking of the fruit (Burdon et al., 2004). Similarly Crisosto and Crisosto (2001) explored consumer acceptance of kiwifruit using 'Hayward'. For their study, 252 consumers at a major supermarket in Fresno County, California, USA were presented slices of kiwifruit ranging from 11-14% SSC. Consumers were asked if they "liked", "disliked", or "neither liked nor disliked" the sample. A degree of liking was also analyzed where the consumers chose their degree of liking using a nine-point hedonic scale (1 = dislike extremely, 9 = like extremely). They found that they can harvest at 6.5% SSC to obtain a 12.5% SSC that in turn is recommended as the minimum maturity standard of "Hayward" kiwifruit based on consumer preference. The consumers' degree of liking increased as SSC increased from 11.6 – 13.5% with a maximum acceptance of 84% the first year and 90% the second year. In another study performed by Jaeger et al. (2011), 300 Japanese consumers were chosen for a study that focused on DMC, size, and price of kiwifruit ('Hayward' and 'Hort16A'). They found that DMC proved to be a key determinant to desirability of kiwifruit. Degree of liking increased as DMC increased, and that increased likelihood of purchase. Fruit were separated into four DMC densities for this experiment. The DMC categories were confirmed using a corresponding SSC value that was determined just prior to consumption by participants. A 9-point category scale was used to assess the study for each participant. For 'Hayward' the relative importance of DMC, price and size

was 51.1%, 36%, and 12.9%, respectively. For ‘Hort16A’ the relative importance of DMC, price, and size was 48.5%, 39.9%, and 11.6%, respectively. For both studies, price was very important but remained less important when compared to DMC. Fruit size consistently contributed a small part in the likelihood of purchase.

Thinning and Fruit Size

Kiwifruit are prolific fruit bearers and have the tendency to overbear, which leads to the production of smaller fruit (Ferguson, 1990; Thakur and Chandel, 2004). Fruit size in kiwifruit determines marketability and price of the fruit; both of which determine profitability—an important factor of any orchard.

Malone (2012) found that fruit thinning of *A. chinensis* ‘AU Golden Sunshine’ increased marketable fruit numbers and marketable yield. In this study, fruit were thinned to approximately 60 fruit/m^2. Fruit thinning was done 28 d after initial fruit set. However, fruit thinning did not increase marketable yield or number of fruit for *A. chinensis* ‘AU Golden Dragon’ or ‘Hort16A’. Hence, the economic benefit of fruit thinning kiwifruit is cultivar dependent, as fruit set can be quite variable among cultivars.

Thakur and Chandel (2004) determined that thinning is required to obtain good size and quality fruit. Their study was conducted using hand pollinated mature vines of *A. deliciosa* ‘Allison’ to determine the best physiological stage for thinning and its relation to number of marketable grades and quality of resulting fruit. . Similar to ‘AU Golden Sunshine’, ‘Allison’ is a prolific fruit bearer often having 3-5, and as many as 7 flower buds per fruiting node. Flower buds were thinned at a fully developed stage before opening. Thinning to six flower buds per fruiting shoot produced a marketable weight of 41.73 kg per vine (42.3% of total yield) for the

"A grade" that consisted of fruit >75 g. This accounted for a 17.3% thinning of the vine. These vines produced 1377 fruit per vine with a total yield of 88.32 kg per vine. Flower thinning to six flowers per fruiting shoot (17.83% thinning) also showed comparable results. Flowers were thinned at full bloom. For this treatment, vines produced 1360 fruit per vine and had a total yield of 83.59 kg per vine. The marketable yield was 34.53 kg per vine (41.3% of total yield) for "A grade" fruit. Fruit thinning to six fruitlets per fruiting shoot (18.59% thinning) was also tested. Fruitlets were thinned 10 d after petal fall. For this treatment, vines produced 1352 fruit per vine with a total yield of 81.85 kg per vine. "A grade" fruit yield was 31.94 kg per vine (39% of total yield). Their no thinning "control" vines produced 1653 fruit per vine with a total yield of 90.82 kg per vine. Marketable yield of "A grade" fruit was 24.88 kg per vine (27.4% of total yield). In summary, they found greatest marketable yield of "A grade" fruit by bud thinning to 6 flower buds per fruiting shoot but total yield still remained similar when compared to their control.

Another study was conducted in New Zealand on fruit thinning of *A. deliciosa* 'Hayward' by Richardson and McAneney (1990). This study did not cover methods for thinning; rather they formulated equations to calculate maximum returns based on fruit density. They found that maximum grower returns resulted from an average fruit weight of 90 g. The weight of 90 g corresponds to a crop load of approximately 50 fruit m^{-2}. They discovered that total yield was strongly dependent on fruit number with yield increasing as crop load increases.

Vasilakakis et al. (1997) were intrigued by factors that affect the fruit size of 'Hayward' kiwifruit. They found that pollination is a limiting factor, where bees play a large role as the most important pollinators. Pollination plays a large role based on the fact that fruit size is highly dependent on seed number per fruit and seeds result from proper pollination (Gonzalez et al., 1998). A second dimension that Vasilakakis et al. (1997) studied was fruit thinning. They

found that fruit thinning affected fruit size significantly. Their method for thinning was to thin to one fruit per node when fruit was approximately the size of an olive, which occurred around 37 d after full bloom. They suggest thinning at this stage because thinning at the pre-blooming stage, while easy and less expensive, is more risky. The risk is due to the potential of an unforeseen flower drop post-thinning from weather or natural physiological causes (fruit drop). A later thinning can also be applied to remove misshapen or unmarketable fruit.

The general objective of thinning is not exactly the same for kiwifruit as it is for other crops. Lescourret et al. (1999) cover thinning in their model for kiwifruit orchard management. They say kiwifruit crop size is not often limited and thinning is done to remove fruits that provide little benefit to the orchard. *Actinidia chinensis* species and *A. deliciosa* 'Hayward' have a tendency to produce flat and fan shaped flower buds that produce unmarketable fruit. Watson and Gould (1994) found fan-shaped fruit to be irregular in histology at maturity. These fruit were irregular in size and would be difficult to ship. A fan-shaped fruit occurs when the terminal meristem fuses with one or both of the lateral meristems resulting in fasciated structures with supernumerary floral organs supported by a single pedicel. Thinning can also be applied to remove lateral fruit that are smaller than the "king" fruit and have little commercial value. Antognozzi et al. (1991) conducted a study on *A. deliciosa* 'Hayward' vines. Buds were chosen that contained one terminal and two laterals for each inflorescence. For their experiment, they chose 40 inflorescences on each vine using 10 vines. Each inflorescence contained three flowers, one terminal and two laterals. They thinned according to four treatments: 1, unthinned; 2, terminal flower and one lateral remaining; 3, terminal flower only remaining; 4, one lateral flower only remaining. Ten different inflorescences were used on each vine for each treatment. For their treatments, they found terminal fruits always had a higher fruit weight and number of

seeds when compared to the lateral fruits. The terminal fruit growth was not dependent on presence or absence of one or both of the lateral fruits.

Pescie and Strik (2004) performed a thinning study on *A. arguta* 'Ananasnaya', commonly known as the hardy kiwifruit. *Actinidia arguta* is a vigorous vine much like 'AU Golden Sunshine'. They concluded that fruit thinning reduces variability in vine performance. Fruit thinning was shown to reduce nonmarketable yield (fruit <12 mm diameter). As fruit number increased, average fruit weight linearly decreased. Thinning before bloom significantly increased marketable fruit weight (14%) and king fruit weight (19%) when compared to control (no thinning) vines. They found highest fruit weight as a result of 50% thinning, though yield was lowest. *Actinidia arguta* is different from other *Actinidia* species in that the king fruit is not different from the two lateral fruits in volume (king, 4.3 cm^3; lateral, 4.5 cm^3). They found no effects of treatments on seed number per fruit.

Jindal et al. (2003) performed a study on *A. deliciosa* 'Hayward' to determine the effects of a combination of hand thinning and the application of various plant growth regulators. They found positive results especially for their treatment consisting of hand thinning to six fruits per shoot in combination with 600 ppm Ethrel, which induced a total thinning of 52%. For this treatment, they obtained an average yield of 49.57 kg per vine with 61.13% being "Grade A" (>80 g). They propose that the increase in fruit size and weight can be attributed to the reduction in number of fruit on the vine that gives a higher leaf to fruit ratio.

Burge et al. (1987) studied the effects of flower thinning on fruit size, vegetative growth, and return bloom of *A. deliciosa* 'Hayward' vines. They considered two size categories: a preferred export size (≥ 90 g) and export size (≥ 70 g). They found that average fruit weight decreased with increasing fruit number per vine. While thinning treatments had no significant

effect on fruit yield of fruit 88 – 97 g, the number of fruit 110-117 g and 98-109 g decreased with increased total fruit number per vine. For this study, the number of flowers was higher the year following a heavy thinning. They counted 4.7 flowers per fruiting shoot on the vines that were not thinned the previous year and 6.5 flowers per fruiting shoot on the vines thinned 50% (max thinning). They counted 10.2% of nodes with lateral flowers on the vines that were not thinned and 20.4% of nodes with lateral flowers on the vines flower thinned 50%. The amount of new vegetative growth was not affected by thinning the previous year. They did not find any change in fruit SSC in relation to fruit numbers per vine.

A study by Lahav et al. (1989) was performed to determine the optimal physiological stage for thinning, optimal fruit number per vine, and the effect of thinning on alternate bearing in relation to fruit yield and size of *A. deliciosa* 'Bruno'. They chose 'Bruno' because it is a prolific cultivar that produces a heavy crop load and small fruit with an estimated 3000-5000 flowers per vine. They thinned vines either at the bud swell stage (9-18 Apr. 1985) or after fruit set (15-27 May 1985). Thinning was done by hand, removing two lateral buds leaving three to five fruits per inflorescence. They found the vines with higher fruit numbers produced smaller fruit where vines with 700 fruits per vine produced fruit with an average weight of 100 g and vines with 4700 fruits produce fruit averaging 38 g. Fruit produced by vines that were thinned at bud swell stage had greater fruit weight than fruit produced by vines thinned at fruit set with respective average fruit weights of 76 g and 70.8 g and respective average fruit number per vine of 1412 and 1366. The vines thinned at bud swell stage produced 61.3% fruit >70 g and vines thinned at fruit set produced 53.7% fruit >70 g.

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CHAPTER THREE

Effective Pollination Period of 'AU Golden Sunshine' and 'AU Fitzgerald'

Optimal kiwifruit production is highly dependent on pollination because fruit size is closely related to the number of seeds per fruit; however, pollination of kiwifruit is impaired by the dioecious nature of the species (Pyke and Alspach, 1986). Developed by Williams (1965), the effective pollination period (EPP) concept indicates the number of days that pollination is effective in producing fruit and is determined by the longevity of the ovules minus the time lag between pollination and fertilization (Sanzol and Herrero, 2001). Effective pollination in kiwifruit is important because successful pollination results in more seeds per fruit, and seed number directly correlates with fruit size (Hopping, 1976; Ferguson, 1990). Goodwin et al. (2013) determined that a fully pollinated 'Hort16A' (*Actinidia chinensis* Planch. var. *chinensis*) flower (2 days after anthesis) produced fruit with up to 694 seeds. Hopping (1976) found 'Hayward' [*A. deliciosa* (A. Chev.) C.R. Liang et A.R. Ferguson var. *deliciosa*] kiwifruit to have up to 1200 seeds.

Wind pollination alone has proved to be insufficient for kiwifruit (Gonzalez et al., 1998). Honey bees appear to be the most important vector of kiwifruit pollination (Clinch, 1984; Ferguson, 1990). However, bees are easily lured away to other pollen sources like white clover, citrus trees or honeysuckle because kiwifruit flowers contain dry and unattractive pollen with no nectar (Palmer-Jones and Clinch, 1974). Therefore, supplemental pollen applications are often utilized to enhance fruit set and fruit size of commercial kiwifruit.

Various factors can be synchronized if an effective pollination period is determined for kiwifruit: male vines can be properly distributed, proper timing of bee hive placement can be achieved, and growers can optimize supplemental pollen applications. Male vines are typically distributed with a 1:6 or 1:8 staminate:pistillate vine ratio in the commercial setting. Beehives are typically stocked at a rate of 8-10 hives per hectare (Goodwin et al., 2013). Because of variable effectiveness in relying solely on natural pollination from honey bee activity in a kiwifruit orchard, many growers will also apply supplemental pollen in their orchard. Proper timing of supplemental pollen application is important because supplemental pollen is expensive. As of February 2012, kiwi pollen sold for $1.55/g by a provider in the U.S. (Pollen Collections & Sales Inc., Lemon Cove, CA). Recommended rates are approximately 500 g/ha and multiple applications are often employed in an effort to achieve successful pollination. Determining the EPP of kiwifruit species/cultivars could allow growers to optimize supplemental pollen applications by applying only during the EPP, and thus, reduce costs.

Kiwifruit flowers are receptive for only a few days following anthesis where pollination can be successful leading to a good marketable fruit set. The EPP for *A. deliciosa* 'Hayward' was determined to be 4 days by Gonzalez et al. (1995). They considered a fruit set of 80% or higher to be effective. They evaluated pollen tube growth, ovule development, and stigma receptivity. It was discovered that the duration of stigmatic receptivity closely fit the EPP, thus it appears that the EPP is limited by stigma receptivity.

The EPP for 'AU Golden Sunshine' (*A. chinensis*) and 'AU Fitzgerald' (*A. deliciosa*) has not yet been determined. There are various factors that may affect the EPP including temperature, flower quality, and chemical treatments (Sanzol and Herrero, 2001). For the present study, temperature and flower quality were taken into consideration but no chemicals treatments

were applied. The main objectives of these studies were to determine the effects of time of pollination on fruit set, fruit size, and seed number of ‘AU Golden Sunshine’ and ‘AU Fitzgerald’.

Materials and Methods

Experimental Design

These experiments were conducted using mature vines of ‘AU Golden Sunshine’ and ‘AU Fitzgerald’. Kiwifruit vines were grown at the Chilton Research and Extension Center in Thorsby, Alabama, USA (lat. 32º 55' N; long. -86º 40' W). ‘AU Golden Sunshine’ vines had been trained to a winged t-bar trellis system with plants spaced 2.4 m × 4.8 m. The ‘AU Fitzgerald’ vines are trained to a pergola trellis system with similar spacing.

Treatment Application

‘AU Golden Sunshine’ flower buds were bagged on April 29, 2013 using wax paper bags (10.2 × 26.2 cm). The same bags were used to bag ‘AU Fitzgerald’ on May 14, 2013. Flower buds were bagged 1 day prior to anthesis; still completely closed but showing some white from petal unfolding, identified as “Stage 5” by Brundell (1975). Anthesis was the day the flower petals opened. The top of the bags were trimmed to allow the opening to pass over the bud and be wrapped around the vine and stapled back onto itself. A small slit was cut in the bottom edge of the bag for water drainage. WatchDog A-Series data loggers (Model A150, Spectrum Technologies, Inc., Aurora, IL, USA) were placed in the vines to record temperature. One data unit recorded open air temperature under the canopy and the other was placed in a wax paper bag to record an in-bag temperature under the canopy. For each vine, 30 flowers were

isolated and hand-pollinated using direct contact of male to female flowers each day at 1, 2, 3, 4, and 5 days after anthesis (DAA) (April 30 – May 4, 2013). 'AU Fitzgerald' buds were bagged on May 14, 2013 and pollinated in the same way as 'AU Golden Sunshine' except we pollinated up to 6 DAA (May 15 – May 20, 2013). For 'AU Golden Sunshine' we used 'Meteor' as the pollinizer. 'Meteor' was used instead of the typical 'AU Golden Tiger' because a late freeze delayed the bloom of several cultivars during this year. 'AU Authur' (*A. deliciosa*) was used as the pollinizer for 'AU Fitzgerald'. Flowers were re-bagged using newly labeled bags immediately following hand-pollination to prevent subsequent open pollination. A color-coded drop tag was placed around the vine next to the flower to allow for subsequent data collection. Bags were removed 16-21 DAA (May 20, 2013) for 'AU Golden Sunshine' and 8-14 DAA (May 29, 2013) for 'AU Fitzgerald'.

Data Collection

Initial fruit set was determined when bags were removed on May 20, 2013 (16-21 DAA) for 'AU Golden Sunshine' and on May 29, 2013 (8-14 DAA) for 'AU Fitzgerald'. Data were collected using a "Y" denoting fruit set and an "N" for no fruit set. There were a few cases of limb drop. If the limb dropped with fruit set, this was recorded as a "Y". Fruit were harvested 151-156 DAA (October 2, 2013) for 'AU Golden Sunshine' and 92-98 DAA (August 20, 2013) for 'AU Fitzgerald'. Fruit size [growth index (GI)] was determined following harvest. GI was determined using three measurements one of major width (W1), minor width (W2) and length (L) [$GI = (L+W1+W2) * 3^{-1}$]. The fruit were then placed in cold storage at 0.5 °C and 85 ± 5% relative humidity. Fruit were removed starting on March 10, 2014 to determine seed number for each fruit. Seeds were removed from the fruit by quartering the fruit longitudinally and scooping

them out using a knife and/or spoon getting as little pericarp as possible. The flesh was then pressed through a 20 mesh (0.85 mm) sieve leaving only the seeds. Seeds were washed with warm water and evenly spread on a paper towel for drying. Seeds were dried in the open at 21 ºC for 24 hours. For each fruit, seeds were scraped from the paper towel and a small sample was weighed using a Mettler Toledo AG104 analytical balance (Mettler Toledo, Switzerland). The weight of the seeds was recorded and that sample was then counted by hand. Three samples were recorded for each day of fruit for each cultivar to provide an average seed weight. The composite seed weight was then determined for each fruit to allow for an average seed number calculation (Goodwin et al., 2013, Hopping and Hacking, 1983; Hopping, 1976).

Statistical Analysis

Analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). Regression analysis was performed testing linear, quadratic and cubic models predicting responses using DAA from bagging as the explanatory variable. The model was chosen that minimized the Akaike information criterion fit statistic (AIC value). Where residual plots and a significant covariance test for homogeneity (COVTEST statement) indicated heterogeneous variance, a RANDOM statement with the GROUP option was used in the analysis. Fruit set was analyzed using logistic regression.

Results

Actinidia chinensis 'AU Golden Sunshine'

For this portion of the study we tested EPP over the course of 5 DAA. The data loggers recorded a canopy mean minimum and maximum temperature of 5.9 ºC and 28.2 ºC,

respectively, with a mean of 16.8 ºC over the course of the pollination period (Fig. 3.1). The in-bag mean minimum and maximum temperatures were 5.8 ºC and 31.4 ºC, respectively, with a mean temperature of 17.4 ºC (Fig. 3.1). Initial fruit set was not different amongst days at 96%, 96%, 100%, 91.3% and 81.5% for flowers hand pollinated 1, 2, 3, 4, and 5 DAA, respectively (Table 3.1). The fruit size data were fairly consistent with the exception of day 4. Due to the lower values for fruit size and seed number on day 4, there was a significant cubic trend for weight, length, width 1, width 2, GI, and seed number. Fruit weight increased as seed number increased (Fig. 3.2). Average seed numbers ranged from 333-570 seeds per fruit (Table 3.1).

***Actinidia deliciosa* 'AU Fitzgerald'**

We tested EPP for 'AU Fitzgerald' over the course of 6 DAA. The canopy mean minimum and maximum temperatures were 14.5 ºC and 30 ºC, respectively, with a mean of 22.6 ºC (Fig. 3.3). The in-bag temperatures mean minimum and maximum temperatures were 14.4 ºC and 33.1 ºC, respectively, with a mean of 23.5 ºC (Fig. 3.3). Initial fruit set was 93%, 100%, 100%, 100%, 81.5% and 40% for flowers hand pollinated 1, 2, 3, 4, 5, and 6 DAA, respectively (Table 3.2). Fruit weight, length, width 1, width 2, GI, and seed number were reduced on day 5 as well. A cubic trend ($\alpha = 0.001$) was observed for all fruit size measurements and seed number, as values were reduced for flowers pollinated 5 DAA, and then slightly increased for flowers pollinated 6 DAA. Though fruit set was greatly reduced for flowers pollinated 6 DAA, the fruit that was successfully pollinated contained more seeds and was larger than fruit resulting from flowers pollinated 5 DAA (Table 3.2). Fruit size and weight increased as seed number increased (Fig. 3.4). With the exception of day 1, fruit set was consistently 100% through day 4 with a drop starting on day 5. Fruit quality data of harvested fruit indicated a similar trend (Table 3.2).

Discussion

Gonzalez et al. (1995) conducted a similar study to determine the EPP of 'Hayward' (*A. deliciosa*). They considered 80% fruit set to be successful pollination, and based on this, determined the EPP of 'Hayward' to be 4 d. Based on the results of the present study, the EPP of 'AU Fitzgerald' is also 4 d. Though 81.5% fruit set was observed for 'AU Fitzgerald' flowers pollinated 5 DAA, the fruit was much smaller with fewer seeds compared to flowers pollinated earlier. It is unclear why average seed number per fruit declined as flowers were pollinated 1-5 DAA, and then increased in fruit resulting from flowers pollinated 6 DAA (Table 3.2; Fig. 3.4). There were only seven fruit harvested out of 31 (23%) for the 6 DAA treatment, and the seed number for these fruit were quite variable: 91, 169, 180, 230, 521, 673, and 1093. Table 3.2 shows a fruit set of 12 out of 31 (39%) for the 6 DAA treatment. The discrepancy is due to five fruit that set on a limb that dropped from the vine and were not present at harvest time. Goodwin et al. (2013) observed similar results in 'Hort16A'. They noticed a decline in seed number as flower age increased from 2 to 6 days, and then an increase in seed number for those pollinated 7 DAA. The effects of flower age on fruit set and fruit size were not reported. Gonzalez et al. (1995) observed 80% fruit set through day 4 for 'Hayward', 36% on day 5, and then almost 0% by day 7. They did not publish data for seed count number or fruit size.

Because fruit set was above 80% for all treatments (1-5 DAA) for 'AU Golden Sunshine', the EPP could not be conclusively determined in this study. This study will require repeating, extending the DAA tested. There has been little or no research pertaining to the EPP of *A. chinensis* cultivars. Goodwin et al. (2013) reported that the seed number of fruit from 'Hort16A' flowers pollinated at different ages was greatest for flowers pollinated 2 DAA (up to

694 seeds). They considered this to be due, in part, to stigma receptivity for *A. chinensis*, as stigma receptivity was also highest during the first 2 days after anthesis. Seed number decreased as flower age increased through day 6, and then curiously increased in fruit from flowers pollinated 7 DAA. However, they did not report effects of flower age on fruit set or fruit size characteristics; hence, EPP was not determined. They did note that petal dehiscence occurred around the third day after anthesis. For 'AU Golden Sunshine', petals dehisced by the third day after anthesis as well, but pollination was still successful via hand pollination. For the present study, we observed a decrease in fruit size and seed number resulting from pollinating 4 DAA, and then a rise on day 5 for 'AU Golden Sunshine'. On day 4 we received 5.36 cm of rain, that is likely the cause of variation in the data. Rain was likely to affect the pollen transfer in the male to female flower contact pollination method. Daily average seed counts for 'AU Golden Sunshine' ranged from 333-570 seeds per fruit over the 5 d pollination period (Table 3.1).

'AU Fitzgerald' was harvested early [92-98 DAA (August 20, 2013)] because an irrigation emitter malfunctioned and was releasing too much water. The location of the emitter was up a slope from the experiment so the water traveled downhill to the experiment location. The irrigation leak was not noticed for a period of time and *Phytophthora* root rot disease started to affect the treatment vines causing defoliation at first and ultimately vine mortality.

Pollination is crucial for producing marketable kiwifruit, and increasing revenue of growers. Since wind pollination is not effective, and pollinators are not rewarded with nectar, successful pollination of kiwifruit is relatively difficult to achieve. Palmer-Jones and Clinch (1974) found that honey bees provide a distinct advantage to pollination of kiwifruit; however, honey bees are easily lured away to other pollen sources. Kiwifruit flowers contain dry and unattractive pollen with no nectar. Severe competition came from white clover, citrus trees, and

honeysuckle, as these species produce nectar that is highly attractive to bees. They noticed that bees visited kiwifruit flowers more in the mornings than in the afternoons. The bees were observed to visit kiwifruit flowers in the afternoons following an early rain event while the flowers were still damp. The bees appear to prefer damp flowers because the pollen can be gathered more readily from the flowers. Even with all of the effort to introduce honey bees and enhance pollination, supplemental pollination is often utilized. Some researchers have even suggested hand pollination as a viable technique. Gonzalez et al. (1998) found the average fruit produced by *A. deliciosa* 'Hayward' with hand pollination was > 110 g, and the majority of the remaining fruit from the same treatment were 80 – 110 g. They stated that hand pollination increased the final value of the crop by 10%. For their study, only 50% of the increase in final crop value was needed to pay the cost of hand pollination. The remaining benefit served as extra income for the producer. A detailed cost-benefit analysis would be necessary to justify the labor costs associated with hand pollination. However, whether using current methods of pollination or hand pollination, there are significant costs associated with achieving successful pollination of kiwifruit. Knowing the EPP of the kiwifruit species/cultivar grown, can allow for concentrating pollination efforts during this time.

Based on the results of this experiment, and the results of Gonzalez et al. (1995), efforts to pollinate *A. deliciosa* cultivars should be concentrated within the first 4 DAA. Though, we do not yet know the exact duration of the EPP for *A. chinensis* species, the EPP appears to be greater than 4 DAA. Extending the duration of bee activity, hand pollination, or supplemental pollination for a greater period of time for *A. chinensis*, compared to *A. deliciosa*, may be warranted. Goodwin et al. (2013) reported that 'Hort 16A' (*A. chinensis*) flowers were successfully pollinated 7 DAA. Fruit set was not reported, but interestingly, resulting fruit had

greater seed numbers than fruit resulting from flowers pollinated 6 DAA. It should be noted that even though the EPP is 4 DAA for the two *A. deliciosa* cultivars tested, and > 5 DAA for 'AU Golden Sunshine', bee activity may be greatly reduced after petal fall and/or anther dehiscence. Goodwin et al. (2013) noted that pistillate flowers from *A. chinensis* dehisced their petals after 2 days while *A. deliciosa* typically hold their petals for 5 d. Flowers that have undergone dehiscence of petals are less likely to be visited by honey bees as Free (1964) found for apple trees. Efforts to enhance pollination after petal and/or anther dehiscence should perhaps be regulated to supplemental pollen application and/or hand pollination.

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Table 3.1. Effects of hand pollinating *Actinidia chinensis* 'AU Golden Sunshine' flowers 1, 2, 3, 4, or 5 days after anthesis on fruit weight, fruit size, fruit set and seed number. Fruit were harvested October 2, 2013.

Day	Weight (g)	Length (mm)	Width 1[z] (mm)	Width 2[y] (mm)	GI[x]	Fruit Set (%)	Seed Number
1	88.6	68.7	47.1	44.6	53.5	96	570
2	94.0	67.2	48.5	44.7	53.4	96	554
3	84.9	65.5	47.3	44.3	52.4	100	552
4	68.4	59.2	44.9	41.8	48.6	91.3	333
5	85.0	63.2	47.6	44.7	51.8	81.5	409
Trend[u]	C***	C*	C***	C***	C**		C*

[z]Width 1 is measured as the major width 90^0 from length measurement.
[y]Width 2 is measured as the minor width 90^0 from Width 1 across horizontal plane.
[x]GI = Growth Index = (Length+Width 1+Width 2) $\cdot 3^{-1}$.
[w]Y signifies a "yes" for fruit set.
[v]Total number of bagged flowers.
[u]Significant cubic (C) trends using orthogonal polynomials at α = 0.05(*), 0.01 (**) or 0.001(***).

Table 3.2. Effects of hand pollinating *Actinidia deliciosa* 'AU Fitzgerald' flowers 1, 2, 3, 4, 5, or 6 days after anthesis on fruit weight, fruit size, fruit set and seed number. Fruit were harvested August 20, 2013.

Day	Weight (g)	Length (mm)	Width 1[z] (mm)	Width 2[y] (mm)	GI[x]	Fruit Set (%)	Seed Number
1	64.5	65.3	43.2	37.8	48.8	93	956
2	68.5	67.2	44.4	38.4	50.0	100	949
3	63.2	63.7	43.8	37.8	48.4	100	891
4	60.0	63.2	42.6	37.1	47.6	100	853
5	27.4	43.3	33.8	30.9	36.0	82	141
6	48.1	52.3	43.1	35.3	43.6	40	422
Trend[u]	C***	C***	C***	C***	C***		C***

[z]Width 1 is measured as the major width 90^0 from length measurement.
[y]Width 2 is measured 90^0 from Width 1 across horizontal plane.
[x]GI = Growth Index = (Length+Width 1+Width 2) $\cdot 3^{-1}$.
[w]Y signifies a "yes" for fruit set.
[v]Total number of bagged flowers.
[u]Significant cubic (C) trends using orthogonal polynomials at $\alpha = 0.001$(***).

Figure 3.1. *Actinidia chinensis* 'AU Golden Sunshine' canopy temperature (°C) data of both open-air temperature and in-bag temperature recorded during pollination period.

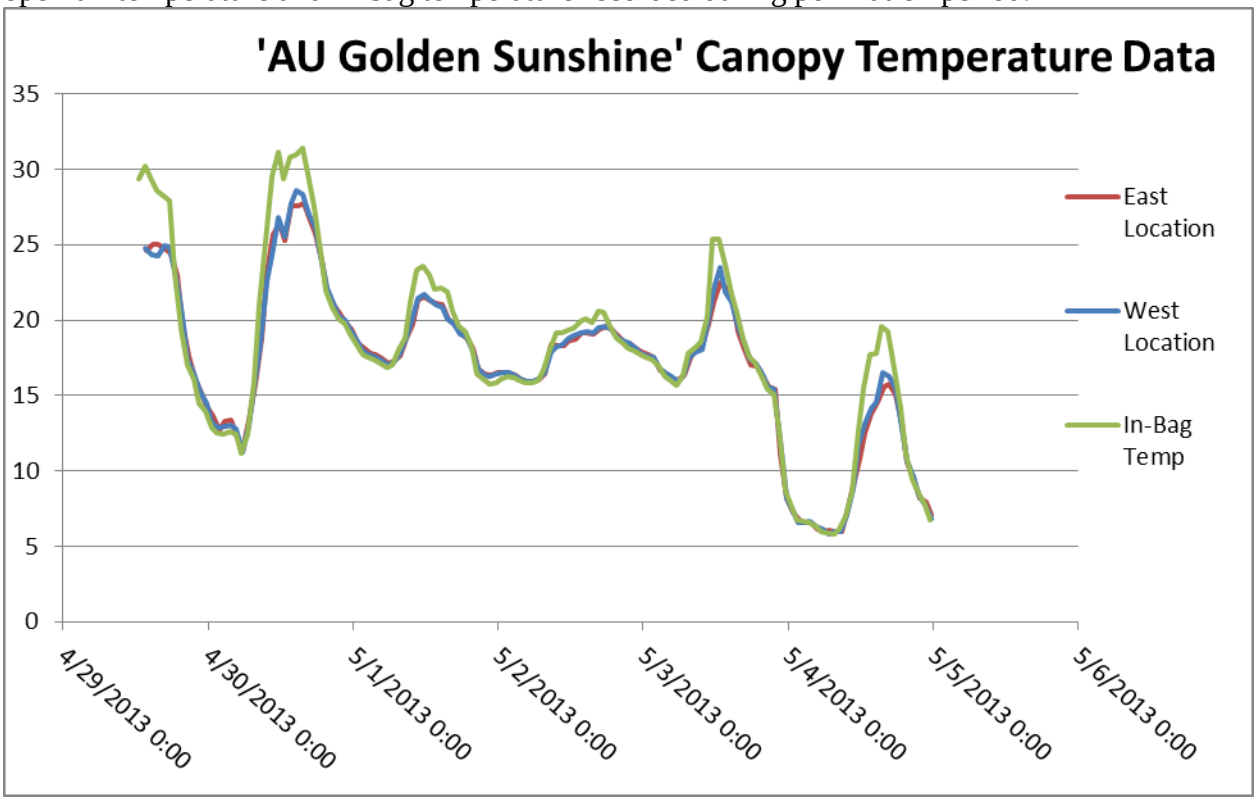


Figure 3.2. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia chinensis* ‘AU Golden Sunshine’.

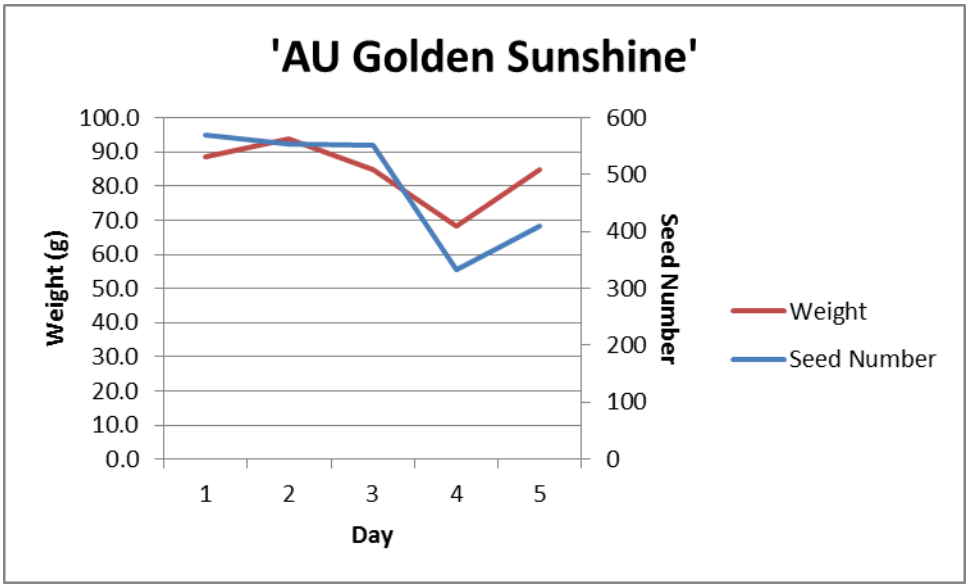


Figure 3.3. *Actinidia deliciosa* 'AU Fitzgerald' canopy temperature (°C) data recorded during pollination period.

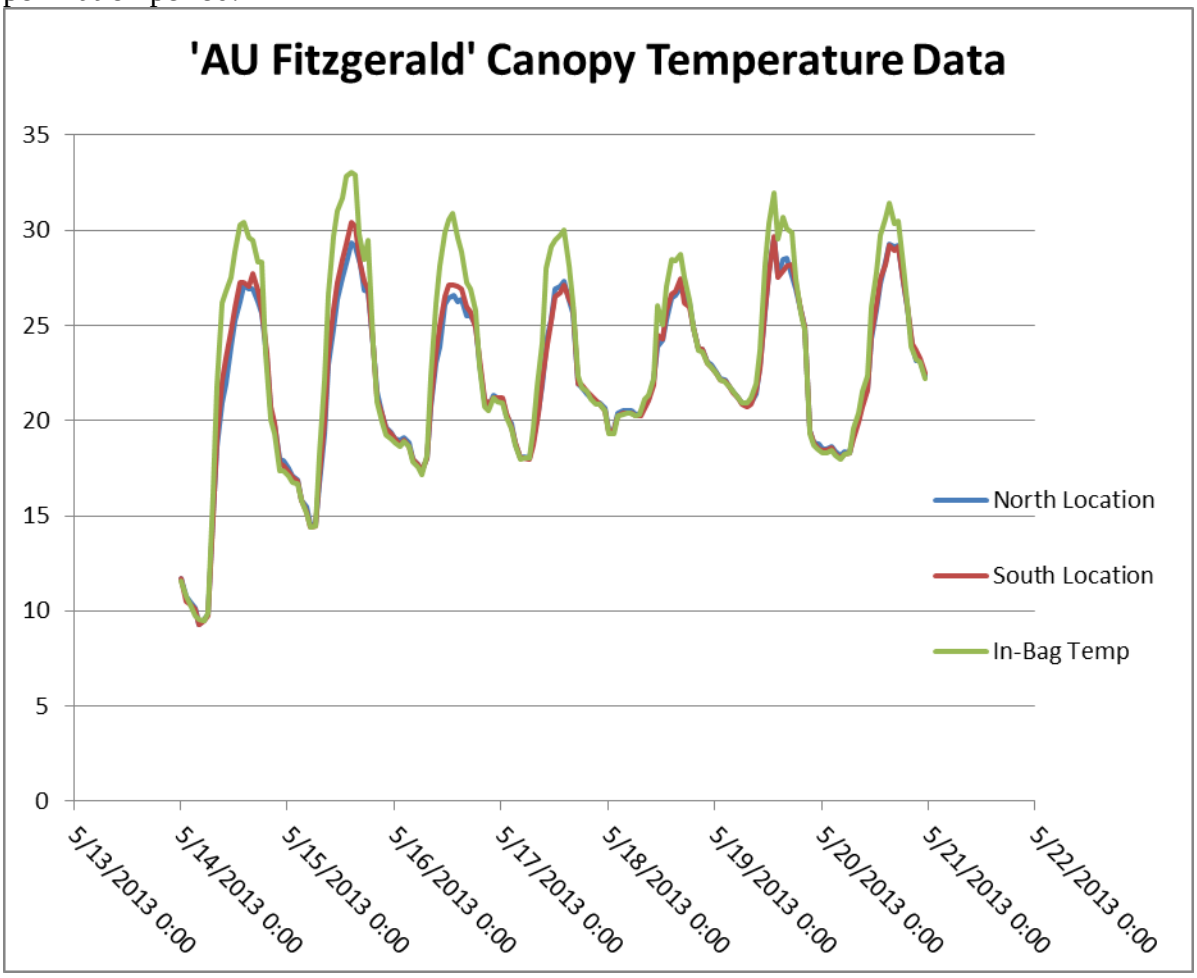
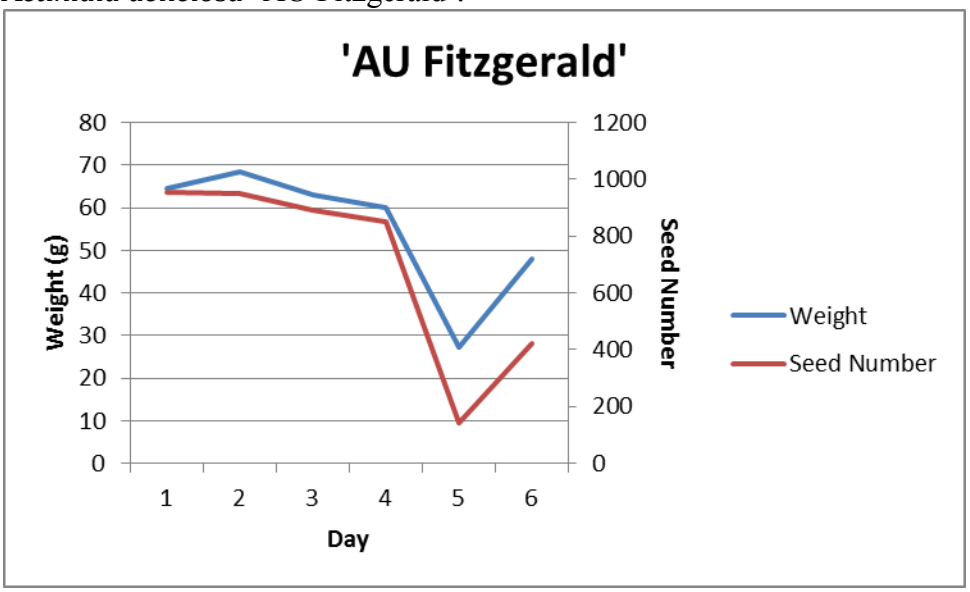


Figure 3.4. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia deliciosa* ‘AU Fitzgerald’.



CHAPTER FOUR

Effects of Lateral Bud Removal and Fruit Thinning on Marketable Yield of 'AU Golden Sunshine'

Various kiwifruit cultivars are prolific fruit bearers and have the tendency to overbear, which leads to the production of smaller fruit (Thakur and Chandel, 2004; Ferguson, 1990). It was shown that thinning *Actinidia deliciosa* 'Bruno' and 'Hayward' at the bud swell stage was more advantageous to produce marketable sized fruit than thinning after fruit set (Lahav et al., 1989; Antognozzi et al., 1991). However, fruit thinning was also shown to be an effective method for controlling fruit number and manipulating fruit size of *A. deliciosa* 'Hayward' by Richardson and McAneney (1990).

The benefits of kiwifruit thinning is highly dependent on cultivar. Studies on different prolific fruit-bearing cultivars of kiwifruit, *A. deliciosa* 'Bruno' and 'Allison', have shown the positive influence fruit thinning had on final fruit weight, but total yield was reduced due to the thinning practices (Lahav et al., 1989; Thakur and Chandel, 2004). Lahav et al. (1989) found that yield had a significant influence on alternate bearing of *A. deliciosa* 'Bruno' with a year of heavy thinning being followed by a greater fruit load year when compared to the vines thinned lightly or not thinned at all.

Vasilakakis et al. (1997) found enhanced fruit size for *A. deliciosa* 'Hayward' when vines were thinned from 2-3 fruit per fruiting node to one fruit per fruiting node early during the growing season. However, thinning may not be practical for all kiwifruit cultivars, as the yield loss in *A. deliciosa* 'Hayward' with fruit thinning may not be compensated by the increase in size of the remaining fruit. Therefore, fruit thinning is often utilized only to remove misshapen or unmarketable fruit. Utilizing fruit thinning to increase fruit size is typically recommended only

on high-yielding cultivars that produce abundant small fruit such as *A. deliciosa* ‘Allison’ or ‘Bruno’ (Thakur and Chandel, 2004; Lahav et al., 1989).

A. chinensis ‘AU Golden Sunshine’ is a relatively new kiwifruit cultivar that appears to be adapted to the climate of the southeastern United States, due in part to its lower chilling hour requirements (Wall et al., 2008). ‘AU Golden Sunshine’ is a prolific fruiting cultivar, producing multiple lateral fruit per fruiting node, typically 3 – 5 lateral fruiting buds/node and as many as seven. Jie and Thorp (1986) counted the number of fruit per cyme of various pistillate cultivars of *A. deliciosa*. For ‘Hayward’, they found no more than two fruit per cyme. For ‘Allison’ they commonly found three fruit per cyme and for Bruno they found four fruit per cyme. The primary flower or “king” flower opens earlier than the secondary flowers or “lateral” flowers. The terminal flower was shown to reach a greater size than the laterals when there are two or three flowers on a single kiwifruit inflorescence (Antognozzi, 1991). The objective of this study is to determine the influence of fruit thinning and/or lateral bud removal on marketable yield and fruit quality of ‘AU Golden Sunshine’.

Materials and Methods

Experimental Design

These experiments were conducted using sixteen mature vines of *Actinidia chinensis* Planch. ‘AU Golden Sunshine’. Kiwifruit vines were grown at the Chilton Research and Extension Center in Thorsby, Alabama, USA (lat. 32º 55' N; long. -86º 40' W). Vines were planted in 1995 from rooted softwood cuttings. The vines are trained to a winged t-bar trellis system with plants spaced 2.4 m × 4.8 m.

This experiment was arranged as a completely randomized block design. Treatments were as follows: 1) no thinning (control) (n = 4), 2) removed all lateral buds (n = 8), and 3) fruit thinning (n = 4). Initially there were four replications and four treatments, but sequential fruit thinning was not needed after lateral bud removal, therefore we included these treatment vines in the lateral bud removal treatment. The fruit thinning treatment consisted of removing lateral fruit only.

Treatment Application

Bud thinning treatments consisted of hand removal of all lateral buds and leaving only the "king" bud on April 18, 2013. Fruit thinning treatments consisted of removing lateral fruit 28 d (May 29, 2013) after initial fruit set, after the initial natural fruit drop had occurred. Experiments were initiated in 2013.

To determine effectiveness of pollen application, we hand-pollinated five 1-day-old flowers per treatment vine. These flowers were bagged prior to anthesis using Lawson 366 wax paper bags (10.2 x 26.2 cm). We pollinated 1 DAA with 1-2 day-old flowers from 'Meteor'. Once hand-pollinated, the flowers were re-bagged until fruit set occurred. For the control, we tagged five similar flowers per treatment vine for comparison (Illustration 4.1).

To determine canopy area, we measured three length and two width measurements. Length measurements were taken in line with the winged t-bar trellis. The first was on the outer most edge, the second was taken along the middle axis of the trellis, and the third was taken on the remaining outer most edge. Width measurements were taken 1 m to the left and right of the main trunk over the top of the canopy. We used a flexible measuring tape to achieve accurate results as the winged t-bar trellis is convex to the ground on the upper side of the canopy. We

deducted any lack of canopy area by measuring any voids where leaves were not present by measuring a length and width of the void and calculating an area. Canopy voids were measured to a specification consisting of voids ≥ 0.1 m^2.

Fruit Sampling and Analysis

Fruit were randomly sampled beginning on August 23, 2013, to determine optimum harvest date. Fruit were harvested when soluble solids content (SSC) was greater than 10% and the internal hue angle was less than 103º to allow full development of the yellow flesh color (Patterson et al., 2003). Fruit was harvested on September 13, 2013. Total fruit yield per vine was determined at harvest. Fruit were graded at harvest into different commercial size categories based on fruit weight. Any fruit ≥ 65 g was marketable fruit, while any fruit < 65 g or misshapen was cull fruit. Since canopy area was not different among the treatment vines, data was collected on a per vine basis. Data collection consisted of total fruit number, total yield (kg), marketable fruit number, marketable yield (kg), cull number, cull weight (kg), fruit number ≥ 88 g, yield weight for fruit ≥ 88 g, pre-harvest drop number, and pre-harvest drop weight. A pre-harvest fruit drop was observed on 'AU Golden Sunshine' vines on August 28, 2013. Ten randomly selected marketable fruit of approximately the same weight and size from each vine were used to determine the effects of treatments on fruit quality. Fruit quality was determined by measuring fresh weight (FW), dry matter content (DMC), soluble solids content (SSC), flesh firmness, internal flesh hue angle, and external hue angle.

External hue angle was taken as a composite average of two readings per fruit using a Minolta CM-2002 spectrophotometer (Minolta, Tokyo, Japan). The readings were taken at a central section of the exterior side of the fruit the second reading being 180º latitudinal fruit

rotation from the first. A 2 mm thick slice of skin and flesh was removed from the shoulder of each kiwifruit, and internal flesh color was determined by measuring the hue angle. Flesh firmness was measured on the same area where the flesh color measurement was taken from each fruit. Firmness was measured with a bench top penetrometer using an 8 mm probe (model FT 327, McCormick Fruit Tech, Yakima, Washington).

A 10 mm section was removed from the stem and stylar end of each fruit to measure SSC. SSC was measured with a Leica Mark 2 Abbe refractometer (Leica Inc., Buffalo, NY, USA) using two drops of juice from stem and stylar end of each fruit. The average of stem and stylar SSC measurements were used to determine fruit SSC. DMC was determined on two 3 mm equatorial slices utilizing a commercial food slicer (Waring Pro®, East Windsor, NJ, USA) taken from each fruit and dried in a food dehydrator (Excalibur® products, Sacramento, CA) at 62.7 ºC for 24 hours. The average DMC of the two slices were used to determine fruit DMC (Fruit Dry Weight/Fruit Fresh Weight × 100).

Statistical Analysis

Analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). The data were analyzed as randomized complete block designs with vines as blocks. Where residual plots and a significant covariance test for homogeneity (COVTEST statement) indicated heterogeneous variance, a RANDOM statement with the GROUP option was used in the analysis. Marketable fruit numbers were analyzed using the normal, Poisson, and negative binomial probability distributions, and the model was chosen that minimized the Pearson Chi-Square / df fit statistic. Least squares means for treatments were

compared using Tukey's test. Means comparisons between hand and open pollination were performed using t-tests. All significances reported were at $\alpha = 0.05$.

Results

Lateral bud removal resulted in a greater marketable fruit number (256 fruit per vine) compared to the control and fruit thinning treatments but there was no difference in the control and fruit thinning (Table 4.1). For the yield data we found trends amongst treatments. The control had the greatest total fruit number per vine with 448 fruit per vine but there was no difference in bud and fruit thinning. Total yield (kg) was not different between the treatments. The number of large fruit ($\geq$ 88 g) was approximately double for the vines that were bud thinned (154), when compared to the un-thinned (79) and fruit-thinned (61) vines (Table 4.1). For this experiment, the canopy areas were not significantly different amongst treatments (Table 4.1). The number of pre-harvest fruit dropped per vine was not significantly different amongst treatments (Table 4.1).

For the quality data, we found a difference in soluble solids content (SSC) between the control and bud and fruit thinning (Table 4.2). SSC was least in the control when compared to bud thinning and fruit thinning. One other quality data trend we noticed was in the internal hue angle (IHA) and external hue angle (EHA) of the fruit. There was a higher IHA and EHA (hue^{o}) for the control when compared to fruit thinning but not greater when compared to bud thinning. This indicates that the fruit from the fruit thinning treatment had greater yellow internal color and greater brown external peel color. There were no differences among treatments for fruit dry matter content (DMC). There were no differences in fruit weight, growth index (GI) among fruit

selected for fruit quality analysis because fruit for quality analysis were selected with similar weights (95-105 g).

Discussion

Removing lateral buds at the bud swell stage was an effective method for increasing marketable fruit numbers for 'AU Golden Sunshine'. Bud thinning of *Actinidia deliciosa* 'Allison', a prolific fruit bearer, increased marketable yield when compared to the no thinning control vines (Thakur and Chandel, 2004).

Fruit thinning increased marketable yield of *A. chinensis* 'AU Golden Sunshine' in a previous study (Malone, 2012). Malone (2012) thinned more than 50% of fruit/m^2 that left 115 fruit/m^2 in the treatments consisting of lateral fruit removal only. In the present study, fruit thinning did not increase marketable yield numbers or total yield weights (kg/vine) when compared to no thinning (control) and lateral bud thinning. Fruit thinning left 29.8 fruit/m^2 where our control had 36.7 fruit/m^2. We tested the effectiveness of open pollination and our application of supplemental pollination utilized in this study by comparing open pollinated flowers with hand pollinated flowers (Table 4.3). Weight of a hand pollinated fruit was 106.5 g while open pollination produced fruit weighing 58.98 g. Fruit size and marketable yield could have been further enhanced with more successful pollination. Fruit that resulted from open pollination (W) was small and misshapen when compared to fruit resulting from hand pollination (R) (Table 4.3, Illustration 4.1).

Studies have shown that thinning typically reduces total yield (Lahav et al., 1989; Richardson and McAneney, 1990; Malone, 2012). Interestingly, there was no difference amongst treatments for total fruit yield (kg) in this study. It is plausible that there was no difference due to

the variability in pollination. We tested for differences in canopy area and found none amongst treatment vines (Table 4.1).

It was found for *A. deliciosa* 'Bruno' and 'Hayward' that thinning at the bud swell stage produces more marketable fruit than thinning after fruit set (Lahav et al., 1989; Antognozzi et al., 1991). Lahav et al. (1989) found for *A. deliciosa* 'Bruno' that vines thinned at the bud swell stage produced 61.3% fruit >70 g and vines thinned at fruit set produced 53.7% fruit >70 g. Fruit weights were 76 g and 70.8 g for vines thinned at bud swell stage and vines thinned at fruit set, respectively. Antognozzi et al. (1991) found before anthesis of *A. deliciosa* 'Hayward' that the terminal peduncle showed more vascular elements than those of the lateral flowers and terminal fruits always had a higher fruit weight and number of seeds when compared to the lateral fruits. They state that this could lead to an increase in the availability of photosynthates that promote cell division in the ovaries. For the present study, fruit from the control vines had lower SSC, and greater EHA and IHA when compared to the lateral bud thinning treatments (Table 4.2). This indicates that the external color was a lighter brown and the internal color was a lighter yellow. It is plausible that a lower SSC was due in part to the greater crop load and the influence of sink competition on the availability of photosynthates and carbohydrates from the vine (Antognozzi et al., 1991). It could also be that maturity was delayed, as all of these indices are indicators (particularly the color measurements) that the fruit were less mature on the control vines.

Richardson and McAneney (1990) conducted a study in New Zealand on fruit thinning of *A. deliciosa* 'Hayward'. This study did not include methods for thinning; rather they formulated equations to calculate maximum returns based on fruit density. They found that maximum grower returns resulted from an average fruit weight of 90 g. They calculated an

approximate 22% reduction in gross returns for the orchardist for every 10% reduction in fruit size from the maximum return weight of 90 g. In the present study, results showed that bud thinning produced the greatest number of fruit ≥ 88 g. The large fruit number was 154 fruit per vine for the lateral bud thinning treatments. The control produced 79 large fruit per vine and the fruit thinning vines produced 61 fruit per vine. Returns for the bud thinning treatment vines would yield greater gross income when compared to the control and the fruit thinning treatment vines.

We recorded fruit drop data because 'AU Golden Sunshine' appears to have a cultivar-specific fruit drop just prior to harvest. Because there were no differences in fruit drop due to thinning treatments, fruit drop does not appear to be related to crop load (Table 4.1).

Fruit thinning was not different from the control for cull numbers or marketable fruit numbers, indicating that reducing the crop load at this time was not advantageous (Table 4.1). Fruit were thinned 28 d after initial fruit set. In a previous study with 'AU Golden Sunshine', fruit thinning 28 d after petal fall increased the marketable yield and reduced total yield (kg) (Malone, 2012). Thakur and Chandel (2004) thinned fruitlets 10 d after petal fall on *A. deliciosa* 'Allison'. Vasilakakis et al. (1997) thinned fruit of *A. deliciosa* 'Hayward' 37 d after full bloom; when the fruit was the size of a large olive. Jindal et al. (2003) removed fruit just following petal fall of *A. deliciosa* 'Allison'.

Antognozzi et al. (1991) found for *A. deliciosa* 'Hayward' that growth of the king fruit was not dependent on presence or absence of one or both of the lateral fruit(s). They suggest that the influence of a fruit and the translocation of assimilates from different sources (sinks) is influenced by the production of growth regulators released by the seeds. They found before anthesis that the terminal peduncle had more vascular elements than the lateral peduncles. This

supports the assumption that fruit size is affected by cell division in the early stages of growth, which was also supported by Lai et al. (1990). For the present study, it is unclear why cull numbers and marketable fruit numbers were similar between the control and the fruit thinning treatments. Crop load was not drastically reduced and pollination was poor throughout (Table 4.1, Table 4.3, Illustration 4.1). It is plausible that insufficient pollination did not allow fruit to reach full potential as Antognozzi et al. (1991) found that seeds influence the translocation of assimilates to the fruit. Lower fruit weight was directly related to lower seed number as a result of insufficient pollination (Hopping, 1976). Based on findings of Antognozzi et al. (1991) and Lai et al. (1990), it is likely that the early stage of bud thinning contributed to the increased fruit size of vines where lateral buds were removed. As the buds were removed, fruit size was affected because cell division of the remaining king buds could have been enhanced in the absence of competition prior to anthesis from lateral bud growth and development.

Lateral bud removal appears to be advantageous for production of 'AU Golden Sunshine'. For this 1-year study, lateral bud removal increased marketable fruit and the percentage of large fruit, compared to no thinning and fruit thinning. Bud thinning is considered riskier due to the potential of freeze damage, etc. that may cause fruit not to set (Vasilakakis et al., 1997). 'AU Golden Sunshine' flowers later than most *A. chinensis* cultivars (~10 d later than 'Hort16A'). Hence, freeze damage has rarely been a concern for 'AU Golden Sunshine' in central Alabama. Based on the results of this study, the advantages of lateral bud removal greatly outweigh the potential negative benefits associated with early crop load reduction. Fruit thinning was not advantageous in this study. However, pollination success was limited throughout this study and fruit set was lower than normal. In years when fruit set is normal, fruit thinning has shown to result in more marketable fruit compared to not thinning (Malone, 2012). This study

will be repeated. ‘AU Golden Sunshine’ often overcrops, and depending on the growing season and pollination success, benefits from crop load reduction. It appears that lateral bud removal will be the most effective way to reduce crop load and realize increased marketable yields.

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Table 4.1. The effects of fruit thinning and lateral bud removal on fruit yield of *Actinidia chinensis* 'AU Golden Sunshine' harvested on September 16, 2013.

Treatment	Total fruit (no.[u])	Total yield (kg)	Marketable fruit[z] (no.)	Cull fruit[y] (no.)	Large fruit[x] (no.)	Fruit drop[w] (no.)	Fruit drop (kg)	Canopy area (m^2)
Control	448a[v]	29.5ns	194b	253a	79b	13ns	0.37ns	12.2ns
Bud thin	373b	30.8	256a	117b	154a	15	0.74	12.8
Fruit thin	399b	25.8	172b	227a	61b	14	0.82	13.4

[z]Fruit ≥ 65 g.
[y]Misshapen fruit and fruit < 65g.
[x]Fruit ≥ 88 g.
[w]Pre-harvest fruit dropped per vine.
[v]Least squares means comparisons within columns using Tukey's test at $\alpha = 0.05$. ns = no difference among treatments.
[u]no. = number

Table 4.2. The effects of fruit thinning and lateral bud removal on fruit quality of *Actinidia chinensis* 'AU Golden Sunshine' harvested on September 16, 2013.

Treatment	Weight (g)	GI[z] (mm)	Firmness (kg)[y]	SSC[x] (%)	DMC[w] (%)	Internal color (hue°)	External color (hue°)
Control	96.4ns	54.4ns	4.7ns	7.9b[v]	17.2ns	103.8a	84.6a
Bud thin	98.5	54.1	4.2	8.6a	17.3	102.8ab	83.4ab
Fruit thin	98.8	54.3	4.6	9.4a	17.3	102.0b	81.4b

[z]GI = Growth Index = (Length + Major Width + Minor Width) $\cdot 3^{-1}$.
[y]Firmness measured with a bench top penetrometer using an 8 mm probe.
[x]SSC = Soluble solids content.
[w]DMC = Dry matter content.
[v]Least squares means comparisons within columns using Tukey's test at $\alpha = 0.05$. ns = no difference among treatments.

Table 4.3. A comparison of fruit traits derived from open pollinated and hand pollinated flowers of *Actinidia chinensis* 'AU Golden Sunshine' that were pollinated 1 day after anthesis with 1-2 day-old flowers from 'Meteor' on April 30, 2013.

Pollination Method	Weight (g)	Length (mm)	Width 1[z] (mm)	Width 2[y] (mm)	GI[x] (mm)
Hand[w]	106.5a[u]	68.4a	46.2a	51.5a	55.4a
Open[v]	58.98b	51.0b	40.9b	43.6b	45.2b

[z]Width 1 was measured as the major width 90^0 from length measurement.
[y]Width 2 was measured as the minor width 90^0 from Width 1 across horizontal plane.
[x]GI = Growth Index = (Length+Width 1+Width 2) $\cdot 3^{-1}$.
[w]Hand pollination was done using direct flower to flower contact of 'AU Golden Sunshine' and 'Meteor'.
[v]Flowers were marked with a hang tag that were of similar physiological stage as the hand pollinated flowers.
[u]Means comparisons between hand and open pollination were performed using t-tests. All comparisons were at $\alpha = 0.05$.

Illustration 4.1. A comparison of fruit traits derived from open pollinated (W) and hand pollinated (R) flowers of *Actinidia chinensis* ‘AU Golden Sunshine’ that were pollinated 1 day after anthesis using direct contact of 1-2 day-old flowers from ‘Meteor’ on April 30, 2013.