

Effective Pollination Period and Influence of Crop Load Management on AU Kiwifruit Cultivars

by

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Abstract

Kiwifruit size and marketability is closely associated with successful pollination and crop load management. Commercial kiwifruit production often involves much effort to enhance pollination due to the inherent difficulties associated with functionally dioecious plants with flowers that do not produce nectar. Determining the length of time that female flowers can be successfully pollinated would aid management decisions. Therefore, the purpose of the first study was to determine the effective pollination period (EPP) for *Actinidia chinensis* ‘AU Golden Sunshine’ and *A. deliciosa* ‘AU Fitzgerald’. In 2013, 30 female flowers of each cultivar that were previously isolated/bagged were hand pollinated each day by direct flower to flower contact with the male pollinizer, and re-bagged to prevent open pollination. ‘AU Golden Sunshine’ flowers were pollinated 1, 2, 3, 4, or 5 days after anthesis (DAA) and ‘AU Fitzgerald’ flowers were pollinated 1, 2, 3, 4, 5, or 6 DAA. Anthesis was considered the day the flower opened. In 2014 and 2015, the same procedures were followed as the year before except 32 female flowers were hand pollinated with harvested male pollen each day with a camel hair brush and the flowers were pollinated for 1, 2, 3, 4, 5, 6, or 7 DAA. ‘AU Fitzgerald’ was not tested in 2014. For ‘AU Golden Sunshine’ in 2013, there was no decrease in fruit set over the 5-day period. Differences in fruit weight, fruit size index and seed number for this year were found between 1-3 and 4-5 DAA. For 2014, differences in fruit set were found between 1-5 and 6-7 DAA while differences in fruit weight, fruit size index and seed number were found between 1-3

and 4-7 DAA. In the last year (2015) for this cultivar, differences in fruit set were found between 1-6 and 7 DAA while differences in fruit weight, fruit size index and seed number were found between 1-5 and 6-7 DAA. Based on fruit set percentages for 2014 and 2015, the EPP for this cultivar is 5 to 6 DAA. For 'AU Fitzgerald', the EPP was more variable. Fruit set was high for the first 4 DAA and then began to decline 5 DAA for the first year (2013) suggesting that the EPP was 4 DAA. Differences in fruit weight, fruit size index and seed number were found between 1-4 and 5-6 DAA. In the second year (2015) however, fruit set remained constant over the 7-day period with differences in fruit weight, fruit size index and seed number found between 1-5 and 6-7 DAA. Flower production and fruit set was higher for 'AU Fitzgerald' in 2015, suggesting that the EPP was affected by the biennial nature of the species.

Another production concern for kiwifruit, is that some cultivars produce excessive yields of small unmarketable fruit. For these cultivars, thinning is necessary to produce fruit of good quality and of marketable size. There are several developmental stages where thinning practices can be implemented, particularly bud swell, bloom and fruit set. The objective of the second study was to determine the effects of lateral bud and fruit removal on marketable fruit yield of *A. chinensis* 'AU Golden Dragon' and the prolific 'AU Golden Sunshine'. Bud-thinning consisted of removing all lateral buds, by hand, leaving only the "king" or terminal bud while fruit-thinning consisted of removing all lateral fruit leaving only the "king" or terminal fruit. Crop load reduction was not advantageous for 'AU Golden Sunshine' or 'AU Golden Dragon' during this study, as no differences were observed between bud or fruit thinning and no thinning treatments for marketable fruit number or marketable yield. Total fruit yield was also not affected by bud or fruit thinning treatments for either cultivar. Thinning treatments did not affect fruit quality for 'AU Golden Sunshine' or 'AU Golden Dragon'.

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Table of Contents

Abstract	ii
Acknowledgments	iv
List of Tables	vi
List of Figures	viii
List of Abbreviations	ix
Chapter 1: Introduction	1
Literature Cited	3
Chapter 2: Literature Review	5
Literature Cited	27
Chapter 3: Effective Pollination Period of ‘AU Golden Sunshine’ and ‘AU Fitzgerald’	33
Literature Cited	48
Chapter 4: Effects of Thinning Lateral Buds and Fruit on Marketable Yield of ‘AU Golden Sunshine’ and ‘AU Golden Dragon’	67
Literature Cited	77

List of Tables

Table 3.1. Effects of hand pollinating <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ flowers 1, 2, 3, 4, or 5 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 2 Oct. 2013 (Thompson, 2014) ^z	52
Table 3.2. Effects of hand pollinating <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 11 Sept. 2014.	53
Table 3.3. Effects of hand pollinating <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 28 Sept. 2015.	54
Table 3.4. Effects of hand pollinating <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ flowers 1, 2, 3, 4, 5, or 6 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 20 Aug. 2013 (Thomposon, 2014) ^z	55
Table 3.5. Effects of hand pollinating <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 19 Oct. 2015.	56
Table 4.1. The effects of fruit thinning and lateral bud removal on fruit yield of <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ harvested on 8 Sept. 2015.	79
Table 4.2. The effects of fruit thinning and lateral bud removal on fruit quality of <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ harvested on 8 Sept. 2015.	80
Table 4.3. A comparison of fruit traits derived from hand pollinated flowers of <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ that were pollinated 1 day after anthesis with supplemental pollen of <i>Actinidia deliciosa</i> on 16 Apr. 2015.	81
Table 4.4. The effects of fruit thinning and lateral bud removal on fruit yield of <i>Actinidia chinensis</i> ‘AU Golden Dragon’ harvested on 8 Sept. 2015.	82
Table 4.5. The effects of fruit thinning and lateral bud removal on fruit quality of <i>Actinidia chinensis</i> ‘AU Golden Dragon’ harvested on 8 Sept. 2015.	83
Table 4.6. A comparison of fruit traits derived from hand pollinated flowers of <i>Actinidia</i>	

chinensis 'AU Golden Dragon' that were pollinated 1 day after anthesis with supplemental pollen of *Actinidia deliciosa* on 8 Apr. 2015..... 84

List of Figures

Figure 3.1. Fruit weight and seed number in relation to day of pollination following anthesis for <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ 2013 (Thompson, 2014).	57
Figure 3.2. <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ canopy temperature (°C) data of both open-air temperature and in-bag temperature recorded during pollination period 2013 (Thompson, 2014).....	58
Figure 3.3. Fruit weight and seed number in relation to day of pollination following anthesis for <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ 2014.	59
Figure 3.4. <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ canopy temperature (°C) data of both open-air temperature and in-bag temperature recorded during pollination period 2014.	60
Figure 3.5. Fruit weight and seed number in relation to day of pollination following anthesis for <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ 2015.	61
Figure 3.6. <i>Actinidia chinensis</i> ‘AU Golden Sunshine’ canopy temperature (°C) data of both open-air temperature and in-bag temperature recorded during pollination period 2015.	62
Figure 3.7. Fruit weight and seed number in relation to day of pollination following anthesis for <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ 2013 (Thompson, 2014).	63
Figure 3.8. <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ canopy temperature (°C) data recorded during pollination period 2013 (Thompson, 2014).	64
Figure 3.9. Fruit weight and seed number in relation to day of pollination following anthesis for <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ 2015.	65
Figure 3.10. <i>Actinidia deliciosa</i> ‘AU Fitzgerald’ canopy temperature (°C) data recorded during pollination period 2015.	66

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
FSI	Fruit Size Index
h	hours
ha	Hectare
IHA	Internal Color
EHA	External Color
kg	Kilogram
L	Liters
m	meter
SSC	Soluble Solids Content
lbf	pounds of force

kgf kilograms of force

CHAPTER ONE

Introduction

Actinidia chinensis ‘AU Golden Sunshine’ and ‘AU Golden Dragon’ as well as *Actinidia deliciosa* ‘AU Fitzgerald’ are three new kiwifruit cultivars that were recently patented by Auburn University and have performed well in Alabama over the last 20 plus years. These cultivars are expected to perform well in the southeastern U.S. where winter chilling averages 800-1200 hours (Dozier et al., 2011). With an emerging kiwifruit industry in this region, determining best management practices to increase marketable yield for these cultivars is therefore crucial.

Shifts in consumer preferences along with increases in supply and demand have switched the focus of kiwifruit production from total yield to good quality fruit of larger sizes (90-115 g) (Lawes et al., 1990; Atkins, 1990). To be successful and profitable, kiwifruit growers must now direct their attention on fruit size. Optimizing orchard management is imperative as many factors influence fruit size, such as pollination and crop load (Lawes et al., 1990).

Closely correlated to seed number, fruit size is highly contingent upon efficient pollination (Pyke and Alspach, 1986; Gonzalez et al., 1998). The dioecious nature of the genus and the lack of nectar produced by the flowers can hinder pollination and make attracting pollinators difficult (Ferguson, 1991; Palmer-Jones and Clinch, 1974). Orchards should be managed properly with appropriate female: male vine ratios and sufficient bee hive numbers to facilitate overcoming these issues. To enhance production, it is also important to know how these flowers can be successfully pollinated. Flower receptivity can be evaluated by determining the effective pollination period (EPP); the period following anthesis in which pollination can effectively produce a fruit (Sanzol and Herrero, 2001). By determining the EPP, growers can

concentrate their efforts during this vital time to increase pollination and fruit size. The EPP for the commercial green kiwifruit standard, *A. deliciosa* ‘Hayward’, was determined to be 4 days after anthesis (DAA) (Gonzalez et al., 1995) but it has yet to be reported for the species *A. chinensis*. Therefore, the aim of the first study was to evaluate the effective pollination period of two of the Auburn University (AU) kiwifruit cultivars, *A. chinensis* ‘AU Golden Sunshine’ and ‘AU Fitzgerald’.

Fruit size is also affected by crop load as some kiwifruit cultivars produce excessive yields of small, unmarketable fruit (Thakur and Chandel, 2004). To produce fruit of good quality and size, thinning is necessary for these cultivars. Thinning strategies can be implemented during several stages of floral/fruit development: bud swell, bloom, and fruit set. Thinning to one fruit per node was shown to increase fruit size of *A. deliciosa* ‘Hayward’ with increased fruit weights observed when thinned prior to fruit set (Vasilakakis et al., 1997). With the prolific bearing cultivar, *A. deliciosa* ‘Allison’, increased marketable yields were observed when vines were thinned before bloom (Thakur and Chandel, 2004). *Actinidia chinensis* ‘AU Golden Sunshine’ often overbears and produces many small fruit of unmarketable size (Malone, 2012). Therefore, the aim of the second study was to determine the effects of removing lateral buds, fruit, or lateral buds plus fruit on the marketable yield of ‘AU Golden Sunshine’ and ‘AU Golden Dragon’.

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CHAPTER TWO

Literature Review

Actinidia

Having originated in the Yangtze Valley in China, the genus *Actinidia* has served as a source of food since A.D. 770 (Morley-Bunker and Lyford, 1999). The fruit, a non-dehiscent berry, grows on deciduous vines along forest lines and amongst mountainous regions in Southern Asia (Ferguson, 1991; Morton, 1987). The Chinese gave this fruit the name “yang tao”, meaning “strawberry peach” (Morton, 1987). Europeans would later change this name to Chinese gooseberry in reference to its flesh color and flavor. In 1962, the fruit underwent another name change by New Zealand growers. In an effort to increase market appeal, the growers changed the name from Chinese gooseberry to “kiwifruit” as it resembled their national bird, the kiwi. The fruit has also been known as “monkey peach”, “sheep peach”, and the “Ichang gooseberry” (Morton, 1987).

The genus *Actinidia* belongs to *Actinidiaceae*, formerly *Dilleniaceae* (Morton, 1987). This genus contains over 50 species all of which are perennial twining plants. (Ferguson, 1990). Fruit from these species naturally vary in size, shape, color, hardness, and edibility (Ferguson, 1999). Kiwifruit was originally identified in this genus as *Actinidia chinensis* Planch (Morton, 1987). It was not until 1984 that a distinction was made between the gold and green varieties. With numerous differences between these variants, Liang and Ferguson (1984) suggested separating them into their own distinct species: *Actinidia deliciosa* for the green fleshed, stiffed hair type and *Actinidia chinensis* would remain for the golden fleshed, soft haired type.

Kiwifruit seeds from China were first introduced to foreign countries such as the United Kingdom, Europe, the United States and New Zealand in the early 1900's (Ferguson, 1990). Commercial cultivation, however, did not begin until the 1930's in New Zealand, and the cultivars used can be traced back to one staminate and two pistillate vines from the single introduction of seed from China in 1904. During this time, Hayward Wright, a New Zealand grower, sent a large fruited kiwifruit strain that would later be known as 'Hayward' to Chico, California. This plant produced most of the material for California's subsequent commercial production with the 'Chico' or 'Chico Hayward' cultivars originating from this plant. New Zealand did not begin to export fruit until 1953, when kiwifruit was exported to Japan, Australia, the United Kingdom, Europe and the United States (Morton, 1987). Kiwifruit plants became widespread as export markets began to grow and kiwifruit became New Zealand's most important export crop (Ferguson, 1990). The cultivars grown today as well as the production practices used have all originated from New Zealand.

It was not until the 1970's that the rest of the world, such as Japan, Italy, France and California, began to commercially produce kiwifruit (Ferguson, 1990). As of 2012, 1.4 million metric tons of kiwifruit were produced around the world according to the UN Food and Agriculture Organization (FAOSTAT, 2015). The top three producing countries were Italy with 384,844 metric tons, New Zealand with 376,400 metric tons, and Chile with 240,000 metric tons. The United States ranked ninth in total kiwifruit production in 2012 with 26,853 metric tons. The majority of this production (98%) was located in California where the dominate cultivar grown was 'Hayward' (California Kiwifruit Commission, 2016).

Cultivars

Actinidia deliciosa

Actinidia deliciosa (A. Chev.) C.F. Liang et A.R. Ferguson, also known as the kiwifruit, has led the emergence of the kiwifruit industry (Ferguson, 1999). One cultivar in particular, ‘Hayward’, has dominated the green fleshed, stiff haired varieties. ‘Hayward’ was a selection made by Hayward Wright from some of the initial Chinese plant material introduced in New Zealand (Morley-Bunker and Lyford, 1999). Originally called ‘Wright’s Giant’, its large sized fruit was flavorful as well as aesthetically pleasing. As these qualities became the preference in New Zealand, as well as abroad, plantings became exclusively ‘Hayward’ and only ‘Hayward’ fruit were allowed to be shipped overseas. The success of the kiwifruit industry is attributed to the qualities, appeal, and storage life of ‘Hayward’.

In the mid to late 1980’s, a New Zealand nursery introduced commercial kiwifruit production to the Southeastern United States (Powell et al., 2000). Little was known about production management practices for this crop as prior cultural information for this region was focused on home gardens. The very first plantings of kiwifruit in the Southeast, commercial and experimental, were located in central and South Alabama in 1987. A majority of the commercial plantings were established in South Alabama, where winter chilling hours normally ranged from 700 to 1000 h, however in previous years these were as low as 500 to 800 h. For all of these plantings (Central and South Alabama), vegetative growth was excellent. However, when the ‘Hayward’ vines began to flower in South Alabama it was evident that the warmer climate would be restrictive. Fruiting in the central part of the state, where chilling hours ranged from 1000 to 1300 h, was acceptable thus making it appear that the lack of chilling hours in southern Alabama obstructed floral and fruit development for this cultivar. The literature during this time had stated a requirement of 400 to 600 h chilling to fulfill the needs for sufficient vegetative and floral

development of kiwifruit however this information had no scientific backing (Powell et al., 1997). There were varying accounts over the years as to what is the chilling hour requirement for ‘Hayward’. A study by Caldwell (1989) in South Carolina determined that ‘Hayward’ needed 950 to 1100 h chilling for ideal vegetative and floral growth while in California, the same cultivar was reported to have a 600 to 850 chilling hour requirement (Grant et al., 1994). Wall et al. (2008) found that 900 h chilling broke dormant bud rest for ‘Hayward’. In this study, no flowers developed suggesting that the chilling hour requirement for maximum floral development exceeds 950 h, which agrees with previous research by Caldwell (1989). These observations indicate the importance of cultivar trials and determining chilling hour requirements. With the introduction of suitable cultivars and best management practices, the Southeastern United States would be optimal for commercial kiwifruit production.

‘AU Fitzgerald’

Over the past 15 to 20 years, Auburn University has been working to establish a new cultivar of *A. deliciosa*, ‘AU Fitzgerald’. This cultivar originated in South Alabama (Summerdale, AL) from seeds sown by Mrs. A. A. Fitzgerald (Dozier et al., 2010). These seeds were from kiwifruit purchased from a local store, probably ‘Hayward’. From these seeds, a female (‘AU Fitzgerald’) and male vine (‘AU Authur’) emerged, flowered and produced a quality crop. The fruit were cylindrical in shape with brown skin that had medium length hairs and green flesh.

The chilling hour requirement for ‘AU Fitzgerald’ was estimated to be 800 h to break dormant bud rest (Wall et al., 2008). It was also estimated that for maximum floral development, 1100 h of chilling was needed for this cultivar although this estimate is unclear due to the low

regression coefficient obtained ($R^2 = 0.50$) and the absence of a clear maximum. Since 'AU Fitzgerald' vines have been fruitful in Summerdale, AL, where accumulated chilling hours average approximately 600 h per growing season, this indicates that the chilling hour requirement for 'AU Fitzgerald' is lower than that of 'Hayward'.

Actinidia chinensis

New Zealand would not be introduced to *Actinidia chinensis* Planch., the soft haired golden fleshed variety, until 1977 (Ferguson, 1999). After its introduction, it was believed that this species had immense commercial potential rivaling all other species of *Actinidia* including *A. deliciosa* with which it has the closest resemblance. In an attempt to increase fruit size as well as improve flavor and flesh color of *A. chinensis*, two New Zealand accessions were crossed in 1987. Four years later, a seedling was discovered from this cross bearing good quality fruit, a distinctly pointed shape, soft hairy skin, and yellow flesh. This selection was later registered under the name 'Hort16A' and was commercially released in 1995 (Patterson et al., 2003). 'Hort16A' would begin being marketed in 1999 under the name ZESPRI™ GOLD Kiwifruit and sold by a division of Kiwifruit New Zealand, ZESPRI International Limited (Ferguson, 1999). Other than 'Hayward', 'Hort16A' was the only other significant kiwifruit cultivar to be traded globally, until recently (Patterson et al., 2003). Vigorous shoot growth as well as earlier bud break and flowering are just a few of the major differences between 'Hort16A' and 'Hayward'. It was also noted that 'Hort16A' is more productive with larger, sweeter fruit than 'Hayward' and it is thought by many to be superior in terms of flavor (Patterson et al., 2003; Ferguson, 1999).

Pseudomonas syringae pv. *actinidiae* (Psa)

Increased preference of *A. chinensis* (gold) species over *A. deliciosa* (green) species within the last 2 decades has led to exclusive plantings of *A. chinensis* ‘Hort16A’ around the globe, especially in New Zealand (Ferguson, 1999). The industry’s reliance on this cultivar, as well as ‘Hayward’, has steered growers to monoculture plantings that have in turn increased the risk for diseases and pests. The first major disease outbreak recorded for the kiwifruit industry occurred in Japan in the late 1980’s, and it was caused by *Pseudomonas syringae* pv. *actinidiae* (Psa), the causal agent for bacterial canker (Takikawa et al. 1989). Psa has since found its way to Italy (Scortichini, 1994) and Portugal (Balestra et al., 2010), as well as many of the other major kiwifruit producing areas around the world. All commercial kiwifruit cultivars are susceptible to Psa, with some more susceptible than others (Everett et al., 2011). *Actinidia chinensis* cultivars were found to be more vulnerable to the pathogen than *A. deliciosa* cultivars, as can be seen with certain cultivars such as ‘Hort16A’, ‘Soreli’, and ‘Jintao’ (Young, 2012).

Seasonal weather usually determines the severity of epidemics (Young, 2012). Bacterial infections are generally controlled by environmental factors such as temperature, light, and moisture, with temperature affecting disease development the most. For Psa, temperatures around 18 C promote pathogenic activity, with temperatures below 15 C or above 20 C tending to slow disease progression. The most serious symptom of Psa (canker) occurs in late winter and early spring when temperatures promote their development. Cankers form in the trunks and leaders of the infected vine causing them to be girdled and die. Buds, canes, leaders, etc. may appear healthy initially, but in late spring, these structures can exude rusty brown ooze and leaves will develop water soaked spots that may be encompassed by a soft yellow halo. At the margins of these leaf spots, the bacterial cells are multiplying and thus advancing the symptoms

of this disease. It is believed that these lesions are the source for the next year's inoculum. Flower buds and canes will also begin to wilt and turn brown.

In New Zealand, Psa symptoms were first observed on gold kiwifruit vines in the Bay of Plenty in November 2010 (Peacock, 2014). Since the initial introduction of bacterial canker in New Zealand, a majority of the production areas was affected. According to Kiwifruit Vine Health's Psa Statistics for (2015), 2724 out of 3276 orchards were identified with Psa in New Zealand. For this kiwifruit producing country, that means that roughly 83% of kiwifruit orchards have been affected by this disease. Kiwifruit is the second most important crop in value for export by New Zealand, earning the country around \$1 billion per year (Everett et al., 2012). Since the introduction of Psa in 2010, New Zealand's kiwifruit industry has experienced at least a 20% decrease in kiwifruit production (Lee-Jones, 2013). The disease has caused concern for growers because exports of gold kiwifruit over the last decade were highly successful and the gold varieties are the most susceptible to the disease. As of 2013, gold kiwifruit was selling at a 70% premium over green kiwifruit around the world. For growers this means they can receive \$60,000 - \$92,000 per hectare for gold kiwifruit compared to \$31,000 - \$35,000 per hectare for green kiwifruit (Lee-Jones, 2013). It was estimated by New Zealand's Ministry for Primary Industry that between 2012 and 2015 Psa will have cost the country \$350 to \$410 million (Lee-Jones, 2013). Orchard costs have also increased as revenue has decreased. This was due to losses from Psa and delays in production as extensively renovated orchards need time to mature. One of New Zealand's major responses to the epidemic was to replace 'Hort16A' vines with new cultivars that have greater disease tolerance. Over 2,000 ha were renovated by the end of 2012, mostly with the new cultivar 'Gold 3'. 'Gold 3' is a fairly new gold kiwifruit cultivar that was released about 2 years after the introduction of Psa in New Zealand (Peacock, 2014). This

cultivar was commercialized in 2010 by Zespri® (Zespri Int. Ltd., Mount Maunganui, NZ) and was observed to be less vulnerable to the pathogen than ‘Hort16A’. Unfortunately, growers who converted to ‘Gold 3’ are still at risk of the new cultivar being infected with Psa because all kiwifruit cultivars were found to be susceptible to this pathogen (Lee-Jones, 2013). With the conversion, growers will also have to expect delays in production as newly grafted vines take around 3 years to mature and achieve full production. New vines, if needed, can take up to 7 years to reach full production. While converting infected ‘Hort16A’ orchards to ‘Gold 3’ was a step in the right direction in combating this epidemic, there are still reports of the new cultivar developing bacterial canker (Lee-Jones, 2013). To successfully produce kiwifruit in these infected areas, more needs to be understood about Psa and best management practices need to be established because there is currently no cure for bacterial canker (Peacock, 2014).

‘AU Golden Sunshine’ and ‘AU Golden Dragon’

Auburn University in conjunction with The Fruit and Tea Institute of Hubei province, P.R. China patented two new *A. chinensis* cultivars, ‘AU Golden Sunshine’ and ‘AU Golden Dragon’, also referred to as ‘Jinyang’ and ‘Jinnong’ respectively (Dozier et al., 2011a; Dozier et al., 2011b). These cultivars were selected from open pollinated orchards in the Hubei province of China and were reproduced asexually in China as well as in Alabama. The fruit produced by ‘AU Golden Sunshine’ is cylindrical with brown skin, short soft hairs and golden yellow flesh. The fruit of ‘AU Golden Dragon’ also has brown skin with short soft hairs and golden yellow flesh but has more of a pronounced elliptical shape when compared to other kiwifruit cultivars (Dozier et al., 2011a).

In Alabama, both cultivars have performed well and each was paired with a pollinizer: ‘AU Golden Tiger’ for ‘AU Golden Sunshine’ and ‘Meteor’ for ‘AU Golden Dragon’ (Dozier et al., 2011a; Dozier et al., 2011b). Of the two cultivars, ‘AU Golden Sunshine’ has the lowest vegetative chilling requirement with 700 h needed for bud break (900 h for optimal flower development) while ‘AU Golden Dragon’ requires 800 h for both vegetative bud break and flower development (Wall et al., 2008). When compared to ‘Hort16A’, the bloom period for ‘AU Golden Sunshine’ is 2.5 wk. later but the fruit ripens ~30 d earlier (Dozier et al., 2011b). For ‘AU Golden Dragon’, the bloom period is approximately 1 wk. before ‘Hort16A’ and the fruit ripens ~50 d earlier (Dozier et al., 2011a). Their fruit shapes also differ as the stylar end of ‘Hort16A’ is pointed while that of ‘AU Golden Sunshine’ is rounded and that of ‘AU Golden Dragon’ is protruding.

Production

As a temperate crop, production of kiwifruit is limited to areas between 34° and 46° north latitude and 30° and 42° south latitude (Ferguson, 1991). Kiwifruit vines perform best in areas with abundant rainfall and temperatures that do not exceed 37.8°C but also have a lengthy period from bud break to harvest free of frost (Ferguson, 1991). They also prefer soils with good drainage and a pH around 6.0. Due to their inability to support themselves, kiwifruit vines require some sort of structure to grow on. For production purposes, there are two main types of structures used: pergolas and T-bars. These structures provide the support needed and allow proper canopy development and ease of management. Previous studies have shown that using other training methods such as the Y trellis, where the canes are grown upwards, lead to poor

results (Snelgar and Manson, 1990). By lowering the angle of the canes, as with pergolas and T-bar systems, flowering and fruit size are increased.

An internal disorder of many fruit crops, alternate bearing (also known as biennial bearing) involves insufficient flowering of whole plants or trees and orchards (Jackson, 1999). The term implies that a heavy or large crop is produced on year and is then followed by a smaller crop the next year. Alternate bearing is natural for some fruit species, however certain occurrences, such as spring frosts or diseases, can initiate the cycle (Jackson, 1999; Schupp, 2011). The alternate bearing cycle can also be caused by plant hormones (gibberellins) produced by the embryos of the excessive amount of fruit set during “on” years (Schupp, 2011). It is also possible that the cycle can be caused by the reduction of carbohydrate reserves during “on” years as well. Flower and fruit thinning during heavy cropping years as well as winter pruning are the main two management practices that can be used to overcome this disorder (Jackson, 1999; Schupp, 2011).

Pollination

Actinidia is a functionally dioecious genus. This characteristic can be a major issue for kiwifruit production because male and female flowers are borne on separate vines. To produce a fruit of the smallest export size (72g) from *A. deliciosa*, a fruit typically needs to contain 700 to 800 seeds that require over 2,000 pollen grains (Thorp, 1994; Pyke and Alspach, 1986). Larger fruit of preferred sizes (93 to 110g) contain roughly 1,000 to 1,400 seeds. *A. chinensis* ‘Hort16A’ flowers that have been fully pollinated 2 DAA can have up to 694 seeds per fruit (Goodwin et al., 2013). Therefore, to produce fruit of marketable size, pollination must be adequate. Pollination is the transfer of pollen from the anther of a flower to the stigma of the same or

different flower (Jackson, 1999). To ensure this, the orchard should be managed with appropriate bee populations and female: male vine ratios. Eight bee hives per hectare should be supplied to guarantee pollination (Morton, 1987). Bee hives are typically brought into the orchards when around 10% of the female flowers are open to reduce competition and to prevent exposing the bees to pesticides (Thorp, 1994). Not all bee hives are brought in at the same time however, as higher percentages of pollen were seen with foragers of later introduced hives, but they should all be in the orchard by the time 40% of the female flowers are open. The hives are usually introduced in intervals that are no longer than 4 d apart. Likewise, a female: male vine ratio of 8:1 or 6:1 is suggested (Strik, 1998; Reil, 1994; Morton, 1987). The vines are typically planted in rows 4.5 to 5 m apart with a male vine every third plant on every third row. Other female: male vine ratios were adopted such as 5:1 or 3:1 as well as the use of strip or overhead male vines, because it was believed that more male vines would be favorable for production purposes (Testolin, 1991; Ferguson et al., 1999). It was later determined in a Goodwin et al. (1999) study that there were no differences in fruit weight or seed number of the fruit produced in orchards with an 8:1 or 3:1 female: male vine ratio. They did find however, with strip or overhead male vine orchard configurations that seed numbers decreased as distance from the male vines increased.

Wind pollination alone is ineffective in producing marketable size kiwifruit (Morley-Bunker and Lyford, 1999). Some pollination of kiwifruit flowers can be attributed to wind, but the arrangement and position of these flowers makes them poorly suited for this type of pollination (Thorp, 1994). A majority of the research conducted concludes that for effective kiwifruit pollination, insects must be involved (Morley-Bunker and Lyford, 1999; Thorp, 1994). Results by Gonzalez et al. (1998) indicated only 12% fruit set for wind pollinated vines, while

wind and insect pollinated vines had 80% fruit set. Fruit size was also affected by pollination method. Fruit weight of wind pollinated vines averaged 39 g while fruit weight of wind and insect pollinated vines averaged 106 g. Weight differences were associated with seed number; the small wind pollinated fruits averaged 33 seeds per fruit, while the larger wind and insect pollinated fruit averaged 688 seeds. Both hand and mechanical pollination methods had high fruit set. Fruit size and weight however were higher when hand pollinated than when open or mechanically pollinated, and had the highest percentage of marketable fruit (Gonzalez et al., 1998).

The primary insect used for pollination purposes is the honey bee (Ferguson, 1990). Unfortunately, bees are not as attracted to the kiwifruit flower as they are to other flowers since kiwifruit flowers lack nectar. Hence, competition for bee visits can be a factor since bees may prefer other pollen sources that produce nectar, such as citrus and clover (Clinch, 1984). Kiwifruit flowers produce pollen that sheds in clumps that is hard for bees to pack into their pollen baskets (Ferguson, 1990). It has been observed that honeybees will generally visit male and female kiwifruit flowers in the morning hours because the pollen is damp and is easier to pack (Palmer-Jones and Clinch, 1974). Honey bees also seem to be more attracted to female flowers than male flowers, as seen in a floral sex preference study by Goodwin et al. (2013). Female and male flowers were placed on a tray in rows, then the tray was hung under a pistillate vine and the number of bee visits recorded. They noticed that out of the 393 honeybee visits, only 2.8% were to ‘Sparkler’, the staminate flowers. Another study showed that out of 180 bee visits, only 2.2% were to ‘Meteor’, the staminate flowers. Pistillate flowers received all of the remaining visits with the majority of the pistillate flowers being visited at least once. They also exposed 21 pairs of flowers, one pair at a time, to study the effect of bee visits. No fruit was

produced from the 21 flowers that did not receive a bee visit. Of the 21 flowers that were visited, only 12 produced a fruit. The average fruit weighed 53.2g and had 93 seeds. A multiple bee visit study was conducted in which 126 flowers were video recorded. Fruit weight and seed number increased up to the fifth visit. The fruit weight and seed number increased by 10.8 g and 78 seeds, respectively, for each additional visit up to the fifth. An average of five visits was documented for flowers that were continuously recorded for the whole day with each visit lasting 12.2 s. For the staminate vine distribution study, they removed all of the flower buds from four of the staminate vines at the north end of the block. They found a 0.8% reduction in staminate pollen being carried with each additional meter from the staminate vine. Seed number also decreased by four seeds per fruit with each additional meter. These results show that it is feasible to plant staminate vines further apart than what was originally suggested for ‘Hort16A’, as honey bees travel long distances carrying the staminate pollen they collected. With fewer staminate vines needed to supply pollen, growers in turn can allocate more orchard space to the more productive pistillate vines.

Open pollination of kiwifruit can result in variable fruit set. In an effort to increase productivity, supplemental pollen can be applied. As an additional way to combat this variability, the effective pollination period (EPP) can be determined (Sanzol and Herrero, 2001). Proper orchard management (appropriate female: male vine ratios and sufficient bee hive populations) in conjunction with the use of supplemental pollen can increase pollination efforts. The EPP was defined as the period following anthesis in which pollination can effectively produce a fruit. This concept was developed by R.R. Williams (1970) as a way to evaluate flower receptivity. A previous study by Gonzalez et al. (1995), determined the EPP for *A. deliciosa* ‘Hayward’ to be 4 days after anthesis (DAA). For this 1-year study, pollen was collected from staminate vines and

dried. Pistillate flowers were isolated with bags prior to anthesis and hand pollinated with the dried pollen before being re-bagged. Twenty-five flowers were bagged each day for 7 d. After 30 d, fruit set was evaluated. There was $\geq 80\%$ fruit set for the first 4 DAA. Five days after anthesis, fruit set was only 36% and continued to drop for the last 2 days. By 7 DAA, there was no fruit set. When plotted with the stigmatic receptivity data, the relationship with fruit set was clearly defined. Stigmatic receptivity for the 4 DAA averaged 84% and then began to decline. A similar pattern between fruit set and stigmatic receptivity suggested that the two are linked. Recent research conducted by Thompson (2014) found similar results to Gonzalez et al. (1995). Fruit set, fruit size and seed number decreased on 5 DAA of the EPP study for *Actinidia deliciosa* 'AU Fitzgerald', suggesting that the EPP is 4 d. Goodwin et al. (2013) also studied stigmatic receptivity. One hundred fifty previously isolated 'Hort16A' flowers were hand pollinated by direct flower contact with a mixture of 'Sparkler' and 'Meteor' pollen and re-bagged for 7 d. Stigmatic receptivity was highest 2 DAA. In this study, the EPP was not reported.

Thinning and Fruit Size

Over the last 25 years, the removal of imposed market regulations on the world fruit trade as well as surges in production, have generated competition within the industry (Atkins, 1990). This opposition within the export market shifted the focus of kiwifruit production from total yield to production of good quality fruit of 90-115 g to meet consumer preferences (Atkins, 1990; Lawes et al., 1990). Thus, growers must now direct their attention on fruit size to be profitable (Atkins, 1990). Issues of concern for growers include inconsistency in kiwifruit production and vine growth (Lawes et al., 1990).

Some kiwifruit cultivars produce excessive yields of small unmarketable fruit that can be a major production concern for growers (Thakur and Chandel, 2004). Crop load relies on the total number of flowers pollinated on each vine because kiwifruit flowers and fruit rarely drop (Grant et al., 1994; Ferguson, 2008). Even poorly pollinated flowers will produce a small fruit that contains a few seeds (Grant et al., 1994). To obtain fruit of good quality and size, crop load management is essential (Thakur and Chandel, 2004; Atkins, 1990). To increase fruit size, growers will commonly include thinning and/or pruning practices in their management programs. The downside to these practices however, is that as the crop load decreases so does total fruit yield. This reduction is significant, but as fruit size increases so will the demand for higher premiums.

Kiwifruit flowers are typically arranged in small inflorescences that are composed of a terminal flower surrounded by lateral flowers (Ferguson, 1991). These inflorescences can be comprised of as few as three flowers or as many as seven including the terminal flower (also known as the “king” flower) that opens before the others. Larger fruit are produced by the terminal flowers, that open earlier and have bigger ovaries with many more locules and ovules than the lateral flowers that open later (Lawes et al., 1990).

In general, terminal flowers of kiwifruit inflorescences set fruit while lateral flowers commonly abort (Antognozzi et al., 1991). Growers typically remove these lateral flowers and/or fruit after fruit set as they are small and of little to no commercial value. To understand the differences in the growth of terminal and lateral fruit, Antognozzi et al. (1991) conducted a study to evaluate fruit size, weight, seed number, maturity, and peduncle characteristics. In this study, mature *A. deliciosa* ‘Hayward’ vines were chosen that had inflorescences with three flowers (one terminal and two laterals) and then applied one of four different treatments before flower

opening: no thinning, removal of one lateral bud, removal of both lateral buds, or removal of the terminal and one lateral bud. Growth of the terminal fruit was not affected by the presence of lateral fruit and was always larger and had more seeds than lateral fruit. Lateral fruit were never able to reach the size of the terminal fruit regardless of removal of terminal or other lateral fruit. Additionally, the peduncles of terminal flowers in triple flower inflorescences were larger and had more vascular bundles than those of lateral flowers. Results suggested that the anatomical features of the peduncle that form during floral development may limit growth of the fruit.

As a prolific fruit bearing cultivar, *A. chinensis* ‘AU Golden Sunshine’ often produces many small, unmarketable fruit (Malone, 2012). Research by Malone (2012) demonstrated that fruit thinning of ‘AU Golden Sunshine’ increased marketable fruit number and yield. In that study, three *A. chinensis* cultivars (‘AU Golden Sunshine’, ‘AU Golden Dragon’ and ‘Hort16A’) were fruit thinned to roughly 60 fruit·m⁻². Thinning entailed leaving the terminal or “king” fruit while removing all lateral fruit 28 d after fruit set. While fruit thinning was found to be beneficial for ‘AU Golden Sunshine’, it did not increase marketable fruit number or yield for ‘AU Golden Dragon’ or ‘Hort16A’ that had lower crop loads when compared to ‘AU Golden Sunshine’. It seems that the advantages of fruit thinning vary depending on the cultivar because fruiting patterns vary.

Recent research by Thompson (2014), however, found that fruit thinning did not increase marketable yield or total weight of *A. chinensis* ‘AU Golden Sunshine’ fruit. In that study, mature ‘AU Golden Sunshine’ vines were given three different thinning treatments: no thinning, removal of lateral buds, or fruit thinning. Fruit thinning treatment entailed leaving the terminal or “king” fruit while removing all lateral fruit. Lateral bud removal was applied 1 wk. before anthesis and fruit thinning was applied 28 d after fruit set. The most marketable fruit per vine

were produced on the bud thinned vines (approximately 256 marketable fruit per vine) whereas fruit thinned and control vines were not different. When compared to the control vines and fruit thinned vines having 79 and 61 large fruit (≥ 88 g) per vine, respectively, the bud thinned vines had roughly twice that number with 154 large fruit per vine. There were no differences in total yield (kg). It was suggested that poor pollination contributed to the lack of variability between treatments and the lower than normal fruit set. While fruit thinning was not found to be beneficial for 'AU Golden Sunshine' likely due to the low crop loads in the control and fruit thinning treatments, a previous study by Malone (2012) indicated that fruit thinning can lead to more fruit of marketable size in years when adequate fruit set is obtained. For Thompson (2014) however, marketable yield increased when lateral buds were removed during the bud swell stage. It therefore appears that lateral bud removal is a possible option for growers working with high yielding kiwifruit cultivars as long as late freezes are not a potential threat.

Similar to 'AU Golden Sunshine', *A. deliciosa* 'Allison' has the tendency to produce excess yields of small fruit of low quality (Thakur and Chandel, 2004). As fruit size is one of the most important factors influencing fruit price, thinning is necessary. Thakur and Chandel (2004) conducted a study to determine how thinning affected the production of good quality marketable fruit and what physiological stage was best for thinning. Mature hand pollinated 'Allison' vines were subjected to nine different thinning treatments: buds thinned to two, four or six flower buds/fruiting shoot; flowers thinned to two, four or six flowers/fruiting shoot; or fruit thinned to two, four or six fruit/fruiting shoot. Buds were removed just before flower opening, flowers were removed during bloom or fruits were removed 10 d after petal fall. Bud thinned vines had higher yields than flower thinned or fruit thinned vines. For grade 'A' fruit (> 75 g), the maximum yield (41.73 kg/vine) was obtained from vines bud thinned to six flower buds/fruiting shoot, that was

higher than any other treatment. These vines produced yields of 88.32 kg/vine with 1,377 total fruits/vine. Vines that were flower thinned to six flowers/fruitlet shoot had similar results with maximum yield of grade 'A' fruit of 34.53 kg/vine. The vines from this treatment produced yields of 83.59 kg/vine with 1,360 total fruits/vine. Bud thinning to two flower buds/fruitlet shoot and flower thinning to two flowers/fruitlet shoot had the highest percentages of grade 'A' fruits of all treatments, 69.68% and 60.23%, respectively. As more buds, flowers, or fruits were removed, the quantity of grade 'B' (50 - 70 g) and 'C' (< 50 g) fruits decreased as grade 'A' fruits increased. Fruit weight and size also increased as more buds, flowers and fruits were removed. Vines thinned to two flower buds/fruitlet shoot had higher fruit weight (79.50 g) and size (length 69.22 mm and breadth 44.40 mm) than any other treatment. Current farm gate prices during that study were used to determine the economic viability of the thinning treatments. Thinning costs were subtracted from the gross returns to establish net benefits for these thinning practices. Financial analysis indicated that vines bud thinned to six flower buds/fruitlet shoot had the maximum net economic benefits (3,808.00 rupees/vine). This treatment had the highest yield of grade 'A' fruit with the best preservation of crop load.

Another prolific fruit bearing cultivar, *A. deliciosa* 'Bruno', was chosen by Lahav et al. (1989) to determine the best physiological stage to thin kiwifruit. The goal of this study was to improve yield and fruit weight as well as study the effects of crop load on alternate bearing. With over 3,000 flowers per vine, the fruit for this particular cultivar are unmarketable due to small size. In that study, vines were thinned at two different dates: flower buds were thinned on 9-18 Apr., 1985 or fruit were thinned on 15-27 May, 1985. For each inflorescence, three to five fruit were left as the two laterals were removed from every third flower. They found that as the number of fruit per vine increased, the size of the fruit decreased. With 700 fruit per vine, the

average fruit weight was around 100 g while vines with 4,700 fruit (un-thinned vines) had an average weight of only 38 g. There were also differences between vines thinned at the bud swell stage and the fruit set stage. Vines thinned at bud swell stage always had larger fruit than the vines thinned at fruit set stage. With an average weight of 76.0 g, vines thinned at the bud swell stage also had the highest percentage of fruit > 70 g of 61.3%. Vines thinned at the fruit set stage had fruit weight that averaged 70.8 g with only 53.7% of the fruit > 70 g. They also found that alternate bearing was significantly influenced by yield. Vines produced more fruit the year following a severe thinning.

Commonly known as hardy kiwifruit, *A. arguta* 'Ananasnaya' is a vigorous kiwifruit cultivar that is grown for its small edible berries (Pescie and Strik, 2004). Fluctuations in fruit weight can be an issue for hardy kiwifruit, so Pescie and Strik (2004) conducted a study to evaluate growth and quality of 'Ananasnaya' fruit. Mature 'Ananasnaya' vines were given varying levels of flower thinning and assessed to determine the link between seed number and fruit size. Four treatments were applied: 15%, 30%, or 50% of flowers were removed before bloom with the fourth treatment being the control (no removal). To implement these treatments, one lateral flower was removed from every other inflorescence for 15% thinning, two lateral flowers were removed from every other inflorescence for 30% thinning, and every other inflorescence was removed for 50% thinning. While marketable yields were not different amongst treatments, king fruit volume along with fruit volume in general increased by 27% and 18%, respectively, regardless of thinning treatment. Lateral fruit volume and weight however were not affected by thinning. Overall, nonmarketable fruit (<12mm in diameter) was decreased by thinning. King fruit weight and marketable fruit weight increased by 19% and 14%, respectively, when thinned before bloom. Kiwifruit vines whose flowers were thinned 50% had

the highest fruit weight of all treatments. There was no effect of thinning treatments on seed weight or seed number per fruit.

Over the years, very little research has been conducted on the cropping behavior of one of the most important commercial kiwifruit cultivars, *A. deliciosa* 'Hayward' (Burge et al., 1987). Seasonal changes in the distribution of fruit in the smaller grade categories can cause major problems in marketing. Burge et al. (1987) conducted a study to determine how crop load effects fruit size, yield, vine growth, and return bloom. For the first year of this study, five thinning treatments were applied to mature 'Hayward' vines one week after full bloom: 0%, 12.5%, 25%, 37.5% or 50% of flowers were removed. During the second year, these same vines were thinned more harshly with treatments being applied at 70% bloom: 0%, 20%, 40%, 60% or 80% of flowers were removed. The results from both years of that study indicated that the number of fruit, yield of export size, preferred export size, and total yield decreased with increasing thinning severity. They also found that mean fruit weight decreased as crop load increased. The same was found for total fruit weight in two of the larger grading categories, 25 (110 - 117 g) and 27 (98 - 109 g); as the number of fruit per vine increased, fruit weight decreased. While fruit grade category 30 (88 - 97 g) was not affected by the thinning, yield of all the other fruit grades (or undersize fruit) decreased with increasing thinning intensity. They also found that the vines flower thinned by 50% the first year of the study, had a 34% increase in flowers the next year.

Fruit Maturity and Harvest

Timing of maturity can vary among kiwifruit cultivars (Ferguson, 1991). 'Hayward' generally reaches maturity around 150 d after flowering while 'Hort16A' usually reaches maturity 130 d after maturity. When ripe, most species of *Actinidia* such as *A. deliciosa* have a

green to dark green flesh (Ferguson, 1991). Chlorophylls a and b generate this vibrant hue that becomes more apparent as starch is converted to sugar during the fruit's ripening process. The flesh of *A. chinensis* cultivars, such as 'Hort16A', however shift from this green color to yellow as the fruit matures (Patterson et al., 2003). Physiologically, 'Hort16A' kiwifruit reach maturity roughly 1 month before 'Hayward', but commercial maturity is reached around the same time as 'Hayward' due to this shift in color. In cold storage, the transition from green to yellow flesh is a slow process for 'Hort16A', therefore the fruit are typically held on the vine until they reach an internal hue angle of 103° or lower.

With few changes in kiwifruit visually, maturity measures such as flesh color, flesh firmness, soluble solids content (SSC), titratable acidity (TA), and total solids (dry weight) must be used to determine ripeness (Mitchell, 1994). The most widely used maturity indexes used for kiwifruit are SSC and flesh firmness. Of the two, SSC is used most often with minimum values used as standards for freshly harvested fruit. The SSC standard for 'Hayward' in New Zealand is 6.2% while California uses 6.5%. The SSC standard used for 'Hort16A' in New Zealand is 10% or higher (Patterson et al., 2003).

Flesh firmness on the other hand is a less accurate measurement of kiwifruit maturity as numerous factors, other than maturity, affects the firmness of the fruit (Mitchell, 1994). Kiwifruit, such as 'Hayward', should be harvested when flesh firmness is around 14 lbf (6.5 kgf) fruit with flesh firmness less than 13 lbf are too soft and more prone to injury. 'Hort16A' is more susceptible to injury at harvest than 'Hayward' because the fruit are softer due to being picked at commercial maturity when flesh firmness is 4 to 5 kgf (Patterson et al., 2003).

Maturity can also be estimated by evaluating total solids (dry weight) which follows the same pattern as SSC during fruit ripening (Mitchell, 1994). Total solids are determined by

cutting the kiwifruit into slices or blending it into a liquid. The samples are then weighed and dried until a stable weight is reached. The beginning fresh weight and end dry weight are then used to determine percent total solids. At early harvest for 'Hayward', dry weight levels are typically around 16% and then increase to 18% or 19% as harvest progresses. Dry weight levels can range anywhere from 18% to 21% for 'Hort16A' at harvest (Patterson et al., 2003).

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CHAPTER THREE

Effective Pollination Period of *Actinidia chinensis* ‘AU Golden Sunshine’ and *Actinidia deliciosa* ‘AU Fitzgerald’

As a recently domesticated crop, kiwifruit has grown from a small specialized commodity for one country to a vital commercial crop grown worldwide (Ferguson, 1999). According to the UN Food and Agriculture Organization, as of 2012, 1.4 million metric tons of kiwifruit were produced around the globe (FAOSTAT, 2015). Italy, New Zealand, and Chile were the top three producing countries with 384,844, 376,400, and 240,000 metric tons, respectively. The United States ranked ninth (26,853 metric tons), with a vast majority of the production (98%) located in California where the main cultivar grown was *Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson ‘Hayward’ (California Kiwifruit Commission, 2016).

The emergence of the kiwifruit industry was led by one cultivar in particular, ‘Hayward’ (Ferguson, 1999). Known as kiwifruit, ‘Hayward’ has dominated the green fleshed varieties (Morley-Bunker and Lyford, 1999). The qualities, appeal and storage life of this cultivar has contributed to the success of the kiwifruit industry. Until recently, the only other cultivar to be traded globally, other than ‘Hayward’, was *A. chinensis* Planch. ‘Hort16A’ (Patterson et al., 2003). This gold fleshed cultivar has the closest resemblance to *A. deliciosa* and has had immense success commercially. ‘Hort16A’ was noted as being more productive than ‘Hayward’, with larger sweeter fruit and thought by many to be superior in flavor (Patterson et al., 2003; Ferguson, 1999). Two years after the introduction of *Pseudomonas syringae* pv. *actinidiae* (Psa) to New Zealand, a fairly new gold kiwifruit cultivar was released, ‘Gold 3’ (Peacock, 2014).

This cultivar was observed to be less vulnerable to the disease than ‘Hort16A’ and was commercialized by Zespri® (Zespri Int. Ltd., Mount Maunganui, NZ) in 2010.

In the Southeastern United States, commercial kiwifruit production was first introduced to in the mid to late 1980’s (Powell et al., 2000). In 1987, commercial and experimental kiwifruit plantings were established in central and South Alabama. Vegetative growth for all of the plantings (Central and South Alabama) was excellent. However, when the ‘Hayward’ vines began to bloom in South Alabama, it was evident that the warmer climate was restrictive. Fruiting was acceptable in the central part of the state, where chilling hours ranged from 1000 to 1300 h, thus making it appear that the lack of chilling hours in South Alabama obstructed floral and fruit development for this cultivar (Wall et al., 2008).

Actinidia deliciosa ‘AU Fitzgerald’ originated in Southern Alabama (Summerdale, AL) from seeds sown by Mrs. A. A. Fitzgerald from fruit purchased at a local store, probably ‘Hayward’ (Dozier et al., 2010). From these seeds, a female (‘AU Fitzgerald’) and male vine (‘AU Authur’) emerged, bloomed and produced a quality crop. The fruit were of a cylindrical shape with brown skin that had medium length hairs and green flesh. ‘AU Fitzgerald’ vines have performed well in Summerdale, AL, where chilling hour accumulation averages less than 700 h per growing season, indicating that the chilling hour requirement is sufficiently lower than ‘Hayward’ (Wall et al., 2008).

Auburn University has worked in conjunction with The Fruit and Tea Institute of Hubei province, P.R. China to patent *A. chinensis* ‘AU Golden Sunshine’ (Dozier et al., 2011). The fruit produced by this cultivar is cylindrical in shape with brown skin that has short soft hairs and a golden yellow flesh. In Alabama, ‘AU Golden Sunshine’ has performed well and was paired with a pollinizer, *Actinidia chinensis* ‘AU Golden Tiger’. ‘AU Golden Sunshine’ has a low

vegetative chilling requirement with 700 h needed for bud break with 900 h needed for optimal floral development (Wall et al., 2008).

Actinidia deliciosa and *A. chinensis* are functionally dioecious species that require inter-planting of female and male plants for sufficient pollination to promote commercial fruit size (Grant et al., 1994). Pollination is the most influential factor affecting fruit size and yield, as kiwifruit size is positively correlated with seed number (Ferguson, 1991). *A. deliciosa* fruit can have more than 1200 seeds per fruit, while *A. chinensis* 'Hort16A' was reported to contain up to ~700 seeds (Goodwin et al., 2013; Hopping, 1976). For adequate pollination, an 8:1 or 6:1 female: male vine ratio is suggested (Reil, 1994).

Alone, wind pollination is ineffective in producing fruit of marketable size (Morley-Bunker and Lyford, 1999). For effective pollination, insects must be involved. For pollination purposed, the honey bee is the primary insect used. Bees however are not typically attracted to kiwifruit flowers compared to other flowers such as citrus and clover (Ferguson, 1991; Clinch, 1984). Kiwifruit flowers naturally lack nectar, which can make attracting pollinators difficult (Clinch, 1984). To reduce competition, growers bring bees into the orchard when female flowers are around 10% bloom (Thorp, 1994). As higher percentages of pollen were seen with foragers from later introduced hives, growers will introduce them at intervals until bloom is around 40%. The pollen produced by kiwifruit sheds in clumps making it difficult for the bees to pack into their pollen baskets (Ferguson, 1990). Bees have been observed visiting kiwifruit flowers in the morning hours when pollen is damp and easier to pack (Palmer-Jones and Clinch, 1974). Growers go to great lengths to ensure successful pollination and will often use supplemental pollen to increase pollination effectiveness and productivity.

To optimize pollination of female vines, it is important to know the length of time that flowers can be successfully pollinated. The effective pollination period (EPP) has been defined as the period following anthesis in which pollination can effectively produce a fruit (Sazol and Herrero, 2001). This concept was developed by R.R. Williams (1970b) as a means to evaluate flower receptivity for fruit crops. The EPP for the commercial green kiwifruit standard, ‘Hayward’, was determined to be 4 days after anthesis (DAA) (Gonzalez et al., 1995). Fruit set during this four-day period remained around 80% or greater. Stigmatic receptivity followed the same pattern as the EPP, as they both remained high for the first 4 DAA and then dropped on day 5. Hence, stigmatic receptivity was suggested to be the limiting factor. Stigmatic receptivity was also studied by Goodwin et al. (2013) for ‘Hort16A’, and was found to be the highest at 2 DAA. The EPP for ‘Hort16A’ was not defined.

With the development of AU kiwifruit cultivars that perform well in the Southeastern U.S., determining best management practices that optimize production of marketable fruit is important for the emerging kiwifruit industries focused on their production. Enhancing pollination of this newly introduced crop will be necessary for producers to increase production of marketable fruit and associated returns on investment. The EPP however has not yet been determined for these cultivars, and to our knowledge, has not been determined for any *A. chinensis* cultivars. By determining the EPP, growers will be able to concentrate their efforts during this crucial time to increase pollination and in turn improve orchard success. Hence, the main objective of the present study was to determine the EPP for the AU kiwifruit cultivars: *A. chinensis* ‘AU Golden Sunshine’ and *A. deliciosa* ‘AU Fitzgerald’.

Materials and Methods

Experimental Design

Kiwifruit vines used for this study were located at the Chilton Research and Extension Center in Thorsby, AL (lat. 32° 55' N; long. -86° 40' W). 'AU Golden Sunshine' vines were established in 1996 while the 'AU Fitzgerald' vines were planted in 2007. These vines were arranged in a randomized complete block design with the 'AU Golden Sunshine' vines trained on a winged t-bar trellis system and the 'AU Fitzgerald' vines trained on a pergola system. Both cultivars had a vine spacing of 2.4 m × 4.8 m. In the study four vines per cultivar were utilized.

Treatment Application

The study was initiated in the spring of 2013 by Thompson (2014) (29 Apr. 2013 for 'AU Golden Sunshine' and 14 May 2013 for 'AU Fitzgerald') with 180 flower buds bagged one day prior to anthesis (i.e. the day the flower opened). The buds that were selected for bagging were completely closed but also had petals that were just beginning to unfold, which has been identified by Brundell (1975) as "Stage 5" of bud development. These flower buds were then covered with white 336 Lawson wax paper bags (10.2 × 26.2 cm) (Lawson Bag Co., Inc., Northfield, IL, USA) to prevent open pollination. Parallel slits had been cut at the top of these bags so that the bag could pass over the bud then be folded around the cane and stapled securely in place allowing the bud to be in the center of the bag. Smaller perpendicular slits had also been cut in the bottom of the bag to allow for water drainage, if needed. The vines also had two WatchDog[®] A-series data loggers (Model A150, Spectrum Technologies, Inc., Aurora, IL, USA) placed in the canopy: one in a wax paper bag for in-bag temperature, the other left out for open air temperature.

After anthesis, 30 bagged flowers were randomly identified each day. These flowers were hand pollinated for 1, 2, 3, 4, or 5 d for ‘AU Golden Sunshine’ (30 Apr. 2013 – 4 May 2013) and 1, 2, 3, 4, 5, or 6 d for ‘AU Fitzgerald’ (15 May 2013 – 20 May 2013) using direct contact of male to female flowers. For ‘AU Golden Sunshine’, the pollinizer flowers were from ‘Meteor’ instead of ‘AU Tiger’ which experienced delayed flowering due to late freezes that spring season. ‘AU Authur’ was used to pollinate ‘AU Fitzgerald’. The flowers were then re-bagged to prevent additional pollination. A labeled hangtag was also placed next to the pollinated flower to identify the treatment day. Ten days after the last treatment was applied, the bags were removed, leaving the tags in place so that the treated fruit could be identified later.

The second year of the study was initiated in the spring of 2014 with 280 ‘AU Golden Sunshine’ flower buds bagged on 28 Apr. 2014 – 2 d prior to anthesis. The same procedures were followed in this year of the study as they were in the previous year, but with slight modifications. After anthesis, 32 bagged ‘AU Golden Sunshine’ flowers were randomly hand pollinated each day for 7 d (30 Apr. 2014 – 6 May 2014) with supplemental *A. deliciosa* pollen (Pollen Collections and Sales, Inc., Lemon Cove, CA, USA) using a camel hair brush. ‘AU Fitzgerald’ was not included in the study this year due to lack of flowers at the same developmental stage.

The third year of the study was initiated in the spring of 2015 with 280 ‘AU Golden Sunshine’ flower buds bagged on 17 Apr., 2015 and 280 ‘AU Fitzgerald’ flower buds bagged on 27 Apr. 2015 – 1 d prior to anthesis. After anthesis, 32 bagged ‘AU Golden Sunshine’ flowers and 32 bagged ‘AU Fitzgerald’ flowers were randomly hand pollinated each day for seven days (18 Apr. 2015 – 24 Apr. 2015 for ‘AU Golden Sunshine’; 28 Apr. 2015 – 4 May 2015 for ‘AU Fitzgerald’). The same materials and procedures were used in this study as in the previous year.

Data Collection

For the first year (2013), bag removal was 16 – 21 DAA (20 May 2013) for ‘AU Golden Sunshine’ and 8 – 14 DAA (29 May 2013) for ‘AU Fitzgerald’ and initial fruit set was evaluated (Thompson, 2014). Fruit set was denoted with a “Y” while no fruit set was denoted with an “N”. If there was an instance where a cane fell but fruit was set, a “Y” was recorded. The fruit were harvested 151 DAA (2 Oct. 2013) for ‘AU Golden Sunshine’ and 92 DAA (20 Aug. 2013) for ‘AU Fitzgerald’ and weight and size of individual fruit recorded the day after. ‘AU Fitzgerald’ was harvested early to avoid potential fruit drop, as some of the vines became infected with *Phytophthora spp.* root rot. Fruit size index (FSI), was determined by using three different fruit measurements: length (L), major width (W1) and minor width (W2) [$FSI = (L + W1 + W2) * 3^{-1}$]. After all measurements were taken, each fruit was labeled and then placed in cold storage at 0.5°C and 85 ± 5% RH until time for seed counts. Fruit were removed from cold storage on 20 Mar. 2013 so that seeds could be extracted and counted. Each fruit was sliced into quarters longitudinally and the white core was removed. A stainless steel spoon was used to scrape the seeds from the pericarp, leaving behind as much flesh as possible. Seeds were placed in a 20 mesh (0.85 mm) sieve and rinsed with warm water to remove any remaining pericarp. Clean seeds were then spread evenly over a labeled paper towel and air dried for 24 hours at 21°C. After 24 hours, the seeds from each fruit were weighed using a Mettler Toledo AG104 balance (Mettler Toledo, Switzerland). To determine average seed weight, a 100-seed sample weight was determined for three randomly chosen fruit from each treatment. The average weight of these three 100-seed samples was used to calculate the total seed number for each fruit within a

treatment. The total counted seeds for these three fruit served as an accuracy check against the calculated seed numbers. An error of $\pm 5\%$ was allowed.

In the second year (2014) of this study, 'AU Golden Sunshine' bags were removed 16 DAA (16 May 2014) and initial fruit set was evaluated on the same day. The fruit for 'AU Golden Sunshine' were harvested 151 DAA (2 Oct. 2014) with data collection (fruit weight, size, and seed number) following the same protocol as the year before.

In the third year (2015), 'AU Golden Sunshine' bags were removed 24 DAA (11 May 2015) and 'AU Fitzgerald' bags were removed 22 DAA (19 May 2015) with initial fruit set evaluation on the corresponding days. 'AU Golden Sunshine' fruit were harvested 164 DAA (28 Sept. 2015) and 'AU Fitzgerald' fruit was harvested 175 DAA (19 Oct. 2015) with data collection (fruit weight, size and seed number) following the same protocol as in previous years.

Statistical Analysis

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experimental design was completely randomized. Regression analysis was performed testing linear, quadratic and cubic models predicting responses using days to pollination from anthesis 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. Estimates of differences in treatment groups (days) were tested using group contrasts. All significances were at $\alpha = 0.05$.

Results

Actinidia chinensis 'AU Golden Sunshine'

In year 1 (2013), fruit set was > 80% for the 5 d period (Table 3.1) (data from Thompson, 2014). All responses were consistent for the 3 DAA but a decrease was observed on day 4 and an increase on day 5. This decrease resulted in cubic trends for all responses. There were no differences found among treatment days 1-3 however, differences were found between the mean of 1-3 DAA and the mean of 4-5 DAA for all responses. A 13.9% difference was observed between fruit weight for 1-3 DAA (89.1 g) compared to 4-5 DAA (76.7 g). For the first 3 DAA, FSI was 53.2 mm while FSI for 4-5 DAA was 50.2 mm with fruit length contributing factor the most. Seed number for the first 3 DAA was 553 seeds versus 354 seeds for 4-5 DAA, a 36% decrease. As seed number decreased over the 5-day period, so did fruit weight and size (Figure 3.1). Mean canopy temperature was 16.8 °C, ranging from 5.9 °C to 28.2 °C (Figure 3.2). Mean temperature inside of the bag was 17.4 °C, ranging from 5.8 °C to 31.4 °C.

In year 2 (2014), differences in fruit set were found between 1-5 and 6-7 DAA (Table 3.2). There was a linear decrease in all responses with increasing DAA except for fruit width 2. Differences were found between days 1-3 and 4-6 for fruit weight, fruit length, width 1, FSI, and seed number. Fruit weight for the first 3 DAA was 104.4 g versus 88.4 g for 4-7 DAA, a 15.3% decrease. FSI was 56.2 mm for 1-3 DAA while 4-7 DAA was 53.0 mm. A 31.5 % difference was observed between seed number for 1-3 DAA (610 seeds) versus 4-7 DAA (418 seeds). As seed number decreased, so did fruit size and weight (Figure 3.3). Mean canopy temperature was 19.2 °C, ranging from 7.6 °C to 31.7 °C (Figure 3.4). Mean temperature inside the bags was 20.1 °C, ranging from 7.5 °C to 35.8 °C.

In year 3 (2015), differences in fruit set were found between 1-6 and 7 DAA (Table 3.3). There was a linear decrease in all responses with increasing DAA. Fruit weight, fruit length, width 1, width 2, FSI and seed number had differences between 1-5 DAA and 6-7 DAA. A 20.1% difference was observed between fruit weight for 1-5 DAA (97.1 g) versus 6-7 DAA (77.6 g). FSI was 43.5 mm for 1-5 DAA while 6-7 DAA was 41.9 mm. Seed number for the first 5 DAA was 562 seeds versus 363 seeds for 6-7 DAA, a 34.5% decrease. As seed number decreased over the 7-day period, so did fruit weight and size (Figure 3.5). Mean canopy temperature was 18.3 °C, ranging from 7.8 °C to 27.5 °C (Figure 3.6). Mean temperature inside of the bag was 18.8 °C, ranging from 7.9 °C to 29.7 °C.

***Actinidia deliciosa* ‘AU Fitzgerald’**

In year 1 (2013), fruit set was high for the first 4 DAA averaging 98% with a decrease observed on day 5 as fruit set was 82% (Table 3.4) (data from Thompson, 2014). All responses were consistent for the first 4 d, but a decrease was observed on day 4 and an increase on day 6. This resulted in cubic trends for all responses. Fruit for day 6 were larger and had more seeds than fruit for day 5, however fruit set for day 6 was only 40%. Differences were found between days 1-4 and 5-6 for fruit weight, fruit length, width 1, width 2, FSI, and seed number. A 41.3% difference was observed between fruit weight for 1-4 DAA (64.3 g) versus 5-6 DAA (37.7 g). FSI was 64.7 mm for 1-4 DAA while 5-6 DAA was 47.8 mm. Seed number for the first 4 DAA was 908 seeds versus 281 seeds for 5-6 DAA, a 69% decrease. As seed number decreased, so did fruit size and weight (Figure 3.7). Mean canopy temperature was 22.6 °C, ranging from 14.5 °C to 30 °C (Figure 3.8). Mean temperature inside the bags was 23.5 °C, ranging from 14.4 °C to 33.1 °C.

In the second year (2015), fruit set was > 95% with no differences observed for the 7-day period (Table 3.5). There was a linear decrease in fruit weight, fruit length, FSI, and seed number with increasing DAA. There were no differences found among treatment days 1-3, but differences were found for fruit weight, fruit length, FSI, and seed number between 1-5 DAA and 6-7 DAA. Fruit weight for the first 5 DAA was 48.2 g versus 42.3 g for 6-7 DAA, a 12.2% decrease. FSI was 43.5 mm for 1-5 DAA while 6-7 DAA was 41.9 mm. An 18.2 % difference was observed between seed number for 1-5 DAA (675 seeds) versus 6-7 DAA (552 seeds). As seed number decreased over the 7-day period, so did fruit size and weight (Figure 3.9). Mean canopy temperature was 17.3 °C, ranging from 8.8 °C to 28.8 °C (Figure 3.10).

Discussion

Results for the EPP determination of ‘AU Golden Sunshine’ suggests that for successful fruit set, flowers should be pollinated within 5 to 6 DAA. However, fruit with the greatest size, weight and seed number occurred when pollinated within 3 DAA for years 1 (2013) and 2 (2014) and within 5 DAA for year 3 (2015). This suggests that pollination success is more likely during the first 3 DAA, and results vary thereafter. This is the first determination of the EPP for the species *A. chinensis* as it had yet to be defined prior to this research. By extending the pollination period from 5 DAA in year 1 to 7 DAA in years 2 and 3, a 69.7% and 43.7% decrease in fruit set was observed for 2014 and 2015 respectively, helping to define the EPP for this cultivar. While Goodwin et al. (2013) did not define the EPP for *A. chinensis* ‘Hort16A’, they did determine stigmatic receptivity to be highest 2 DAA. They also found that flowers hand pollinated 2 DAA had the highest seed number (fruit had up to 694 seeds) with stigmatic receptivity being considered the contributing factor. As the flowers aged from 2 to 6 DAA, seed number declined.

Goodwin et al. (2013) also reported that petal dehiscence began around 3 DAA. Similar results were seen in the present study as flowers pollinated up to 3 DAA were observed to have the greatest seed number for all three years of the study. Petals also began to dehisce 3 DAA while fruit set remained $\geq 80\%$ for all years.

The year 1 (2013) results for 'AU Fitzgerald' suggests that the EPP was 4 DAA. During this year, fruit set averaged 98% for the first 4 DAA before declining to 81.5% for day 5. While fruit set was above 80% on this day, the fruit were smaller and had less seeds than the flowers pollinated during the first 4 DAA. Flowers pollinated 6 DAA had greater seed number than day 5 flowers and the reasons behind the variability are unknown. For year 2 (2015), fruit set remained high averaging 95% over the 7-day period therefore making the EPP difficult to define. No differences in fruit set were observed for this cultivar, however differences were observed for fruit weight, size and seed number between 1-5 and 6-7 DAA. In year 2 (2015), a decrease in fruit set, weight, size and seed number was observed 4 DAA that increased on day 5 and then declined again 6 DAA. For the 31 fruit that were harvested on day 5, notable variability was observed in fruit weight (23.54 to 102.9 g), fruit size (34.5 to 55.1), and seed number (86 to 1932). Six out of the 31 fruit were flat, fan-shaped and larger than normal shaped fruit, and also had more core, pericarp and locules (Watson and Gould, 1994). Both *A. deliciosa* and *A. chinensis* have a tendency to produce these abnormally shape fruit. With irregularities in size, these fruit are difficult to ship and are therefore considered unmarketable. Prior to Watson and Gould's (1994) study, little was known about the development of these abnormally shaped fruit or how to prevent them. Through their research, it was discovered that flat and fan shaped fruit result from flat floral meristems. As for correcting the issue, little is still known.

Year 1 (2013) EPP results for ‘AU Fitzgerald’ were similar to findings by Gonzalez et al. (1995) for *A. deliciosa* ‘Hayward’. In their one-year study, successful pollination was considered $\geq 80\%$ fruit set, which was observed within the first 4 DAA. It was therefore suggested that the EPP for ‘Hayward’ is 4 DAA. The EPP for ‘AU Fitzgerald’ was also determined to be 4 DAA as fruit set remained above 80% during the first year. In year 2 (2015), fruit set for ‘AU Fitzgerald’ remained above 80% for all 7 DAA with no clear differences among treatments. The EPP therefore could not be conclusively determined. It seems plausible that this variability was due to the alternate bearing tendencies of the species *A. deliciosa* (Morley-Bunker and Lyford, 1999). Though crop load was not assessed, the vines experienced some cold damage in January of 2014, as the temperature approached 7 °F on 7 Jan. 2014 (National Weather Service, 2014). This resulted in a relatively low crop year with good fruit size. Subsequently, flower production was prolific in 2015 and crop load management was not sufficient to prevent an overabundance of small fruit. Due to the excessive crop load during 2015, final fruit weight averaged 46.5 g (Table 3.5) this year, whereas ‘AU Fitzgerald’ fruit typically averages approximately 60.2 g (Dozier et al., 2010). Presently, no research has been conducted on the effects of alternate bearing on pollination of kiwifruit flowers. Williams (1970a), however, found associations between cropping behavior and the EPP for certain pear and apple cultivars. For the pear cultivar *Pyrus communis* L. ‘Doyenne’ du Comice’, which has poor crop loads, the EPP is 1 DAA while the heavily cropped cultivar *Pyrus communis* L. ‘Conference’ has an EPP of 10 DAA. Longer EPPs have also been found with cultivars that have a tendency to alternate bear during heavy cropping years than in “off” years. A study by Buszard and Schwabe (1995) on the morphology of apple flowers after heavy cropping years observed the EPP of *Malus domestica* L. Borkh. cv. ‘Cox’s Orange Pippin’ to be influenced by crop loads of the previous year. The results showed that trees

de-fruited in the prior year had flowers that were receptive to pollen at opening while trees that carried a heavy crop load in the prior year had flowers that were not fully receptive to pollen until 3 DAA. These heavily cropped trees had maximum fruit set with flowers pollinated 3 DAA and no fruit set 7 DAA (EPP was 6 DAA) while previously de-fruited trees were able to set fruit 10 DAA. Similar results were observed in the present study of 'AU Fitzgerald' as fruit set remained high for the 7-day period with an excessive production of small unmarketable fruit. Thinning is typically employed during production to counteract the effects of excessive crop loads of kiwifruit. Previous research has shown that crop load can influence alternate bearing tendencies in kiwifruit, with increases in flowering and higher fruit set observed in vines that had previously been severely thinned (Burge et al., 1987; Lahav et al., 1989).

With a shift in kiwifruit production from total yield (kg) to fruit of good quality and of certain sizes (90 to 115 g), growers must now focus on fruit size in order to be profitable (Atkins, 1990; Lawes et al., 1990). Inconsistencies in production however, have created issues for growers (Lawes et al., 1990). One of the major issues is the dioecious nature of this genus that can impede pollination while the lack of nectar production by these flowers can also make attracting pollinators problematic (Ferguson, 1991; Palmer-Jones and Clinch). To overcome these issues, growers spend significant amounts of time and money to manage their orchards properly to guarantee that pollination is sufficient. By determining the EPP for the kiwifruit species/cultivar grown, growers can concentrate their efforts during this important time to increase pollination and in turn improve orchard success and profitability.

Based on the findings of this study, pollination efforts for *A. chinensis* 'AU Golden Sunshine' should be concentrated within the first 5 to 6 DAA. Year 1 (2013) results for *A. deliciosa* 'AU Fitzgerald' suggest that the EPP is 4 DAA, which also coincides with previous

research by Gonzalez et al. (1995) for *A. deliciosa* 'Hayward'. Defining the tendency for 'AU Fitzgerald' to alternate bear is needed as well as its effect on EPP for kiwifruit, as alternate bearing appeared to affect the EPP for 'AU Fitzgerald' in this study. Looking at all years of this study, differences were observed for each cultivar for fruit weight, size and seed number that did not correspond with the differences seen in fruit set. It appears that greater fruit weight, size and seed number result from pollination within the first 3 to 5 DAA for both cultivars, and variable results may occur when pollinating > 3 DAA. While growers can pollinate 'AU Golden Sunshine' flowers up to 6 DAA and 'AU Fitzgerald' flowers possibly up to 7 DAA with adequate fruit set, it appears to be more beneficial to focus on the first 3 to 5 DAA in order to enhance marketable yield.

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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 (DAA) on fruit characteristics. Fruit were harvested 2 Oct. 2013 (Thompson, 2014)^z.

DAA	Weight (g)	Length (mm)	Width		FSI ^w	Fruit Set ^v (%)	Seed Number
			Width 1 ^y (mm)	Width 2 ^x (mm)			
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**	Q*	C*
Difference among days 1-3 ^t	0.2372 ^s	0.9999	0.2851	0.2140	0.641	NS	0.9999
Difference between days 1-3 and 4-5	0.0025	0.0002	0.0061	<0.0001	0.0013	NS	<.0001

^zThompson, A.B. 2014. Determining the effective pollination period and effects of crop load reduction on AU kiwifruit cultivars. Auburn University, Auburn. M.S. Thesis.

^yWidth 1 is measured as the major width 90° from length measurement.

^xWidth 2 is measured as the minor width 90° from Width 1 across horizontal plane.

^wFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^vY signifies a “yes” for fruit set.

^uSignificant quadratic and cubic (C) trends using orthogonal polynomials at $\alpha = 0.05$ (*), 0.01 (**), or 0.001(***).

^tEstimates of differences in treatment groups (days) were tested using group contrasts at $\alpha = 0.05$.

NS = Not significant.

^sProbability greater than calculated F-value.

Table 3.2. Effects of hand pollinating *Actinidia chinensis* ‘AU Golden Sunshine’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 11 Sept. 2014.

DAA	Weight (g)	Length (mm)	Width 1 ^z (mm)	Width 2 ^y (mm)	FSI ^x	Fruit Set ^w (%)	Seed Number
1	106.7	74.0	50.1	45.5	56.5	87.1	635
2	103.0	72.1	50.1	45.8	56.0	85.1	592
3	103.4	70.8	51.3	46.2	56.1	78.1	602
4	88.2	66.1	48.2	44.7	53.0	84.4	375
5	94.5	68.1	49.2	45.6	54.3	78.1	522
6	82.5	64.1	47.4	43.8	51.8	50.0	356
7	0	0	0	0	0	0	0
Trend ^v	L***	L***	L*	NS	L***	L*	L***
Difference among days 1-3 ^u	0.9029 ^t	0.9779	0.8492	NS	0.9491	NS	0.8171
Difference between days 1-3 and 4-6	0.0002	<.0001	0.0227	NS	0.0002	NS	<.0001
Difference among days 1-5						0.9901	
Difference between days 1-5 and 6-7						<.0001	

^zWidth 1 is measured as the major width 90° from length measurement.

^yWidth 2 is measured as the minor width 90° from Width 1 across horizontal plane.

^xFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^wY signifies a “yes” for fruit set.

^vNot significant (NS) or linear (L) trends using regression analysis at $\alpha = 0.05$ (*) or 0.001 (***).

^uEstimates of differences in treatment groups (days) were tested using group contrasts at $\alpha = 0.05$. NS = Not significant.

^tProbability greater than calculated F-value.

Table 3.3. Effects of hand pollinating *Actinidia chinensis* ‘AU Golden Sunshine’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis on fruit characteristics. Fruit were harvested 28 Sept. 2015.

Day	Weight (g)	Length (mm)	Width 1 ^z (mm)	Width 2 ^y (mm)	FSI ^x	Fruit Set ^w (%)	Seed Number
1	102.3	69.4	51.6	45.8	55.6	78.1	591
2	105.3	69.3	53.2	45.9	56.1	75.0	668
3	95.1	67.1	51.0	45.1	54.4	84.4	596
4	94.5	66.5	50.6	45.4	54.2	71.9	488
5	88.4	63.2	50.2	44.9	52.8	65.7	468
6	82.5	62.3	48.9	43.5	51.6	70.8	428
7	72.7	60.1	46.7	42.7	49.8	37.5	298
Trend ^v	L***	L***	L*	L**	L***	L*	L***
Difference among days 1-5 ^u	0.6595 ^t	0.3623	0.9878	1.0000	0.5449	NS	0.3746
Difference between days 1-5 and 6-7	0.0026	0.0011	0.1778	0.0246	0.0031	NS	0.0006
Difference among days 1-6						0.8146	
Difference between days 1-6 and 7						0.0484	

^zWidth 1 is measured as the major width 90° from length measurement.

^yWidth 2 is measured as the minor width 90° from Width 1 across horizontal plane.

^xFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^wY signifies a “yes” for fruit set.

^vLinear (L) trends using regression analysis at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).

^uEstimates of differences in treatment groups (days) were tested using group contrasts at $\alpha = 0.05$.

NS = Not significant.

^tProbability greater than calculated F-value.

Table 3.4. Effects of hand pollinating *Actinidia deliciosa* ‘AU Fitzgerald’ flowers 1, 2, 3, 4, 5, or 6 days after anthesis (DAA) on fruit characteristics. Fruit were harvested 20 Aug. 2013 (Thompson, 2014)^z.

DAA	Weight (g)	Length (mm)	Width 1 ^y (mm)	Width 2 ^x (mm)	FSI ^w	Fruit Set ^v (%)	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***
Differences among days 1-4 ^t	0.6028 ^s	0.9299	0.2851	0.2140	0.589	NS	0.9992
Differences between days 1-4 and 5-6	<.0001	<.0001	0.0061	<.0001	<.0001	NS	<.0001

^zThompson, A.B. 2014. Determining the effective pollination period and effects of crop load reduction on AU kiwifruit cultivars. Auburn University, Auburn. M.S. Thesis.

^yWidth 1 is measured as the major width 90⁰ from length measurement.

^xWidth 2 is measured 90⁰ from Width 1 across horizontal plane.

^wFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^vY signifies a “yes” for fruit set.

^uSignificant cubic (C) trends using orthogonal polynomials at $\alpha = 0.001$ (***).

^tEstimates of differences in treatment groups (days) were tested using group contrasts at $\alpha = 0.05$. NS = Not significant.

^sProbability greater than calculated F-value.

Table 3.5. Effects of hand pollinating *Actinidia deliciosa* ‘AU Fitzgerald’ flowers 1, 2, 3, 4, 5, 6 or 7 days after anthesis on fruit characteristics. Fruit were harvested 19 Oct. 2015.

Day	Weight (g)	Length (mm)	Width 1 ^z (mm)	Width 2 ^y (mm)	FSI ^x	Fruit Set ^w (%)	Seed Number
1	48.4	60.0	37.9	32.9	43.6	93.8	693
2	50.3	58.0	41.6	31.9	43.8	93.8	755
3	50.9	60.2	40.7	33.0	44.6	96.9	706
4	42.4	54.4	38.9	32.0	41.7	90.6	532
5	49.0	54.7	43.5	33.3	43.8	100.0	690
6	40.2	53.0	38.7	32.2	41.3	96.9	571
7	44.4	54.2	40.3	33.2	42.6	98.4	533
Trend ^v	L*	L***	NS	NS	L*		L***
Difference among days 1-5 ^u	0.9674 ^t	0.4899	NS	NS	0.9885	NS	0.6865
Difference between days 1-5 and 6-7	0.0088	0.0007	NS	NS	0.0196	NS	0.0016

^zWidth 1 is measured as the major width 90° from length measurement.

^yWidth 2 is measured 90° from Width 1 across horizontal plane.

^xFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^wY signifies a “yes” for fruit set.

^vNot significant (NS) or linear (L) trends using regression analysis at $\alpha = 0.05$ (*) or 0.001 (***).

^uEstimates of differences in treatment groups (days) were tested using group contrasts at $\alpha = 0.05$.

NS = Not significant.

^tProbability greater than calculated F-value.

Figure 3.1. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia chinensis* 'AU Golden Sunshine' 2013 (Thompson, 2014).

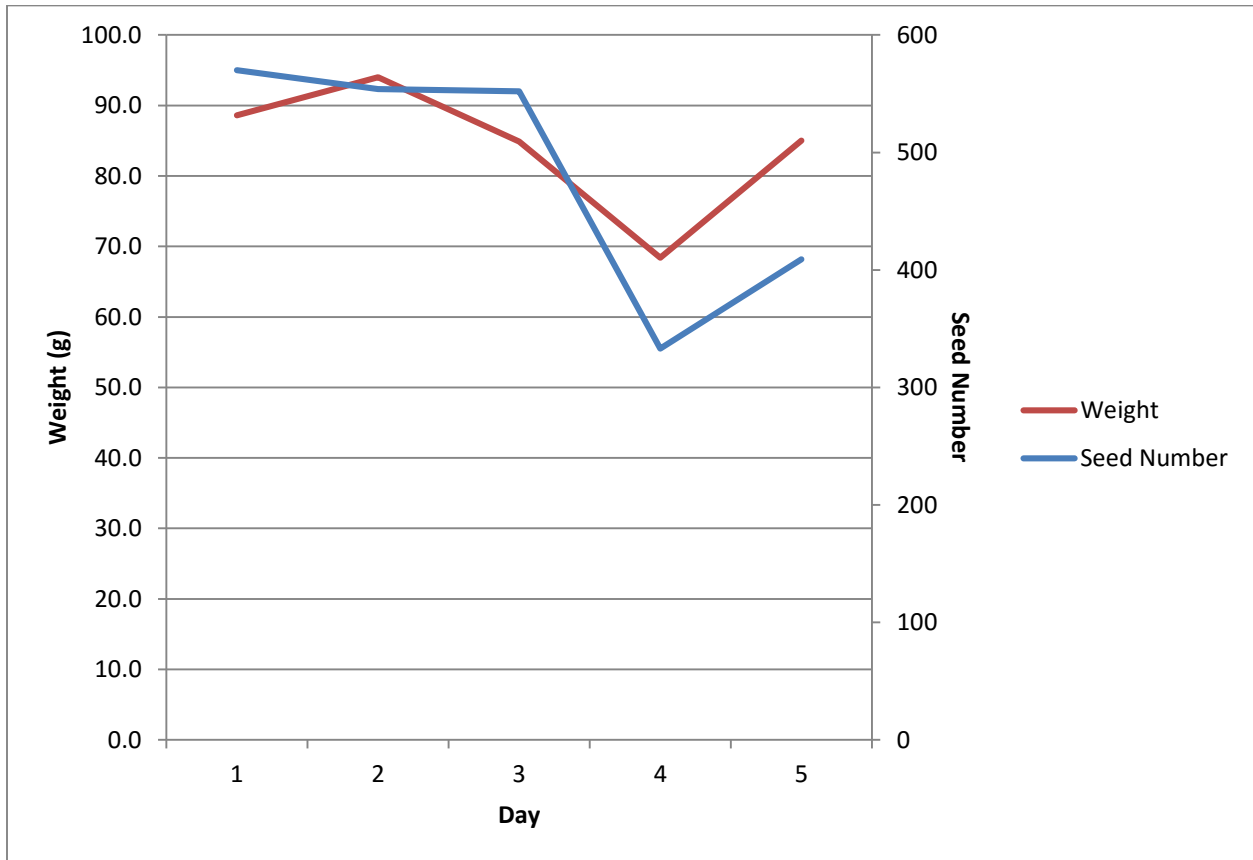


Figure 3.2. *Actinidia chinensis* 'AU Golden Sunshine' canopy temperature (°C) data of both open-air temperature and in-bag temperature recorded during pollination period 2013 (Thompson, 2014).

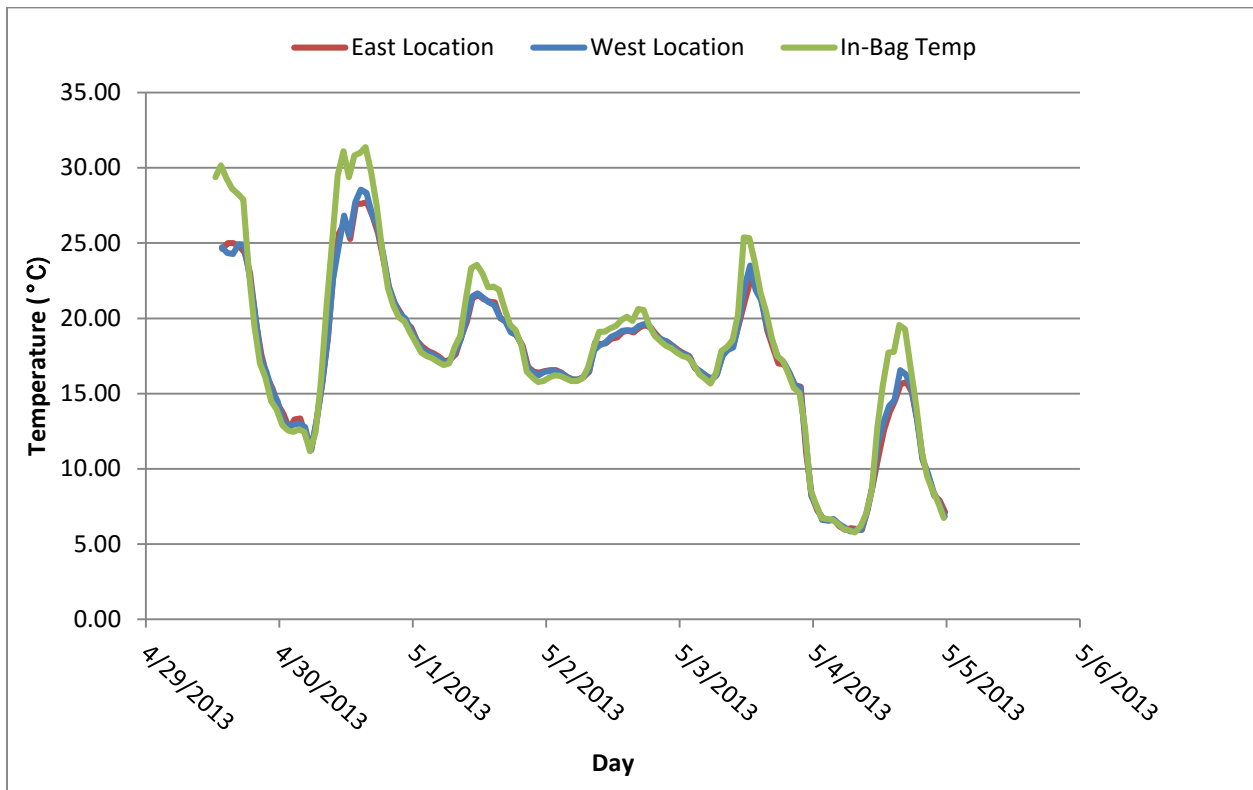


Figure 3.3. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia chinensis* 'AU Golden Sunshine' 2014.

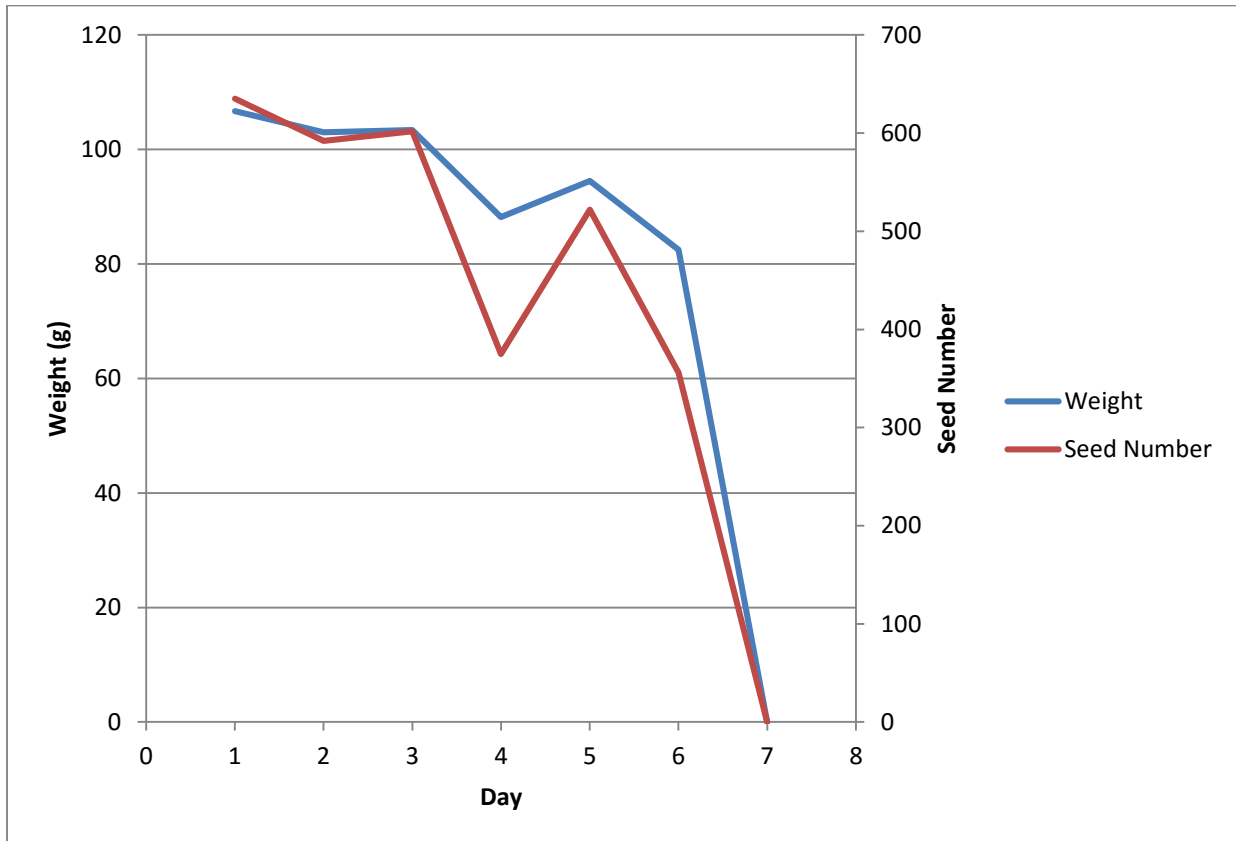


Figure 3.4. *Actinidia chinensis* 'AU Golden Sunshine' canopy temperature ($^{\circ}\text{C}$) data of both open-air temperature and in-bag temperature recorded during pollination period 2014.

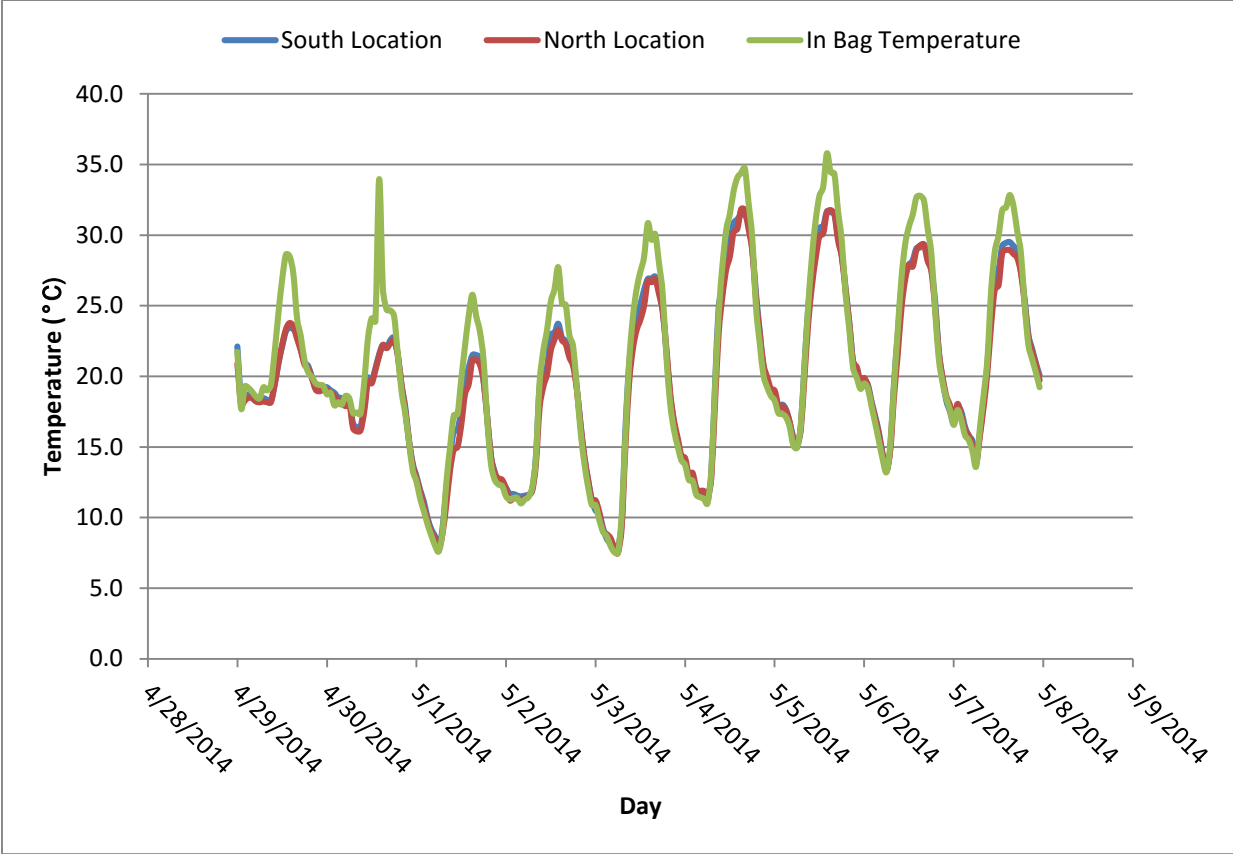


Figure 3.5. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia chinensis* 'AU Golden Sunshine' 2015.

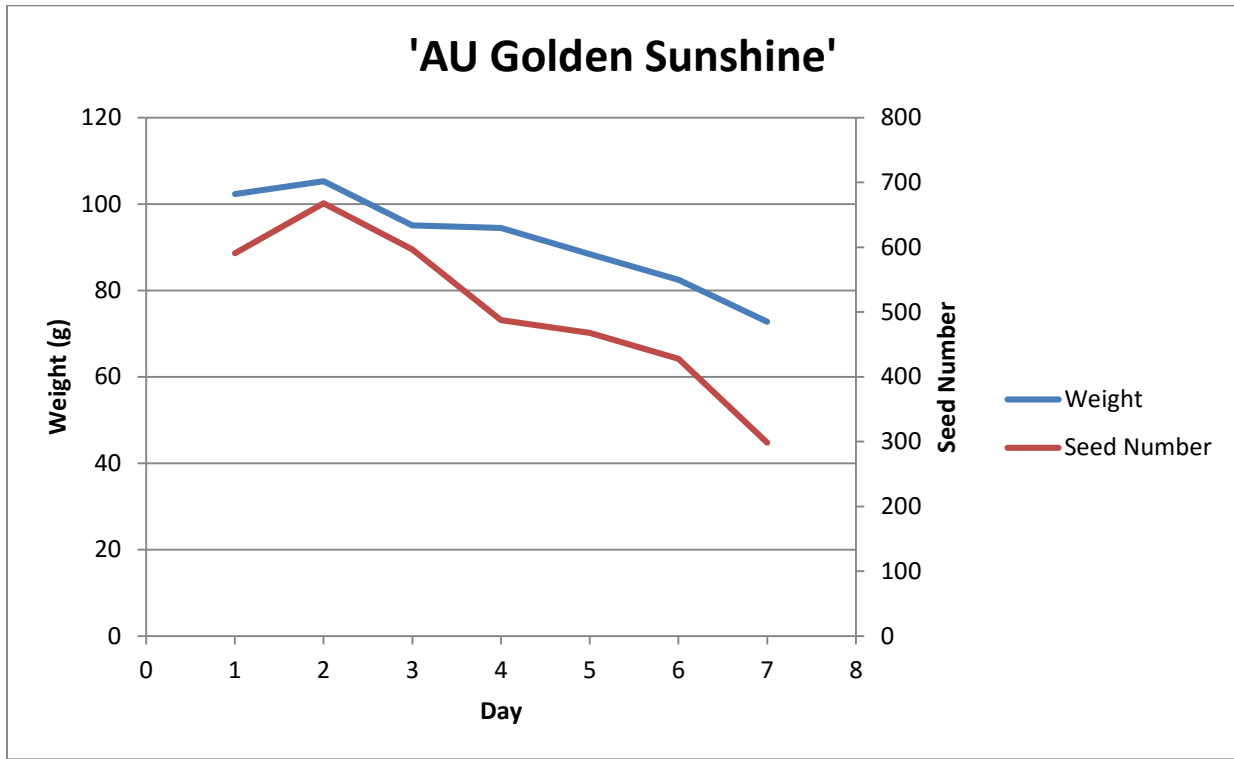


Figure 3.6. *Actinidia chinensis* 'AU Golden Sunshine' canopy temperature ($^{\circ}\text{C}$) data of both open-air temperature and in-bag temperature recorded during pollination period 2015.

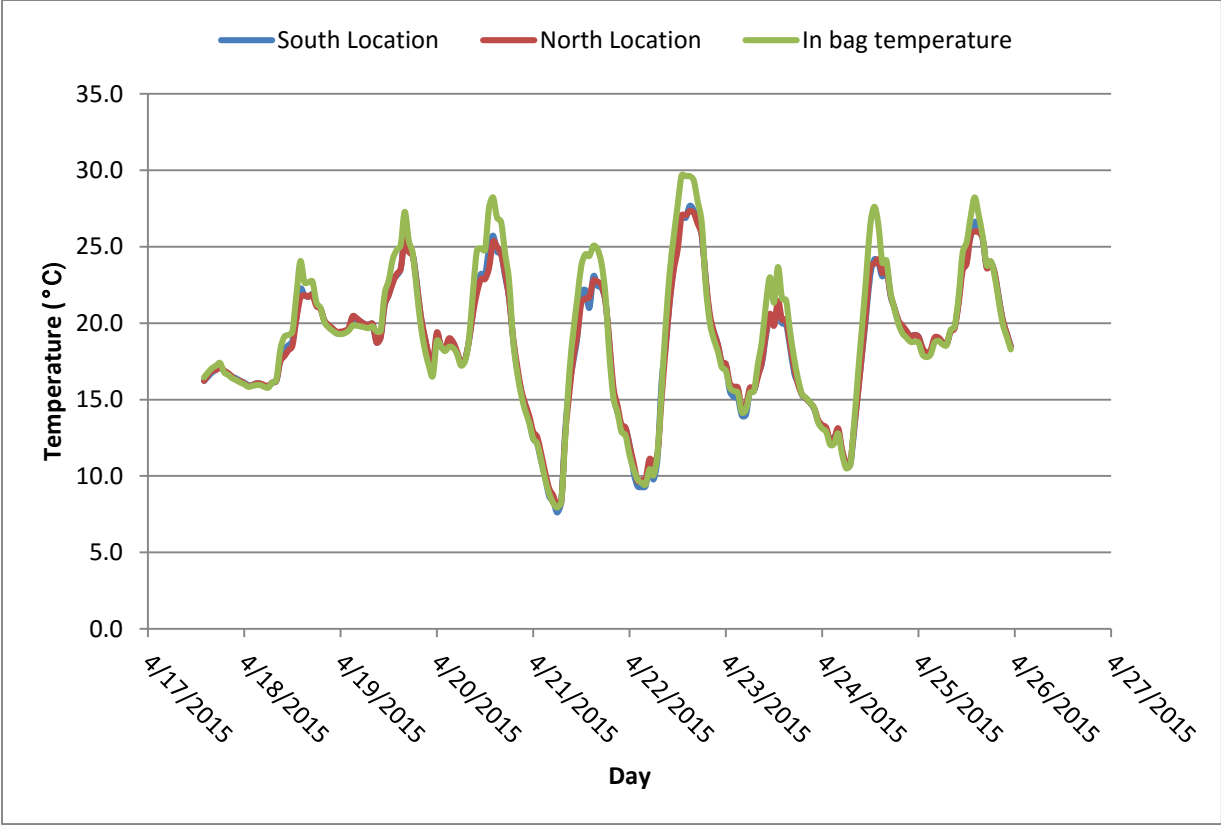


Figure 3.7. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia deliciosa* 'AU Fitzgerald' 2013 (Thompson, 2014).

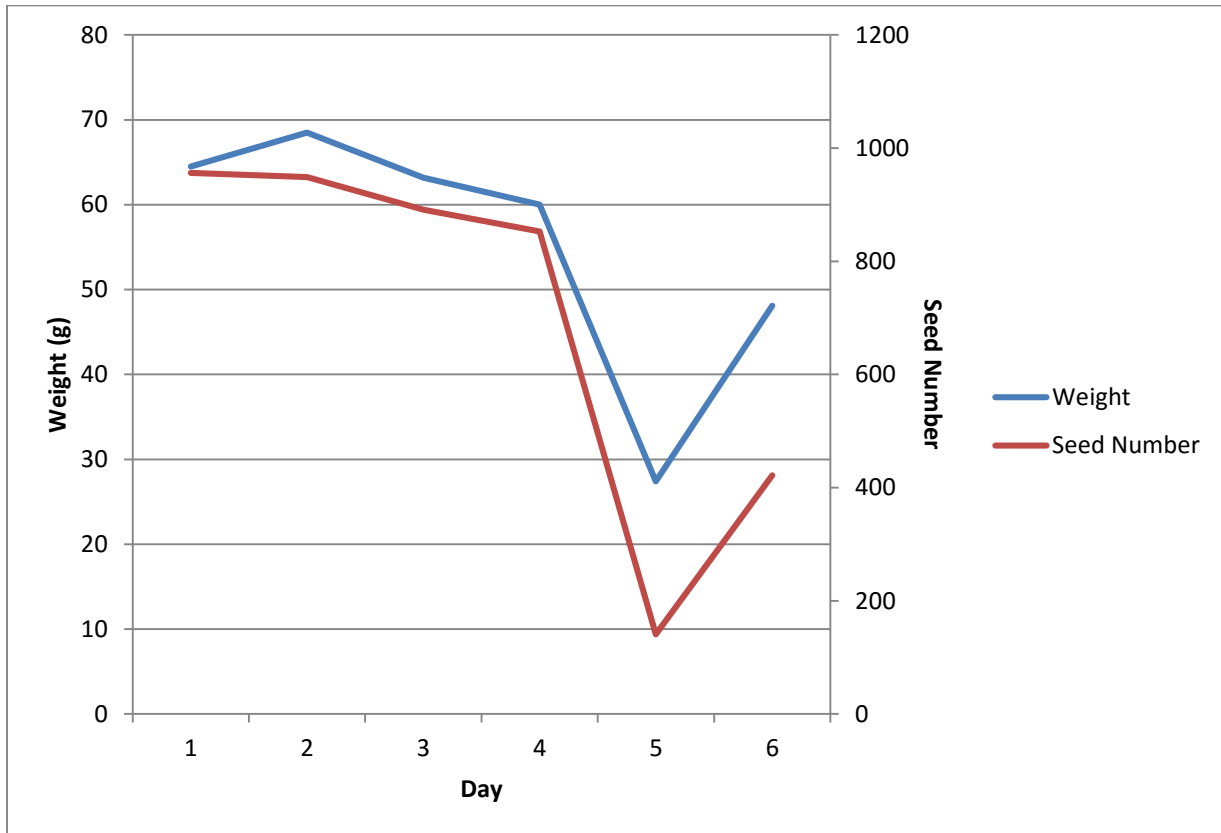


Figure 3.8. *Actinidia deliciosa* 'AU Fitzgerald' canopy temperature (°C) data recorded during pollination period 2013 (Thompson, 2014).

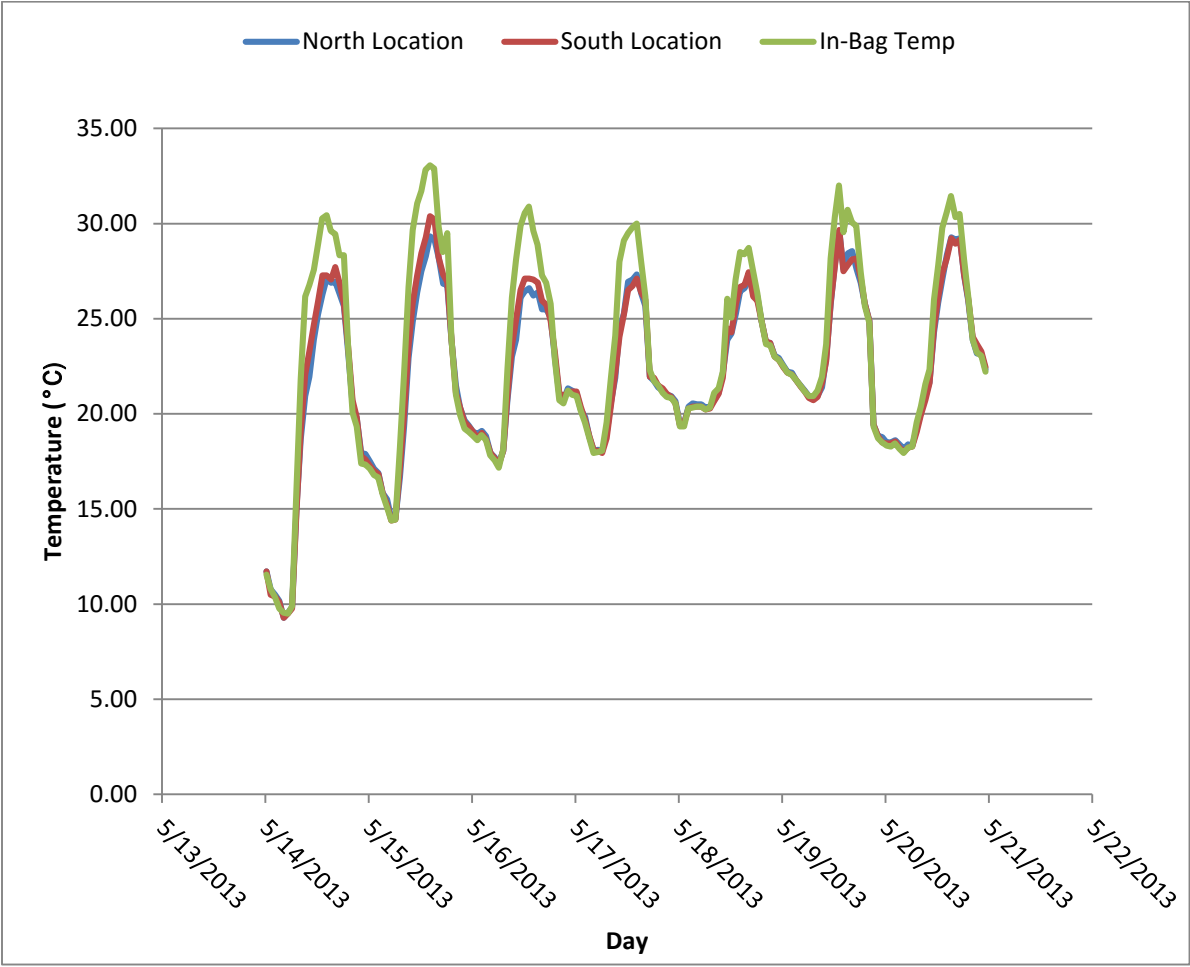


Figure 3.9. Fruit weight and seed number in relation to day of pollination following anthesis for *Actinidia deliciosa* 'AU Fitzgerald' 2015.

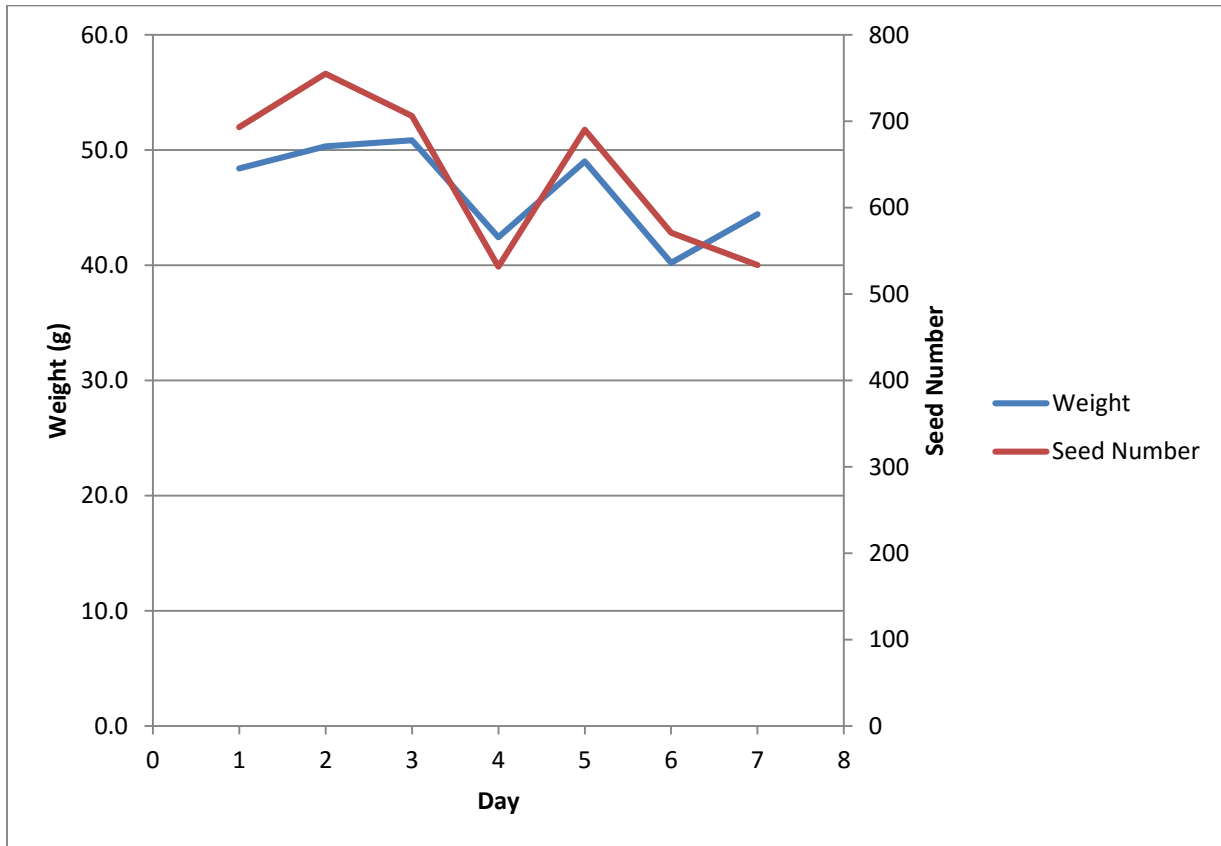
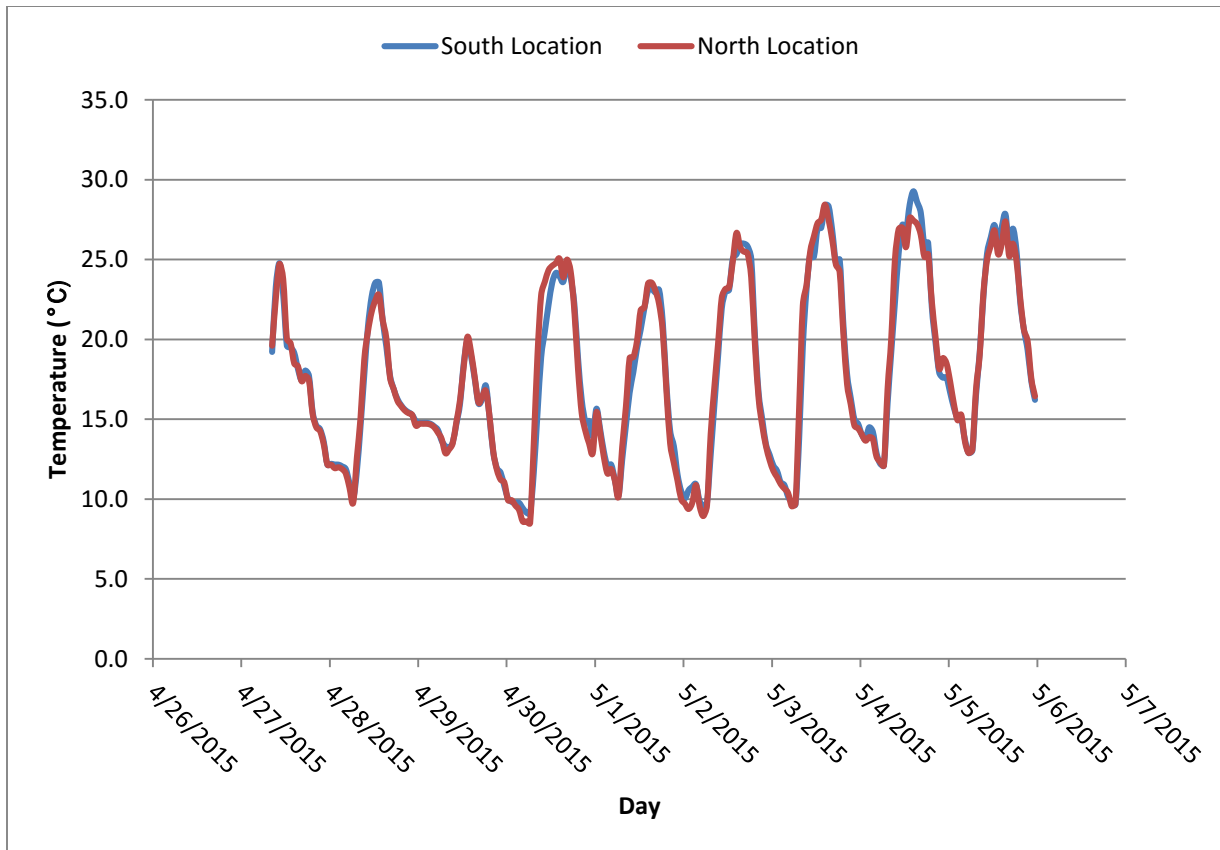


Figure 3.10. *Actinidia deliciosa* 'AU Fitzgerald' canopy temperature ($^{\circ}\text{C}$) data recorded during pollination period 2015.



CHAPTER FOUR

Effects of Thinning Lateral Buds and Fruit on Marketable Yield of *Actinidia chinensis* ‘AU Golden Sunshine’ and ‘AU Golden Dragon’

Two kiwifruit cultivars have comprised the majority of commercial kiwifruit production worldwide, the green fleshed *Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson ‘Hayward’ and the golden fleshed *Actinidia chinensis* Planch. ‘Hort16A’ (Ferguson, 1999). One of the main factors determining fruit price and orchard profitability of kiwifruit is fruit size (Thakur and Chandel, 2004; Pescie and Strik, 2004). Crop load affects fruit size as some kiwifruit cultivars produce excessive yields of small, unmarketable fruit (Thakur and Chandel, 2004). To obtain fruit of good quality and size for these cultivars, thinning is necessary. There are several stages during development when thinning strategies can be implemented, particularly bud swell, bloom, and fruit set.

Kiwifruit flowers are typically arranged in small inflorescences that are composed of a terminal flower surrounded by lateral flowers (Ferguson, 1991). These inflorescences can have as few as three flowers or as many as seven with the terminal flower (also known as the “king” flower) opening before the others. Larger fruit will be produced by the “king” flowers, as the flowers that open earlier have bigger ovaries with many more locules and ovules than flowers that open later (Lawes et al., 1990).

A study of *A. deliciosa* ‘Hayward’ showed that thinning to one fruit/node increased fruit size (Vasilakakis et al., 1997). They also determined that final fruit weights increased as thinning was performed earlier. Increased marketable yields were also observed in a bud thinning study of a prolific bearing cultivar, *A. deliciosa* ‘Allison’ (Thakur and Chandel, 2004). The same results

were seen in a study on hardy kiwifruit *A. arguta* ‘Ananasnaya’, as the average fruit weight increased by 14% when thinned before bloom (Pescie and Strik, 2004). As a prolific fruit bearing cultivar, *A. chinensis* ‘AU Golden Sunshine’ often produces many small, unmarketable fruit (Malone, 2012). Malone (2012) showed that fruit thinning of ‘AU Golden Sunshine’ can increase marketable yield. In a study by Thompson (2014), fruit thinning did not increase marketable yield of ‘AU Golden Sunshine’ fruit, but marketable yield did increase when lateral buds were removed during the bud swell stage. The objective of this study was to determine the effects of removing lateral buds or fruit on the marketable yield of ‘AU Golden Sunshine’ and ‘AU Golden Dragon’.

Materials and Methods

Experimental Design

Kiwifruit vines used were located at the Chilton Research and Extension Center in Thorsby, AL, USA (lat. 32° 55' N; long. -86° 40' W). Both ‘AU Golden Sunshine’ and ‘AU Golden Dragon’ vines were established in 2001. These vines were arranged in a completely randomized block design with both the ‘AU Golden Sunshine’ and ‘AU Golden Dragon’ vines trained on a winged t-bar trellis system. Both cultivars had a vine spacing of 2.4 m × 4.8 m.

Three treatments were implemented, with ‘AU Golden Sunshine’ treatments having three replications and ‘AU Golden Dragon’ having seven replications per treatment (each vine was considered a replication). The three treatments were: 1) no thinning (control), 2) removal of lateral buds only leaving the “king” buds and 3) removal of lateral fruit only leaving the “king” fruit.

Treatment Application

The study was initiated in the spring of 2015 (8 Apr. 2015) with three ‘AU Golden Sunshine’ and seven ‘AU Golden Dragon’ vines being subjected to the first treatment, lateral bud thinning. All of the lateral buds were removed by hand leaving only the “king” bud. Fruit thinning treatments were implemented 16 days after anthesis (DAA) on 24 Apr. 2015 for seven ‘AU Golden Dragon’ vines and 20 DAA on 6 May 2015 for three ‘AU Golden Sunshine’ vines. All lateral fruit on these vines were removed by hand only leaving the “king” fruit. During treatment application, the number of buds and fruit removed were recorded. ‘AU Golden Sunshine’ had approximately 2966 ± 1144 buds and 1394 ± 252 fruit removed from the bud and fruit thinned vines, respectively. For ‘AU Golden Dragon’, approximately 156 ± 75 buds and 44 ± 13 fruit were removed from the bud and fruit thinned vines, respectively.

Each vine was manually pollinated with dry *A. deliciosa* pollen (Pollen Collections and Sales, Inc., Lemon Cove, CA, USA) using a tractor drawn air sprayer. Due to the high rainfall during the bloom period, ‘AU Golden Dragon’ only received pollen application one time on 9 Apr. 2015. Pollen was applied twice to ‘AU Golden Sunshine’ on 20 Apr. 2015 and 24 Apr. 2015. To determine the effectiveness of the pollen applications for each cultivar, ten randomly chosen, newly opened flowers were also hand pollinated on each bud-thinned vine. These flowers were covered with white wax paper bags (10.2×26.2 cm) (336 Lawson, Lawson Bag Co., Inc., Northfield, IL, USA) one day prior to anthesis (8 Apr. 2015 for ‘AU Golden Dragon’ and 16 Apr. 2015 for ‘AU Golden Sunshine’) to prevent open pollination. After the flowers were hand pollinated with supplemental *A. deliciosa* pollen, they were then re-bagged and marked with colored plastic hang tags. The bags were removed after fruit set and then evaluated. Ten

open pollinated flowers (control) were also tagged on each bud thinned vine to serve as a comparison.

Five measurements were taken on each vine to determine canopy area using a flexible measuring tape: three length measurements and two width measurements. The first length measurement was taken along the outer most edge of the vine, the second was taken in the middle of the vine, and the third was taken on the opposite outer most edge of the vine with all measurements running parallel to the winged t-bar trellis. The two width measurements were taken over the canopy 1 m off to the left and right of the vine's trunk and ran perpendicular to the winged t-bar trellis. Any gaps in canopy coverage (missing leaves) were accounted for by taking length and width measurements of the void and then using them to calculate the missing area. This calculation was then deducted from the total canopy area. Because canopy area was not different between the vines, data were reported on a per vine basis.

Data Collection

Fruit from both cultivars was harvested on 8 Sept. 2015 when the soluble solids content (SSC) was approximately 10% and the internal hue angle was approaching 103° (Patterson et al., 2003). Prior to harvest (4 Sept. 2015), a pre-harvest drop was observed and the dropped fruit for each vine was counted and recorded. At harvest, the total yield for each vine was determined and graded into the different commercial size categories. Fruit ≥ 65 g was considered marketable (size category 45) and fruit that was < 65 g or misshapen was considered culls (Rushing, 2014). Data was collected per vine as canopy area was not different among treatments. For each vine, total fruit number, total yield weight (kg), marketable fruit number, marketable yield weight (kg), cull number, cull weight (kg), fruit number ≥ 88 g, fruit ≥ 88 g yield weight (kg), and pre-

harvest drop number were collected. During data collection, 10 fruit of marketable size and of the same size category were randomly selected from each vine to determine if fruit quality was affected by the different treatments. To determine fruit quality, the following measurements were taken on each fruit: fresh weight (FW), flesh firmness, dry matter content (DMC), soluble solids content (SSC), external hue angle, and internal hue angle.

External and internal hue angle were measured using a Minolta CM-2002 spectrophotometer (Minolta, Tokyo, Japan). The average of two readings per fruit was used to determine the external hue angle. The first reading was taken on the exterior in the center of the fruit, and the second reading was taken in the same location but with the fruit rotated laterally 180° from the first reading. To measure the internal hue angle, a 2 mm slice of skin was removed from the shoulder of the fruit to expose the flesh. This same area of exposed flesh was also used to measure flesh firmness using a bench top penetrometer with an 8 mm flat ended probe (model FT 327, McCormick Fruit Tech, Yakima, WA, USA). Two approximate 3 mm slices from the middle of each fruit were cut using a commercial food slicer (Waring Pro®, East Windsor, NJ, USA) to determine DMC. Each individual slice was weighed before placing in a food dehydrator (Excalibur® products, Sacramento, CA, USA) to dry for 24 hours at 67.4 °C. Once dried, the slices were re-weighed and the initial and post weights were used to determine the average DMC for each fruit (fruit dry weight/fruit fresh weight x 100). SSC was measured using juice from 10 mm sections from the stem and stylar ends of each fruit using a Leica Mark 2 Abbe refractometer (Leica Inc., Buffalo, NY, USA). The average of readings for the stem and stylar ends was used to determine the SSC for each fruit.

Statistical Analysis

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The experiment was a randomized complete block design. 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 either the normal, Poisson, and negative binomial probability distribution, 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

Actinidia chinensis 'AU Golden Sunshine'

Bud-thinned vines had fewer total fruit compared to control and fruit thinned vines (Table 4.1). There were no differences among treatments for total yield, marketable fruit, cull fruit, large fruit (≥ 88 g), and fruit drop number. Though there were more than 2 times the number of marketable fruit and ~ 3.4 times the number of large fruit harvested from fruit-thinned vines compared to control vines, there were no statistical differences likely due to variation and the low degree of freedom for this study (only 3 reps). Similarly, there were $1.4\times$ the number of marketable fruit and $2.3\times$ the number of large fruit in bud-thinned vines compared to control vines. Though not statistically different, there were ~ 2 times greater cull fruit for control vines compared to bud thinned and fruit thinned vines. Treatments did not affect fruit quality (Table 4.2). For the pollination check, 93.3% (28 out of the 30) of hand pollinated flowers set fruit while only 40% (12 out 30) of the open pollinated flowers set fruit. Fruit weight and size were

greater for hand-pollinated flowers than open pollinated (Table 4.3), indicating that mechanical pollen application was not effective. Fruit weight was 2.4 times greater when flowers were hand pollinated compared to open pollinated flowers.

***Actinidia chinensis* ‘AU Golden Dragon’**

Crop load was low overall for this cultivar, with relatively few lateral buds or lateral fruit set. Hence, the total fruit number was not different between the treatments. There were no differences among treatments for total yield, marketable fruit number, cull fruit number, large fruit (≥ 88 g) number, or fruit drop number. Though not statistically different, there was 20.1% difference in cull fruit number for control vines compared to fruit thinned vines. Fruit quality was also not affected by treatments (Table 4.5). A 25% difference was observed between hand and open pollinated flowers for the pollination check (Table 4.6). Hand pollinated flowers had 91.4% (64 out of 70) of flowers set fruit while open pollinated flowers had 68.6 % (48 out of 70) of flowers set fruit. Fruit weight and size were greater with hand-pollinated flowers than with open pollinated, indicating again that mechanical pollen application was not effective. Fruit weight was 1.6 times greater when flowers were hand pollinated compared to open pollinated flowers.

Discussion

Results for *A. chinensis* ‘AU Golden Sunshine’ and ‘AU Golden Dragon’ indicate that marketable yield was not influenced by flower bud or fruit removal in this study. Previous research by Thompson (2014) however, found that the greatest numbers of marketable size fruit (256 per vine) for ‘AU Golden Sunshine’ were produced on bud thinned vines. These vines also had roughly twice the number of large fruit (≥ 88 g) with 154 large per vine compared to 79 and

61 large fruit per vine for control and fruit thinned vines, respectively. There were no differences among treatments in regards to total yield. The lack of variability between thinning treatments and lower than normal fruit set that year were believed to be caused by poor pollination. Increased fruit size was observed with early stages of bud thinning where only lateral buds were removed (Antognozzi et al., 1991). The absence of competition from lateral buds prior to anthesis enhanced cell division in the remaining terminal (“king”) bud thus increasing fruit size. In contrast, Malone (2012) found that fruit thinning of ‘AU Golden Sunshine’ yielded more marketable size fruit in years where adequate fruit set was obtained. Fruit thinning to 60 fruit·m⁻² left an average of 19 marketable size fruit·m⁻² compared to only 8 marketable size fruit·m⁻² for the lateral fruit removal treatment. While fruit thinning was found to be beneficial for ‘AU Golden Sunshine’ in that study, it was not beneficial for ‘AU Golden Dragon’ that experienced lower crop loads than ‘AU Golden Sunshine’. Similar results were observed in the present study as fruit thinning treatments had no effect on marketable fruit number (ranged from 83-95 fruit per vine) or yield (ranged from 7.2-8.2 kg) for ‘AU Golden Dragon’. It appears that as fruiting patterns vary, the advantages of fruit thinning also vary depending on the kiwifruit cultivar.

Research by Lahav et al. (1989) on the best physiological stage to thin *A. deliciosa* ‘Bruno’ kiwifruit found that vines thinned at the bud swell stage always had larger fruit than those thinned at the fruit set stage. Bud thinned vines also had the highest percentage of fruit > 70 g with fruit averaging 76.0 g compared to 70.8 g for fruit thinned vines. Similar results were found by Thakur and Chandel (2004) for *A. deliciosa* ‘Allison’. Vines that were thinned to two flower buds/fruitlet shoot (69.68%), and two flowers/fruitlet shoot (60.23%) had the highest percentage of grade ‘A’ fruit compared to all other treatments. Greater fruit weight (79.50 g) and size (length 69.22 mm and breadth 44.40 mm) was found with vines thinned to two flower

buds/fruitlet shoot than with any other treatment. They also determined the economic viability of thinning using the current farm gate prices. Net benefits were established for thinning by subtracting thinning costs from gross returns. They found that vines thinned to six flower buds/fruitlet shoot had the maximum net economic benefit while yielding the greatest number of grade 'A' fruit and preserving the best crop load.

In the present study, crop load was not affected by bud or fruit removal for either 'AU Golden Sunshine' or 'AU Golden Dragon'. With no differences found in canopy area for either cultivar, we believe that poor pollination was a contributing factor. Effectiveness of pollination (both open and supplemental pollination) was tested in this study by comparing open pollinated flowers to flowers that were hand pollinated. A 68.5 g difference in fruit weight was observed between hand pollinated flowers and open pollinated flowers of 'AU Golden Sunshine' while a 37.9 g difference was observed for 'AU Golden Dragon'. Pollination was likely hindered by the excessive rainfall experienced this season. Average rainfall in Alabama during April of 2015 was 7.12 in., 2.33 in. higher than normal for this time of the year (Christy, 2015). Marketable fruit number and yield could have possibly been greater had pollination been more successful.

Fruit drop data was recorded for both cultivars due to 'AU Golden Sunshine' tendency to drop fruit prior to harvest. There were no differences for fruit drop for either cultivar in regards to thinning treatment. It appears that fruit drop is not influenced by crop load.

A major production concern for growers is excessive yields of small unmarketable fruit that are produced by some kiwifruit cultivars (Thakur and Chandel, 2004). As kiwifruit flowers and fruit rarely drop, crop load relies heavily on total number of pollinated flowers (Grant et al., 1994; Ferguson, 2008). Therefore, to obtain fruit of good size and quality, crop load management is essential (Thakur and Chandel, 2004; Atkins, 1990). Management programs commonly

employ thinning and/or pruning practices to increase fruit size. As crop load decreases however, so does total fruit yield. The demand for higher premiums for growers as fruit size increases on the other hand outweigh any reductions in total yield.

Neither bud or fruit removal was different from the control for marketable fruit number or marketable yield suggesting that crop load reduction was not advantageous for ‘AU Golden Sunshine’ or ‘AU Golden Dragon’ during this season. This contrasts previous research by Thompson (2014) in which lateral bud removal increased marketable and large fruit (≥ 88 g) numbers of ‘AU Golden Sunshine’ when compared to fruit thinning and no thinning treatments. Malone (2012) however indicated that fruit thinning ‘AU Golden Sunshine’ can lead to more fruit of marketable size in years where adequate fruit set is obtained. Low crop loads due to poor pollination was the likely cause for variability in the present study. Management practices need to be addressed to enhance pollination for ‘AU Golden Sunshine’ and ‘AU Golden Dragon’ to improve crop loads and success. As a prolific fruit bearing cultivar, ‘AU Golden Sunshine’ benefits from crop load reduction in years where pollination is successful. For Thompson (2014), marketable yield increased for when lateral buds were removed during the bud swell stage. Marketable fruit number and yield increased for Malone (2012) when vines were fruit thinned. While thinning was not advantageous in the present study, it appears that lateral bud and fruit removal are possible options for growers working with high yielding kiwifruit cultivars such as ‘AU Golden Sunshine’ to reduce excessive crop loads and in turn increase marketable yields.

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Table 4.1. The effects of fruit thinning or lateral bud removal on fruit yield of *Actinidia chinensis* 'AU Golden Sunshine' harvested on 8 Sept. 2015.

Treatment	Total fruit (no. ^v)	Total yield (kg)	Marketable fruit ^z (no.)	Cull fruit ^y (no.)	Large fruit ^x (no.)	Fruit drop ^w (no.)
Control	650a ^u	32.8ns	139ns	512ns	44ns	12ns
Bud thin	436b	31.3	195	241	101	7
Fruit thin	561a	39.7	280	281	149	31

^zFruit \geq 65 g.

^yMisshapen fruit and fruit $<$ 65 g.

^xFruit \geq 88 g.

^wPre-harvest fruit dropped per vine.

^vno. = number

^uLeast squares means comparisons within columns using Tukey's test at $\alpha = 0.05$. ns = no difference among treatments.

Table 4.2. The effects of fruit thinning or lateral bud removal on fruit quality of *Actinidia chinensis* 'AU Golden Sunshine' harvested on 8 Sept. 2015.

Treatment	Weight (g)	Firmness (kg) ^x	SSC ^z (%)	DMC ^y (%)	Internal color (hue°)	External color (hue°)
Control	88.4ns ^w	1.27ns	14.5ns	0.19ns	99.2ns	75.5ns
Bud thin	88.1	0.83	13.7	0.18	99.1	75.5
Fruit thin	88.5	0.75	14.7	0.19	98.6	75.0

^zSSC = Soluble solids content.

^yDMC = Dry matter content.

^xFirmness measured with a bench top penetrometer using an 8 mm probe.

^wLeast 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 hand pollinated flowers of *Actinidia chinensis* ‘AU Golden Sunshine’ that were pollinated 1 day after anthesis with supplemental pollen of *Actinidia deliciosa* on 16 Apr. 2015.

Pollination Method	Weight (g)	Length (mm)	Width 1 ^z (mm)	Width 2 ^y (mm)	FSI ^x (mm)
Hand ^w	118.4a ^v	64.6a	57.1a	48.6a	56.8a
Open ^u	49.9b	42.6b	43.4b	38.2b	41.3b

^zWidth 1 was measured as the major width 90° from length measurement.

^yWidth 2 was measured as the minor width 90° from Width 1 across horizontal plane.

^xFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^wHand pollination of was done by applying supplemental pollen from *Actinidia deliciosa* with a camel hair brush to ‘AU Golden Sunshine’ flowers. Data derived from 28 fruit.

^uFlowers were marked with a hang tag that were of similar physiological stage as the hand pollinated flowers. Data derived from 12 fruit.

^vMeans comparisons between hand and open pollination were performed using t-tests. All comparisons were at $\alpha = 0.05$.

Table 4.4. The effects of fruit thinning or lateral bud removal on fruit yield of *Actinidia chinensis* 'AU Golden Dragon' harvested on 8 Sept. 2015.

Treatment	Total fruit (no. ^v)	Total yield (kg)	Marketable fruit ^z (no.)	Cull fruit ^y (no.)	Large fruit ^x (no.)	Fruit drop ^w (no.)
Control	251ns ^u	14.9ns	83ns	164ns	33ns	14ns
Bud thin	239	14.7	94	146	40	12
Fruit thin	230	14.8	95	131	46	11

^zFruit \geq 65 g.

^yMisshapen fruit and fruit $<$ 65g.

^xFruit \geq 88 g.

^wPre-harvest fruit dropped per vine.

^vno. = number

^uLeast squares means comparisons within columns using Tukey's test at $\alpha = 0.05$. ns = no difference among treatments.

Table 4.5. The effects of fruit thinning or lateral bud removal on fruit quality of *Actinidia chinensis* 'AU Golden Dragon' harvested on 8 Sept. 2015.

Treatment	Weight (g)	Firmness (kg) ^x	SSC ^z (%)	DMC ^y (%)	Internal color (hue°)	External color (hue°)
Control	90.4ns ^w	0.67ns	13.9ns	0.17ns	99.3ns	77.5ns
Bud thin	90.8	0.72	13.6	0.17	99.1	78.7
Fruit thin	89.4	0.94	13.7	0.17	98.8	79.8

^zSSC = Soluble solids content.

^yDMC = Dry matter content.

^xFirmness measured with a bench top penetrometer using an 8 mm probe.

^wLeast squares means comparisons within columns using Tukey's test at $\alpha = 0.05$. ns = no difference among treatments.

Table 4.6. A comparison of fruit traits derived from hand pollinated flowers of *Actinidia chinensis* ‘AU Golden Dragon’ that were pollinated 1 day after anthesis with supplemental pollen of *Actinidia deliciosa* on 8 Apr. 2015.

Pollination Method	Weight (g)	Length (mm)	Width 1 ^z (mm)	Width 2 ^y (mm)	FSI ^x (mm)
Hand ^w	101.6a ^v	62.0a	55.4a	48.2a	55.2a
Open ^u	63.7b	49.0b	48.7b	42.3b	46.7b

^zWidth 1 was measured as the major width 90° from length measurement.

^yWidth 2 was measured as the minor width 90° from Width 1 across horizontal plane.

^xFSI = Fruit Size Index = (Length + Width 1 + Width 2) · 3⁻¹.

^wHand pollination of was done by applying supplemental pollen from *Actinidia deliciosa* with a camel hair brush to ‘AU Golden Dragon’ flowers. Data derived from 64 fruit.

^vMeans comparisons between hand and open pollination were performed using t-tests. All comparisons were at $\alpha = 0.05$.

^uFlowers were marked with a hang tag that were of similar physiological stage as the hand pollinated flowers. Data derived from 48 fruit.