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

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Additional index words. dioecious, anthesis, pollen, fruit set, fruit size, seed number

Abstract. Commercial kiwifruit production often requires substantial inputs for successful pollination. Determining the length of time that female flowers can be successfully pollinated can aid management decisions concerning pollination enhancement. The purpose of this research was to determine the effective pollination period (EPP) for ‘AU Golden Sunshine’ and ‘AU Fitzgerald’. Either 30 (2013) or 32 (2014, 2015) flowers of ‘AU Golden Sunshine’ were hand pollinated each day for 1 to 5 (2013) days after anthesis (DAA) or 1 to 7 DAA (2014, 2015), and then isolated to prevent open pollination. Anthesis was considered the day the flower opened. Similarly, ‘AU Fitzgerald’ flowers were pollinated and then isolated 1 to 6 DAA in 2013 and 1 to 7 DAA in 2015. For ‘AU Golden Sunshine’ in 2013, fruit set was consistent over the 5-day period, but fruit weight, fruit size index, and seed number decreased between 1 and 3 and 4 and 5 DAA. In 2014, fruit set decreased between 1 and 6 and 7 DAA, whereas fruit weight, fruit size index, and seed number each decreased in a linear trend. In 2015, fruit set also decreased between 1 and 6 and 7 DAA, whereas all other responses decreased linearly. Based on fruit set in 2014 and 2015, the EPP for ‘AU Golden Sunshine’ was 6 DAA. The EPP for ‘AU Fitzgerald’, however, was more variable. In 2013, fruit weight, fruit size index and seed number decreased between 1 and 4 and 5 and 6 DAA, suggesting that the EPP was 4 DAA. In 2015, fruit set remained consistent over the 7-day period with fruit weight, fruit size index, and seed number decreasing linearly. Differences in temperature and the alternate bearing tendency of kiwifruit species likely contributed to the discrepancies between the years for the EPP. For each cultivar, reductions in fruit weight, size, and seed number were observed before an observed decrease in fruit set. Greater fruit weight, size, and seed number were observed when flowers were pollinated within the first few DAA, with results varying thereafter.

As a recently domesticated crop, kiwifruit has grown from a small, specialized commodity for one country (New Zealand) to a vital commercial crop grown worldwide (Ferguson, 1999). The vast majority of production in the United States (98%) is in California, where the main cultivar grown is *Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson ‘Hayward’ (California Kiwifruit Commission, 2016). Emergence of the international kiwifruit industry was led by one cultivar in particular, ‘Hayward’ (Ferguson, 1999). ‘Hayward’ has dominated the green-fleshed varieties (Morley-

Bunker and Lyford, 1999). Fruit quality, 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 was *Actinidia chinensis* Planch. ‘Hort16A’ (Patterson et al., 2003). This gold-fleshed cultivar has the closest resemblance to *A. deliciosa* and has had much success commercially. ‘Hort16A’ was noted as being more productive than ‘Hayward’, having larger, sweeter fruit and thought by many to be superior in flavor (Ferguson, 1999; Patterson et al., 2003). However, ‘Hort16A’ was observed to be highly susceptible to *Pseudomonas syringae* pv. *actinidiae* (Psa), and 2 years after the introduction of Psa to New Zealand, a new gold-fleshed kiwifruit cultivar was released, ‘Gold3’ (Peacock, 2014). This cultivar was observed to be less susceptible to the disease than ‘Hort16A’ and was commercialized by Zespri (Zespri International Ltd., Mount Maunganui, NZ) in 2010.

In the southeastern United States, commercial kiwifruit production was first introduced in the mid to late 1980s (Powell et al., 2000). In 1987, commercial and experimental kiwifruit plantings were established in central and southern Alabama. The vegetative

growth of these plantings was acceptable, but it soon became evident that the warm climate of southern Alabama was restrictive for flower production of ‘Hayward’. Fruiting was acceptable in the central part of the state, where chilling hours ranged from 1000 to 1300 HR, thus it appeared that the lack of chilling hours in south Alabama obstructed floral and fruit development for this cultivar (Wall et al., 2008).

‘AU Fitzgerald’ (*A. deliciosa*) originated in southern Alabama (Summerdale, AL; lat. 30°29' N, long. 87°42' W) from seeds sown by Mrs. A. A. Fitzgerald from fruit purchased at a local store, probably ‘Hayward’ (Dozier et al., 2010). From these seeds, female (‘AU Fitzgerald’) and male plants (‘AU Author’) emerged, bloomed, and produced a quality crop. The fruit were cylindrical in shape with brown skin that had medium-length hairs and green flesh. ‘AU Fitzgerald’ plants have performed well in Summerdale, AL, where chilling hours average less than 700 per growing season, indicating that the chilling hour requirement is markedly lower than ‘Hayward’ (Wall et al., 2008).

Auburn University has worked with The Fruit and Tea Institute of Hubei province, P.R. China, to patent *A. chinensis* ‘AU Golden Sunshine’ (Dozier et al., 2011a). The fruit produced by this cultivar are cylindrical, 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, *A. chinensis* ‘AU Golden Tiger’ (Dozier et al., 2011b). ‘AU Golden Sunshine’ has a low vegetative chilling requirement with 700 h needed for budbreak and 900 h needed for optimal floral development (Wall et al., 2008).

A. deliciosa and *A. chinensis* are functionally dioecious species that require interplanting 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, whereas *A. chinensis* ‘Hort16A’ was reported to contain up to ≈700 seeds per fruit (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; the honeybee is the primary insect used. However, bees are not typically attracted to kiwifruit flowers compared with other flowers such as citrus and clover (Clinch, 1984; Ferguson, 1991). Kiwifruit flowers naturally lack nectar, which can make attracting pollinators difficult (Clinch, 1984). Growers go to great lengths to ensure successful pollination and often use supplemental pollen applied by hand or mechanically to increase pollination effectiveness and productivity.

Received for publication 27 Sept. 2018. Accepted for publication 10 Jan. 2019.

This research was supported by the Alabama Agricultural Experiment Station, the Alabama Nut, Fruit, and Vegetable Industry, and the Hatch program of the National Institute of Food and Agriculture, U.S. Department of Agriculture.

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To optimize pollination of female plants, it is important to know the length of time that flowers can be successfully pollinated. The EPP has been defined as the period following anthesis in which pollination can effectively produce a fruit (Sanzol and Herrero, 2001). This concept was developed by R.R. Williams (1970b) as a means of evaluating flower receptivity for fruit crops. The EPP for the commercial green kiwifruit standard, 'Hayward', was determined to be 4 DAA (Gonzalez et al., 1995). Fruit set during this 4-d period was 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 United States, determining best management practices that optimize production of marketable fruit is important for the emerging kiwifruit industry. Enhancing pollination of this newly introduced crop will be necessary for producers to increase production of marketable fruit to increase associated returns on investment. The EPP has not previously been determined for the AU 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 objective of this study was to determine the EPP for the AU kiwifruit cultivars: *A. chinensis* 'AU Golden Sunshine' and *A. deliciosa* 'AU Fitzgerald'.

Materials and Methods

Plant material. Kiwifruit plants 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' and 'AU Fitzgerald' plants were established in 1996 and 2007, respectively. 'AU Golden Sunshine' plants were trained on a winged T-bar trellis system and 'AU Fitzgerald' plants were trained on a pergola system. Both cultivars had a vine spacing of 2.4 m × 4.8 m. In 2013, three plants per cultivar were used, and four plants per cultivar were used in the subsequent years.

Effective pollination period. The study was initiated in the spring of 2013 (29 Apr. 2013 for 'AU Golden Sunshine' and 14 May 2013 for 'AU Fitzgerald') with 180 flower buds per cultivar bagged before anthesis. Anthesis was considered the day the flower opened. The buds 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 wax paper bags (10.2 × 26.2 cm) (336; Lawson Bag Co., Inc., Northfield, IL) to prevent open pollination. Parallel slits had been cut in 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 been cut in the bottom of the bag to allow for water drainage, if needed. Plants had two WatchDog A-series data loggers (Model A150; Spectrum Technologies, Inc., Aurora, IL) placed within the canopy during the initiation of the study each year: one in a wax paper bag to record in-bag temperature, the other left outside of the bag to record open air temperature. The data loggers were removed after fruit set evaluation.

After anthesis, 30 flowers that had been previously isolated were randomly selected among the three plants each day at 1, 2, 3, 4, or 5 DAA for 'AU Golden Sunshine' (30 Apr.–4 May 2013) and at 1, 2, 3, 4, 5, or 6 DAA for 'AU Fitzgerald' (15–20 May 2013) and hand pollinated using direct contact of male to female flowers. Treatments were arranged in a randomized complete block design with each plant considered a block. 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 Tiger' is typically recommended as the pollinizer for 'AU Golden Sunshine' (Dozier et al., 2011a, 2011b). 'AU Authur' was used to pollinate 'AU Fitzgerald'. The pollinated flowers were then re-bagged, as previously described, to prevent additional pollination. A labeled hangtag was also placed next to the pollinated flowers to identify the treatment. Ten days after the last treatment was applied, the bags were removed for fruit set evaluation, leaving the tags in place so that the treatment could later be identified.

The second year of the study was initiated on 28 Apr. 2014, by bagging 280 'AU Golden Sunshine' flower buds that were considered at stage 5 of bud development. A severe thunderstorm prevented pollination the day after bagging; therefore, pollination began 2 d after the flowers were initially bagged. The flowers appeared newly opened, or at anthesis, when the bags were removed for the first day of pollination. The same procedures were followed as in the previous year, but with slight modifications. After anthesis, 32 bagged 'AU Golden Sunshine' flowers were randomly selected among the four plants and hand pollinated each day at 1, 2, 3, 4, 5, 6, or 7 DAA (30 Apr.–6 May 2014) with supplemental *A. deliciosa* pollen (Pollen Collections and Sales, Inc., Lemon Cove, CA) using a camel-hair brush. 'AU Fitzgerald' was not included in the study this year because of insufficient flower production.

The third year of the study was initiated on 17 Apr. 2015 for 'AU Golden Sunshine' and on 27 Apr. 2015 for 'AU Fitzgerald', by bagging 280 flower buds, for each cultivar, that were considered at stage 5 of bud development. After anthesis, 32 bagged 'AU Golden Sunshine' flowers and 32 bagged 'AU Fitzgerald' flowers were randomly selected among the four plants and hand pollinated each day at 1, 2, 3, 4, 5, 6, or 7 DAA (18–24 Apr. 2015 for 'AU Golden

Sunshine'; 28 Apr.–4 May 2015 for 'AU Fitzgerald'). The same materials and procedures were used in this experiment as in the previous year.

Data collection. In year 1, bag removal was 21 DAA (20 May 2013) for 'AU Golden Sunshine' and 14 DAA (29 May 2013) for 'AU Fitzgerald' and initial fruit set was evaluated by denoting fruit set with a "Y" and no fruit set with an "N." If there was an instance in which a cane broke off, but fruit was set, a "Y" was recorded. Fruit were harvested 151 DAA (2 Oct. 2013) for 'AU Golden Sunshine' and 92 DAA (20 Aug. 2013) for 'AU Fitzgerald' with weight and size of each individual fruit recorded the following day. 'AU Fitzgerald' was harvested early to avoid potential fruit drop, as some of the plants became infected with *Phytophthora* spp. root rot that was confirmed via enzyme-linked immunosorbent assay tests. Fruit size index (FSI), was determined by using three different fruit measurements: length (L), major/widest width (W1), and minor/shortest width (W2) [$FSI = (L + W1 + W2) \times 3^{-1}$]. After all measurements were taken, each fruit was labeled and then placed in cold storage at 0.5 °C and 85% ± 5% relative humidity. 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 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 h at 21 °C. After 24 h, seeds from each fruit were weighed using a balance (AG104; Mettler Toledo, Greifensee, Switzerland). To determine average seed weight, a 100-seed sample weight was determined for three randomly chosen fruit from each treatment (day). 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 ±5% was allowed.

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

In year 3, '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 were harvested 175 DAA (19 Oct. 2015) and data (fruit weight, size, and seed number) were collected 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). Regression analysis was performed testing linear, quadratic, and cubic models predicting responses using days to pollination from anthesis as the explanatory variable. Where residual plots and a significant covariance test for homogeneity (COVTEST statement) indicated heterogeneous variance, a RANDOM statement with the GROUP option was used in the analysis. Fruit set data were analyzed using the binomial probability distribution. Estimates of differences in treatment groups (DAA) were tested using group contrasts. All significances were at $\alpha = 0.05$.

Results

EPP of A. chinensis 'AU Golden Sunshine'

In year 1 (2013), fruit set was >80% with no differences observed over the 5-d period (Table 1). All other responses were similar for the first 3 DAA with a decrease observed on day 4, followed by an increase on day 5. These changes resulted in cubic trends for all responses, except fruit set. There were no differences in responses among 1 to 3 DAA; however, there were differences between the mean of 1 to 3 DAA and the mean of 4 to 5 DAA. Fruit weight was 13.9% higher for 1 to 3 DAA (89.1 g) than 4 to 5 DAA (76.7 g). For the first 3 DAA, FSI was 53.2 mm, and FSI for 4 to 5 DAA was 50.2 mm with fruit length as the largest contributing factor. Seed number for the first 3 DAA was 553 seeds vs. 354 seeds for 4 to 5 DAA, a 36% decrease. The observed decrease in fruit weight and size over the 5-d period corresponded with the decrease in seed number. Mean canopy temperature was 16.8 °C, ranging from 5.9 to 28.2 °C. Mean temperature inside of the bag was 17.4 °C, ranging from 5.8 to 31.4 °C. The temperature inside the bag was >30 °C for 4 h the first DAA and remained <30 °C 2 to 5 DAA.

In year 2 (2014), there was a linear decrease in all responses, except fruit set, with increasing DAA (Table 1). For fruit set, a quadratic decrease occurred between days 1 and 6 and day 7 as fruit set dropped from >70% for 1 to 6 DAA to 0% for day 7. Fruit weight and size decreased as seed number decreased. Mean canopy temperature was 19.2 °C, ranging from 7.6 to 31.7 °C. Mean temperature inside the bags was 20.1 °C, ranging from 7.5 to 35.8 °C. The temperature inside the bag remained <30 °C 1 to 3 DAA and was >30 °C for 2, 8, 7, and 6 h 4 to 7 DAA, respectively.

In year 3 (2015), a quadratic decrease was observed between days 1 and 6 and day 7 for fruit set, as fruit set dropped from >70% for 1 to 6 DAA to 37.5% for day 7. There was a linear decrease in all other responses with increasing DAA (Table 1). As seed number decreased over the 7-day period, so did fruit weight and size. Mean canopy temperature was 18.3 °C, ranging from 7.8 to 27.5 °C. Mean temperature inside of the bag was 18.8 °C, ranging from 7.9 to 29.7 °C.

EPP of A. deliciosa 'AU Fitzgerald'. In year 1 (2013), fruit set decreased quadratically

with increasing DAA with differences found between days 1 and 5 and day 6 (Table 2). All responses, except fruit set, were similar among the first 4 DAA, but decreased on day 5 and increased on day 6. This resulted in quadratic trends for all responses. Flowers pollinated 6 DAA had larger fruit with more seeds than flowers pollinated 5 DAA; however, fruit set 6 DAA was only 40%. Differences occurred between 1 and 4 DAA and 5 and 6 DAA for fruit weight, FSI, and seed number. A 41.3% decrease in fruit weight occurred between 1 and 4 DAA (64.3 g) and 5 and 6 DAA (37.7 g). FSI was 64.7 mm for 1 to 4 DAA, whereas FSI for 5 to 6 DAA was 47.8 mm, a 26.1% decrease. Seed number for the first 4 DAA was 908 seeds and 281 seeds for 5 to 6 DAA, a 69% decrease. Fruit size and weight decreased as seed number decreased. Mean canopy temperature was 22.6 °C, ranging from 14.5 to 30 °C. Mean temperature inside the bags was 23.5 °C, ranging from 14.4 to 33.1 °C. The temperature inside the bag was >30 °C for 5, 2, 1, 0, 4, and 4 h for 1 to 7 DAA, respectively.

In 2015, fruit set was >95% with no differences observed over the 7-d period (Table 2). There was a linear decrease in fruit weight, FSI, and seed number with increasing DAA. As seed number decreased over the 7-d period, fruit size and weight also decreased. Mean canopy temperature was 17.3 °C, ranging from 8.8 to 28.8 °C.

Discussion

Results for the EPP determination of 'AU Golden Sunshine' suggest that for successful fruit set, flowers should be pollinated within 6 DAA. This is the first determination of the EPP for the species *A. chinensis*. 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. It is possible that the results for 2014 could have been hindered by a delay in pollination. Although it appeared that the flowers were newly opened when pollination was initiated 2 d after bagging, they could have opened the day before. If the flowers did emerge during the thunderstorm, that would mean that 1 DAA would have been 2 DAA and would possibly explain why there was no fruit set by 7 DAA, as the pollination period was pushed back by 1 d for this year. However, a more likely contributing factor was temperature. The mean temperature inside the bags was 20.1 °C with 23 cumulative h > 30 °C in 2014 compared with 17.4 °C with 4 cumulative h > 30 °C in 2013 and 18.8 °C with 0 h > 30 °C in 2015. As one of the leading issues affecting fertilization, high temperatures have been shown to not only quicken the growth of pollen tubes but also affect pistil development of several fruit crops (Sanzol and Herrero, 2001). High temperatures hasten maturation of both the stigma and ovule, thereby restricting receptivity and impeding fruit set. With temperatures inside of the bag

recorded as high as 35.8 °C toward the end of the 2014 study, it is likely that fruit set was hampered due to early maturation and organ degeneration, thereby explaining the lack of fruit set at 7 DAA.

Although Goodwin et al. (2013) did not define the EPP for *A. chinensis* 'Hort16A', they did determine stigmatic receptivity to be highest 2 DAA. They reported 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 ≈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 3 years of the study. Petals also began to dehisce 3 DAA, whereas fruit set remained ≥80% for all years.

In 2013, the results for 'AU Fitzgerald' suggest that the EPP was 4 DAA. For year 2 (2015), however, fruit set remained high, averaging 95% over the 7-d period making the EPP difficult to define. In this year, 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 from the flowers pollinated 5 DAA, 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 of the 31 fruit were flat, fan-shaped, and larger than normal-shaped fruit, having more core, pericarp, and locules, which likely contributed to the observed increase in fruit weight and size (Watson and Gould, 1994). Both *A. deliciosa* and *A. chinensis* have a tendency to produce these abnormally shaped fruit. With irregularities in size, these fruits are difficult to ship and are therefore considered unmarketable. Before the study by Watson and Gould (1994), 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 1-year study, successful pollination was considered ≥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 because fruit set remained well above 80% 4 DAA and fruit set decreased along with pronounced reductions in fruit weight, FSI, and seed number 5 to 6 DAA in year 1 of this study. In year 2 (2015), fruit set for 'AU Fitzgerald' remained above 80% through 7 DAA with no differences among DAA. Although there was a linear reduction in fruit weight, FSI, and seed number as DAA increased, the EPP could not be conclusively determined. The discrepancy between the 2 years could be due to

Table 1. Effects of hand pollinating *Actinidia chinensis* 'AU Golden Sunshine' flowers 1, 2, 3, 4, 5, 6, or 7 d after anthesis (DAA) on fruit characteristics.

DAA	Wt (g)	FSI ² (mm)	Fruit set ³	Seed no.
2013				
1	88.6	53.5	27/28	570
2	94.0	53.4	25/26	554
3	84.9	52.4	25/25	552
4	68.4	48.6	21/23	333
5	85.0	51.8	22/27	409
Significance ^x	C***	C*	NS	C*
Difference among days 1–3 ^w	0.2372 ^v	0.641	NS	0.9999
Difference between days 1–3 and 4–5	0.0025	0.0013	NS	<0.0001
2014				
1	106.7	56.5	27/31	635
2	103.0	56.0	28/33	592
3	103.4	56.1	25/32	602
4	88.2	53.0	27/32	375
5	94.5	54.3	25/32	522
6	82.5	51.8	16/32	356
7	0	0	0/28	0
Significance	L***	L***	Q***	L***
Difference among days 1–6			0.0982	
Difference between days 1–6 and 7			<0.0001	
2015				
1	102.3	55.6	25/32	591
2	105.3	56.1	24/32	668
3	95.1	54.4	27/32	596
4	94.5	54.2	23/32	488
5	88.4	52.8	20/30	468
6	82.5	51.6	17/24	428
7	72.7	49.8	5/16	298
Significance	L***	L***	Q*	L***
Difference among days 1–6			0.7852	
Difference between days 1–6 and 7			<0.0001	

²FSI = fruit size index = (Length + Width + Width 2) * 3⁻¹.

³Number of flowers that set fruit/number of flowers hand pollinated.

^xSignificant linear (L), quadratic (Q), or cubic (C) trends using orthogonal polynomials at $\alpha = 0.05$ (*) or 0.001(***). NS = nonsignificant.

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

^vProbability greater than calculated *F*-value.

Table 2. Effects of hand pollinating *Actinidia deliciosa* 'AU Fitzgerald' flowers 1, 2, 3, 4, 5, 6, or 7 d after anthesis (DAA) on fruit characteristics.

DAA	Wt (g)	FSI ²	Fruit set ³	Seed no.
2013				
1	64.5	48.8	28/30	956
2	68.5	50.0	28/28	949
3	63.2	48.4	26/26	891
4	60.0	47.6	29/29	853
5	27.4	36.0	22/27	141
6	48.1	43.6	12/30	422
Significance ^x	Q***	Q***	Q*	Q***
Differences among days 1–4 ^w	0.1019 ^v	0.1467	NS	0.9992
Differences between days 1–4 and 5–6	<0.0001	<0.0001	NS	<0.0001
Differences among days 1–5			0.9693	
Differences between days 1–5 and 6			0.0027	
2015				
1	48.4	43.6	30/32	693
2	50.3	43.8	30/32	755
3	50.9	44.6	31/32	706
4	42.4	41.7	29/32	532
5	49.0	43.8	32/32	690
6	40.2	41.3	31/32	571
7	44.4	42.6	30/31	533
Significance	L*	L*	NS	L***

²FSI = fruit size index = (Length + Width + Width 2) * 3⁻¹.

³Number of flowers that set fruit/number of flowers hand pollinated.

^xSignificant linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.05$ (*) or 0.001(***). NS = nonsignificant.

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

^vProbability greater than calculated *F*-value.

temperature. The mean temperature inside the bags was 23.5 °C with 16 cumulative h >30 °C 1 to 6 DAA in year 1 compared with 17.3 °C with 0 h >30 °C in year 2. It is also plausible that the discrepancy between the 2 years was due to alternate bearing tendencies of the species *A. deliciosa* (Morley-Bunker and Lyford, 1999). Although crop load was not assessed, plants experienced some freeze injury in Jan. 2014, as the temperature approached –14 °C on 7 Jan. 2014 (National Weather Service, 2014). These temperatures resulted in a relatively low crop yield, but 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 2) this year, whereas 'AU Fitzgerald' fruit typically averages 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. 'Doyenné du Comice', which has poor crop loads, the EPP is 1 DAA, whereas the heavily cropped cultivar *Pyrus communis* L. 'Conference' has an EPP of 10 DAA. Longer EPPs have also been found with cultivars that tend to alternate bear during heavy cropping years compared with "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. '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, whereas 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), whereas 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-d period with an excessive production of small unmarketable fruit. Thinning is typically used 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 plants that had been severely thinned beforehand (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 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, whereas

the lack of nectar production by flowers can also make attracting pollinators problematic (Ferguson, 1991; Palmer-Jones and Clinch, 1974). 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 6 DAA. Year 1 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'. Further describing the tendency for 'AU Fitzgerald' to alternate bear is needed, as well as the effect it has on the EPP for kiwifruit, because alternate bearing appeared to affect the EPP for 'AU Fitzgerald' in this study. Importantly, high temperatures during bloom may contribute to variable fruit set and fruit quality by reducing the EPP. In all years of this study, differences were observed for each cultivar for fruit weight, size, and seed number that did not correspond with differences observed for fruit set. It appears that greater fruit weight, size, and seed number result from pollination within the first few DAA for both cultivars and variable results may occur thereafter. Although 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 few DAA to enhance marketable yield.

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