Influence of Fruit Thinning and a Natural Plant Extract Biostimulant Application on Fruit Size and Quality of 'AU Golden Dragon', 'AU Golden Sunshine', and 'Hort16A' Kiwifruit

By

Jonathan L Malone

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Approved by

James Spiers, Chair, Assistant Professor of Horticulture
Floyd Woods, Associate Professor of Horticulture
Elina Coneva, Associate Professor of Horticulture
William Dozier, Professor of Horticulture

Abstract

Fruit thinning and the application of the natural biostimulant Benefit®Kiwi are expensive cultural practices, and the effectiveness of these practices on increasing fruit size of *Actinidia chinensis* cultivars grown in Alabama is not currently known. The influence of these two cultural practices on three kiwifruit cultivars namely 'AU Golden Dragon', 'AU Golden Sunshine', and 'Hort-16A' over two growing seasons were determined with regard to fruit size, quality, and marketability. Marketable yield of 'AU Golden Dragon' was not affected by Benefit®Kiwi applications or fruit thinning treatments. 'AU Golden Sunshine', the most prolific fruiting cultivar in this study, had higher marketable yield in response to fruit thinning, while its marketable yield was not affected by Benefit®Kiwi. Marketable yield of 'Hort-16A' was greater from the Benefit®Kiwi-treated plants. Due to variation in crop load observed, future research is needed to determine the exact efficacy of Benefit®Kiwi and fruit thinning on 'Hort-16A'. Fruit quality of marketable fruit was not appreciably affected by fruit thinning or Benefit®Kiwi treatments. Although minimal thinning and application of Benefit®Kiwi are standard production practice for gold kiwifruit production in New Zealand, the effectiveness of these practices varies significantly for specific cultivars of *A. chinensis* cultivated under the present study. Results of this study further provide information regarding cultivation and production practices specific to the southeastern US.

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List of Abbreviations

AU	Auburn University
°F	Degrees Fahrenheit
%	Percent
°C	Degrees Celsius
mg	Milligram
g	Gram
Ha	Hectare
kg	Kilogram
SSC	Soluble solids content
IC	Internal Color
DMC	Dry Matter Content
TA	Titratable Acidity
SSC:TA	Soluble solids content: Titratable acidity ratio
DW	Dry Weight
FW	Fresh Weight
ml	Milliliters

CHAPTER ONE

Introduction

One major aspect of kiwifruit production is fruit size, which has a direct relationship with the profitability of kiwifruit orchards (Lahav et al., 1989). Larger fruit demand higher prices which in turn lead to increased revenue for the orchardist (Atkins, 1990). *Actinidia chinensis* 'AU Golden Dragon' and *A. chinensis* 'AU Golden Sunshine' are two new kiwifruit cultivars that were developed in a joint effort between Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Wuhan, Hubei Province, China. These two new cultivars were patented and are expected to perform well in the southeast United States due to their lower chill hour requirements. Both cultivars have performed well in central Alabama, which has an average winter chilling of 800-1200 hours (US PP22,191 P2; US PP22,159 P3). The influence of fruit thinning and Benefit®Kiwi applications on fruit size has not been evaluated for these two new cultivars. Understanding the influence of cultural practices on fruit size of other kiwifruit cultivars can serve as basis for recommended cultural practices for 'AU Golden Dragon' and 'AU Golden Sunshine'.

Fruit size is the determining factor for profitability of kiwifruit orchards. Fruit thinning, the use of natural plant extracts as biostimulants, and plant growth regulators have been studied extensively on 'Hayward', 'Hort16A', and other kiwifruit cultivars to determine the effect of these practices on fruit size and quality. Research is needed to determine the effects of these practices on the two new kiwifruit cultivars 'AU Golden Dragon' and 'AU Golden Sunshine'. The purpose of this project is to determine the influence of fruit thinning and Benefit®Kiwi applications on marketable yield and fruit quality of these two new cultivars as compared to the commercial standard 'Hort16A'.

CHAPTER TWO

Literature Review

Origin of Kiwifruit

Kiwifruit is native to Southeast Asia. It is indigenous to China, most notably in the forest margins of the Yangtze Valley where the kiwi vine can grow to a height of 30 feet (9.14 m) or more (La Rue, 1994). Throughout history kiwifruit has been designated by various names. Since the Tang Dynasty (A.D. 618-907) of China, kiwifruit was known as Mihoutoa or monkey peach because wild monkeys were known to consume the ripe fruit (Ferguson, 2004). Kiwifruit was also known as the Chinese gooseberry due to its origin, and gooseberry due to its characteristic flavor association with the European gooseberry (Ferguson, 2004). The kiwi is a symbol of New Zealand, which is where kiwifruit begot its current name, not because of any similarities between the Kiwi bird and the kiwifruit (Ferguson, 2004).

In 1899, E.H. Wilson traveled to China as a designate of the English nursery of James Veitch and Sons to find plants that displayed economic and aesthetic value for use in private gardens in England (Ferguson, 2004). Wilson surveyed and documented flowering plants during spring and summer months and returned in late fall to collect seeds. In winter of 1899, Wilson traveled to Ichang, China sorting and assessing seeds for shipment to England (Ferguson, 2004). Wilson was responsible for introducing kiwifruit to the westerners living in Ichang. One such westerner was Katie Fisher, the sister of Isabel Fisher, both of which were New Zealanders who were responsible for the introduction of kiwifruit to New Zealand in the early 20th century (La Rue, 1994). They gave the kiwifruit seeds they brought home to Alexander Allison. Allison grew the seeds in Wanganui, New Zealand where the plants successfully fruited in 1910 (La

Rue, 1994). It is believed that all 'Hayward' kiwifruit currently grown in New Zealand are descendants of the vines Allison grew (La Rue, 1994).

The United States Department of Agriculture (USDA) introduced kiwifruit to the United States in the early 1930's as a potential crop for both the southern and western states (La Rue, 1994). During early 1960, kiwifruit was first cultivated in California and has progressively increased in acreage from 50 acres to 4,300 acres by 2006 (Mainland and Fisk, 2006). Although currently there are no large commercialized growers in the eastern United States, kiwifruit vines have fruited in Virginia and South Carolina and are part of evaluation programs in Alabama and Georgia.

Kiwifruit was first traded globally / internationally in 1960 and has progressively increased in number of new cultivars introduced and availability (Nishiyama, 2007). The genus *Actinidia* currently has 76 species and 130 different taxa, only a few of which have any economic importance (Jaegar et al., 2003, Nishiyama, 2007). The kiwifruit is one of only four new fruits introduced into trade in the twentieth century (Nishiyama, 2007). Not all kiwifruit are similar; there are differences in size, pubescence, internal color, sweetness, storage parameters, and chilling hours (Bliss, 1994).

Kiwifruit are now cultivated worldwide most notably in Italy, China, New Zealand, Chile, France, Greece, Japan, and the United States (Nishiyama, 2007). As of 2010 the leading three countries that are producers of kiwifruit are Italy with 365,858 tons produced at a value of $258,523,000 dollars, New Zealand with 282,248 tons produced at a value of $199,092,000 dollars, and Chile at 144,295 tons produced at a value of $92,728,000 dollars (FAOSTAT, 2012).

Kiwifruit Cultivars

Actinidia deliciosa 'Hayward'

The most common kiwifruit cultivar grown commercially is *A. deliciosa* 'Hayward' (Ferguson, 1991). 'Hayward' kiwifruit accounts for 75% of the global kiwifruit production (Ferguson, 2008). 'Hayward' kiwifruit gained popularity due to its large fruit, internal green color, aesthetic appearance, superior flavor, and extended storage life that is beneficial for international shipment and trade (Ferguson, 1999). 'Hayward' kiwifruit was selected by Mr. Hayward Wright, a New Zealand nurseryman, from the 1st or 2nd generation of a small seedling population taken from the wild. All 'Hayward' cultivars grown today are descendants of the single plant Wright selected in 1925 (Ferguson, 1999).

In New Zealand, 'Hayward' kiwifruit yields approximately 25 metric tons to the canopy hectare, which would equate to roughly 6000 trays/ha (Ferguson, 2008). 'Hayward' kiwifruit are not as prolific in fruit bearing as other commercial cultivars, but due to superior fruit quality attributes it has become the primary commercially exported kiwifruit cultivar. 'Hayward' kiwifruit require 950 chilling hours for vegetative bud break, and 1150 chilling hours for optimum flower development (Caldwell, 1989). With the high amount of chilling hours required for proper flowering to occur, 'Hayward' kiwifruit may not be suitable for all production areas.

Actinidia chinensis 'Hort16A'

A. chinensis cultivars were classified as *A. deliciosa* until 1984, when *A. chinensis* was determined to be a different species due to its physical and internal fruit qualities (Nishiyama, 2007). The golden internal flesh color characteristic to *A. chinensis* fruit is due to reduction in chlorophyll and the transformation of the fruits' chloroplasts to chromoplasts during maturation and ripening (McGhie and Ainge, 2002).

In 1995, a research and development company, New Zealand Institute for Plant and Food Research Ltd, patented a new cultivar of golden kiwifruit designated *A. chinensis* 'Hort16A', known commercially as ZESPRI® GOLD (Patterson et al., 2003). 'Hort16A' was the first kiwifruit cultivar developed through a kiwifruit breeding program and was the first cultivar of *A. chinensis* fruit to be traded internationally (Ferguson, 2008). Current global commercial production of *A. chinensis* is approximately 7.5% of kiwifruit production, which includes 'Hort16A' (Ferguson, 2008). 'Hort16A' has given the New Zealand kiwifruit industry an advantage, as it is the only major *A. chinensis* cultivar traded internationally (Patterson et al., 2003). 'Hort16A' accounts for 17-18% of New Zealand's kiwifruit exports (Nishiyama, 2007).

'Hort16A' is a very vigorously growing cultivar that produces higher yields than 'Hayward' with an estimated 10,000-20,000 trays/ha (Patterson et al., 2003). 'Hort16A' has a distinct 'subtropical' flavor (Jaeger and Harker, 2005; Jaegar et al., 2003) and is sweeter with a soluble solid content of 9-14% at harvest when compared to 'Hayward' with a soluble solid content of 6.5%.

'AU Golden Dragon' and 'AU Golden Sunshine'

Two new cultivars of *A. chinensis*, 'AU Golden Dragon' and 'AU Golden Sunshine', have been developed in a joint effort between Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Hubei province, P.R. China. These two cultivars have been evaluated for performance and fruit quality characteristics since 1995 at the Chilton Research and Extension Center in Thorsby, AL. 'AU Golden Dragon' fruit is elliptical in shape, while

‘AU Golden Sunshine’ fruit is cylindrical, much like the commercial standard *A. chinensis* cultivar ‘Hort16A’. Both ‘AU Golden Dragon’ and ‘AU Golden Sunshine’ have high soluble solids and percent dry matter content at harvest similar to the commercial *A. chinensis* standard ‘Hort16A’.

In Alabama, ‘AU Golden Dragon’ blooms around March 30 and ‘Hort16A’ blooms on April 8. ‘AU Golden Sunshine’ bloom period typically is the last to initiate and occurs around the 20th of April (Dozier, personal communication). Since ‘AU Golden Sunshine’ is the last to bloom, fruit could potentially be protected from late season freeze injury and damage. ‘AU Golden Dragon’ fruit mature earlier than ‘AU Golden Sunshine’ and ‘Hort16A’, and harvest is typically August 20 – September 1. Although ‘AU Golden Sunshine’ is the last to bloom, which is due to the high number of growing degree hours (GDH) required for it to bloom (15000 GDH for ‘AU Golden Sunshine’, 9500 GDH for ‘AU Golden Dragon’) (Wall et al., 2008), it matures approximately 30 days earlier than the commercial standard ‘Hort16A’, and harvest typically begins in mid-September in central Alabama. The two new cultivars of kiwifruit mature earlier compared to ‘Hort16A’, which facilitates extended market availability of golden kiwifruit (Burnie, 2009).

The two new cultivars have potential to enhance Alabama’s economy. The potential net value on return is $10,765 dollars an acre (Burnie, 2009). In New Zealand, the current golden kiwifruit industry accounts for 17-18% of all kiwifruit exports and is worth $160 million dollars (Nishayama, 2007). Current estimates indicate if Alabama farmers produced 465 acres of kiwifruit with a prediction of 6000 trays per acre at the current $6 dollars/tray, it would total $16 million dollars in total revenue within the state (Burnie, 2009).

Kiwifruit Production Requirements

Kiwifruit vines should be grown in well-drained soils. Plenty of water should be available as the water requirements can be up to 120,000 $L \cdot Ha^{-1} \cdot d^{-1}$ (Norton, 1994). Kiwifruit vines are best grown on T-bar or pergola trellis systems due to the vigorous vine growth habits, which can extend up to 20 feet (6.09 m) a year for 'Hayward' vines (Reil, 1994). 'Hort16A' vines are even more vigorous as this cultivar exhibits secondary shoot growth from primary shoots, which is uncharacteristic of 'Hayward' vines (Patterson et al., 2003). Kiwifruit vines can be propagated via tissue culture, grafting, or by rooting softwood, semi-hardwood, or hardwood cuttings (Spiers, personal communication).

Winter Chilling and Dormancy

Chilling hour requirement (Richardson model) is defined as an hour where the temperature remains at or below 7.2°C, but above 0°C (45°F - 32°F) (Powell et al., 2000). The dormant buds of kiwifruit vines require a certain minimal number of chilling hours for proper flower development to occur. Flower induction occurs in the late summer, and all over-wintering buds have the potential to produce fruit (Linsley-Noakes and Allan, 1987; Polito and Grant, 1984). Insufficient winter chilling drastically reduces flower development the following spring, reducing the current year crop potential. 'Hayward' kiwifruit vines grow best in temperate climates where the winter provides more than 950 chilling hours for proper flower development (Wall, 2008). However, maximum flower development for 'Hayward' is achieved at 1150 chill hours (Caldwell, 1989). Wall (2008) maintained cuttings in cold storage at 4ºC to determine chilling requirements for 'AU Golden Dragon' and 'AU Golden Sunshine' and calculated the chilling hours using the Richardson model. Wall (2008) reported 'AU Golden Dragon' requires 800 hours of chilling for dormant bud rest and maximum flower development. In addition, 'AU Golden Sunshine' requires 700 hours to satisfy chilling for dormant bud rest, and at least 900 chill hours for maximum flower development. 'AU Golden Dragon' and 'AU Golden Sunshine' both have lower chilling hour requirements compared to 'Hort16A' (Dozier, personal communication), and could be suited for more southern regions (warmer winters) where cultivars such as 'Hayward' do not typically set fruit.

In warmer climates, bud break and bud fertility (number of flowers per winter bud) are inadequate due to insufficient chilling hours to satisfy rest (Costa et al., 1997). Hydrogen cyanamide (H_2CN_2) is a growth regulator used to break dormancy of many fruit crops (Engin et al., 2010). H_2CN_2 is chemically used to replace insufficient winter chilling, promote uniform budbreak, and improve yields in various fruit crops (Costa et al., 1997; Dozier et al., 1990). Application of H_2CN_2 has been reported to promote uniform bud break (Walton, 1996), and to stimulate flowering and fruiting in kiwifruit (Powell et. al, 2000).

Flowering and Pollination

Kiwifruit are dioecious, producing either male or female flowers on separate plants. Hence, both male and female plants must be available for fruit set to occur. Final fruit size is largely determined within the first 50 days after flowering (Hall et al., 1996). Flower size and quality are important determinates in final fruit size (McPherson et al., 2001). Kiwifruit can have multiple flowers per fruiting node. The primary flower or "king" flower opens earlier than the secondary flowers or "lateral" flowers. Flowers that open earlier tend to have a larger ovary with increased number of locules and ovules that produce larger fruit when compared to flowers that open late (Lawes et al., 1990; Cruz-Castillo et al., 1991). Pollination of kiwifruit flowers occurs via wind or insects, mainly bees (Vasilakakis et al., 1997), and can also be artificially applied in an orchard system. Effective pollination is essential for fruit set, quality, and final fruit size (Patterson et al., 2003). Seed number, the result of pollination, is positively correlated with final fruit weight at harvest (Vasilakakis et al., 1997). Approximately 1000 – 1100 seeds are required for 'Hayward' fruit size to reach 100 g (Hopping, 1990). Interestingly, an equivalent weight of 'Hort16A' fruit is achieved with 400-600 seeds (Patterson et al., 2003). 'Hayward' fruit increase in size and percent dry matter throughout the growing season, with the largest size increase occurring within the first 100 days following bloom (Mitchell, 1994). 'Hort16A' is a rapidly growing fruit gaining 1.6 g of weight a day 40-50 days after pollination, 1.1 g a day 40-80 days after pollination, and up to 0.5 g a day 100-120 days after pollination and fruit set has occurred (Patterson et al., 2003).

Pruning

Pruning is one of the most important cultural practices utilized in kiwifruit production for vine health and return bloom. Pruning is performed during the winter when vines are dormant, and in the summer when vines are actively growing. Winter pruning, in general, consists of removing the old growth (2 year-old cane) that has previously fruited in order to make room for the current year growth (1 year-old cane) to be tied to the existing trellis structure. Fruit develop on fruiting laterals (spurs) from previous season's growth (1 year-old cane) (Miller et. al, 2001). New vegetative growth competes with fruit for carbohydrate resources (source/sink relationship) (Minchin et. al, 2010). Hence, summer pruning is utilized to reduce vegetative growth to lessen carbohydrate losses and competition between vegetative and fruit growth (Miller et. al, 2001). In addition, summer pruning opens the canopy for natural pollinators (bees), allows more airflow within the canopy, and maximizes light interception – all of which promote fruit quality (Grant et al., 1994; Henzell et. al, 1986). Tip squeezing, a relatively new pruning method, is used to control the vegetative vigor of 'Hort16A'. This pruning method involves crushing shoot tips of actively growing canes, thereby inhibiting new development of lateral shoots from buds below the squeezed tip (Patterson and Currie, 2011).

Girdling

Girdling is the practice of removing the bark and underlying cambium tissue of the trunk to restrict phloem transport between the canopy and roots, and has been practiced for thousands of year to improve crop production (Goren et al., 2004). Cane girdling is a more extensive process by which all of the canes are girdled rather than the main trunk. Girdling restricts carbohydrate transport from the source to sinks (vegetative structures, reproductive structures, roots). It has been shown that girdling before bloom improves budbreak and thus results in increased flower production in kiwifruit (Snelgar and Manson, 1992). Late summer girdling has been used to promote return bloom the following spring in many fruit crops (Goren et al., 2004). Girdling has been found to increase fruit size of peach, apple, grape, citrus, and persimmons (Goren et al., 2004). Also, it is well documented that girdling can increase fruit size of both 'Hayward' and 'Hort16A' kiwifruit cultivars (Patterson and Currie, 2011). Woolley and Cruz-Castillo (2006) reported girdling increases fruit size in both *A. chinensis* and *A. deliciosa* fruit, and credits the increase of fruit size to the prevention of carbohydrate loss from the leaves to other parts of the plant. Boyd and Barnett (2011) reported that girdling can increase DMC and advance maturity of 'Hort16A', however girdling can also affect vine productivity and fruit quality if the girdle remains open over a long period of time. Lai et al. (1989) reported that when a non-fruiting lateral was present fruit size was increased due to greater availability of photoassimilates beyond the cane girdle; fruit size was reduced when a non-fruiting lateral was not present. The increase of fruit size is closely related to fruit/ leaf ratio. Cane girdling restricts the overall availability of carbohydrates by preventing the flow from neighboring canes. Whereas, trunk girdling allows photoassimilates to flow freely throughout the canopy from canes with excess assimilate accumulation to canes with lower assimilate availability.

Thinning

Various cultivars of kiwifruit are prolific fruit bearers and have the tendency to overcrop, which leads to the production of smaller fruit (Thakur and Chandel, 2004). One method for controlling fruit number and manipulating fruit size is fruit thinning (Richardson and McAneney, 1990). Fruit thinning is generally applied in the orchard to remove misshapen or unmarketable fruit. Various studies have related fruit thinning to final attainment of fruit weight in different cultivars of kiwifruit (Lahav et al., 1989; Thakur and Chandel, 2004). These studies illustrate the positive influence of fruit thinning on final fruit weight, however, ultimately marketable yield was compromised due to thinning practices. A similar study illustrating positive influence of thinning in *A. deliciosa* ‘Hayward’ thinned down to one fruit per fruiting node early in the growing season resulted in significant improvement in fruit size (Vasilakakis et al., 1997). However, thinning may not be practical for all kiwifruit cultivars. Yield loss in *A. deliciosa* ‘Hayward’ due to excessive fruit thinning may not be compensated by the increase in size of the remaining fruit. Fruit thinning is only recommended on high-yielding cultivars that produce abundant small fruit such as *A. deliciosa* ‘Allison’ (Thakur and Chandel, 2004).

Flower thinning is an effective low cost method for kiwifruit orchard management to reduce kiwifruit number when applied early in the season. It has been hypothesized that thinning at the initial flowering stage may strongly influence final kiwifruit size as opposed to thinning after established fruit set (Vasilakakis et al., 1997). Antognozzi et al. (1991) noted thinning regardless of time or intensity has a positive influence on fruit size, and thinning prior to flower bud-swell was better than thinning after fruit set. The intensity of flower thinning directly influences final yield (Burge et al., 1987, Pescie and Strik, 2004). Burge et al. (1987) reported flower thinning in *A. deliciosa* ‘Hayward’ increased marketable yield of larger commercial size grades (98-117 g), however reduced yields of smaller size grades (64-87 g) was observed. Similarly, Pescie and Strik (2004) reported that thinning before bloom reduced yield of hardy kiwifruit, *A. arguta* ‘Ananasnaya’, however, the average marketable fruit weight increased by 14%. The beneficial practice of flower thinning potentially could result in unforeseen negative results in marketable yield, as it is nearly impossible to determine which flowers will produce fan or misshapen fruit.

Benefit®Kiwi

The fruit biostimulant, Benefit®Kiwi (previously Benefit®PZ and Benefit®Gold) is an organic nitrogenous fertilizer produced by Valagro® of Italy. Valagro® of Italy, indicates Benefit®Kiwi is a natural plant extract that increases fruit size by promoting cell division during early stages of kiwifruit development (Valagro, 2011). Under current commercial practices, Benefit®Kiwi is the only product allowed for use to increase fruit size in New Zealand (Brown and Woolley, 2010), and is widely used in ‘Hort16A’ orchards (Patterson et al., 2003). Different responses to Benefit®Kiwi application has been reported based on cultivar. Brown and Woolley (2010) found that the average fruit weight for ‘Hort16A’ vines treated with Benefit®Kiwi increased 26.4 g compared to untreated vines. Similarly, in an earlier study, application of Benefit®Kiwi reportedly increased fruit size of *A. chinensis* by 16.9 g per fruit (Woolley and

Cruz-Castillo, 2006). In contrast, it has also been documented that fruit of *A. deliciosa* treated with Benefit®Kiwi had no significant increase in fruit size (Brown and Woolley, 2010; Woolley and Cruz-Castillo, 2006).

CPPU

CPPU (N-(2-chloro-4-pyridyl)-N'-phenylurea) is a synthetic cytokinin like substance that has growth stimulating capabilities and has been reported to increase fruit weight in grapes and kiwifruit (Brown and Woolley, 2010; Iwahori et al., 1988; Lorenzo et al., 2007; Nickell, 1986; Woolley and Cruz-Castillo, 2006). CPPU has been used in Japan, Italy, and China to increase fruit weight of kiwifruit (Brown and Woolley, 2010). Final fruit size is based on cell division and cell enlargement (Brown and Woolley, 2010). Cell division is controlled endogenously within plant tissues by natural plant hormones (Lorenzo et al., 2007). Cytokinin is a naturally occurring plant hormone that promotes cell division. Iwahori et al. (1988) reported that CPPU showed high cytokinin activity. Woolley and Cruz-Castillo (2006) reported 43 and 47g weight increase in response to CPPU application for *A. chinensis* and *A. deliciosa* respectively. Similarly, Brown and Woolley (2010) reported 46 and 31g weight increase for *A. chinensis* and *A. deliciosa* respectively, when treated with CPPU.

Harvesting Kiwifruit

'Hort16A' kiwifruit mature approximately a month earlier than 'Hayward' fruit. 'Hort16A' kiwifruit are generally harvested when soluble solid content (SSC) is between 9-14% with an internal hue angle of 103° or less to ensure optimum kiwifruit sweet flavor (Clark et al., 2004). Hue angle is a unit of measure corresponding to color coordinates utilizing the international CIELAB. 'Hayward' kiwifruit are recommended to harvest when SSC is 6.2-6.5%.

Internal color is not used as a harvest index for ‘Hayward’ kiwifruit. ‘Hort16A’ internal color is initially green then shifts to yellow, whereas ‘Hayward’ kiwifruit remain green all season long. Standard postharvest handling techniques normally utilized for ‘Hayward’ kiwifruit should be modified in order to protect ‘Hort16A’ kiwifruit from unintentional bruising and damage. ‘Hort16A’ kiwifruit has a characteristic pronounced ‘beak’ on the blossom end that potentially predisposes ‘Hort16A’ to frequent unintentional fruit bruising (Patterson et al., 2003). Therefore, care and diligence should be taken into consideration during postharvest transport and handling in order to maintain consumer acceptance and shelf life.

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Chapter Three

The Effects of Fruit Thinning and Benefit®Kiwi on Yield and Quality of Three Cultivars of *Actinidia chinensis*

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

Various cultivars of kiwifruit are prolific fruit bearers and have the tendency to overbear, which leads to the production of smaller fruit (Thakur and Chandel, 2004). An effective method for controlling fruit number and manipulating fruit size is fruit thinning (Richardson and McAneney, 1990). The beneficial influence of kiwifruit thinning is highly dependent on kiwifruit cultivar. Studies on different cultivars of kiwifruit have indicated the positive influence fruit thinning had on final fruit weight, but total yield was reduced due to the thinning practices (Lahav et al., 1989, Thakur and Chandel, 2004). Significant enhancement in fruit size has been reported for *A. deliciosa* 'Hayward' when vines are thinned to one fruit per fruiting node early during the growing season (Vasilakakis et al., 1997). However, thinning may not be practical for all kiwifruit cultivars, as the yield loss in *A. deliciosa* 'Hayward' due to fruit thinning may not be compensated by the increase in size of the remaining fruit. Therefore, fruit thinning is often utilized only to remove misshapen or unmarketable fruit. Utilizing fruit thinning to increase fruit size is typically recommended only on high-yielding cultivars that produce abundant small fruit such as *A. deliciosa* 'Allison' (Thakur and Chandel, 2004).

The fruit biostimulant Benefit®Kiwi (previously Benefit®PZ and Benefit®Gold) is an organic nitrogenous fertilizer produced by Valagro® of Italy. According to Valagro®, Benefit®Kiwi is a natural plant extract that increases fruit size by promoting cell division in the early stages of fruit development (Valagro, 2011). Under current commercial practice in New Zealand, Benefit®Kiwi is commonly used in *A. chinensis* 'Hort16A' orchards (Patterson et al., 2003). Average fruit weight for 'Hort16A' vines treated with Benefit®Kiwi was reported to be approximately 26.4 g greater than kiwifruit from untreated vines (Brown and Woolley, 2010). Similarly, Woolley and Cruz-Castillo (2006) found that Benefit®Kiwi increased *A. chinensis* fruit weight by 16.9 grams. Applications of Benefit®Kiwi on fruit of *A. deliciosa* did not result in increased fruit size (Brown and Woolley, 2010), and the effectiveness of Benefit®Kiwi has not been determined for many cultivars of kiwifruit.

A. chinensis 'AU Golden Dragon' and *A. chinensis* 'AU Golden Sunshine' are two new kiwifruit cultivars that were developed in a joint effort between Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Wuhan, Hubei Province, China. These two new cultivars were patented and are anticipated to perform well in the southeast United States due to their lower chill hour requirements (Wall et al., 2008). In central Alabama, both cultivars are considered more prolific in regard to fruit set when compared to the commercial standard 'Hort16A'. 'AU Golden Dragon' blooms approximately 10 days prior to and attains optimal harvest maturity 4-6 weeks prior to 'Hort16A'. 'AU Golden Sunshine' blooms ~ 10 days after 'Hort16A' and reaches harvest maturity 3-4 weeks prior to 'Hort16A'. 'AU Golden Sunshine' is a prolific fruiting cultivar, producing multiple lateral fruit per fruiting node, as many as five to seven. 'AU Golden Dragon' typically has three or less fruiting laterals per fruiting node in comparison to 'Hort16A', which typically produces a single fruit per fruiting node. The effectiveness of fruit thinning and biostimulant applications may be variable among the cultivars due to the differences in fruiting characteristics and fruit development periods. The influence of cultural practices on fruit size and quality has not been evaluated for these two new cultivars. Therefore, the objective of this study was to determine the influence of two fruit thinning levels and two fruit thinning levels combined with Benefit®Kiwi applications on marketable yield and fruit quality of three *A. chinensis* cultivars.

Materials and Methods

Experimental Design

Three separate experiments were conducted using sixteen mature vines each of *Actinidia chinensis* Planch. var. 'AU Golden Dragon', 'AU Golden Sunshine', and 'Hort16A'. Kiwifruit vines were grown at the Chilton Research and Extension Center in Thorsby, Alabama, USA (lat. 32º 55' N; long. -86º 40' W). Vines were planted in 1995 from rooted softwood cuttings. The vines had been trained to a winged T-bar trellis system with plants spaced 2.4 m × 4.8 m. Experiments were arranged as a completely randomized design for each cultivar. Vines were randomly assigned to one of four treatments: consisting of minimal fruit thinning, fruit thinning, minimal fruit thinning + Benefit®Kiwi, fruit thinning + Benefit®Kiwi, with 4 replicate vines per treatment.

Treatment Application

Fruit thinning treatments were thinned to approximately 60 fruit/m^2. Minimal fruit thinning treatments consisted of removing all lateral fruit leaving only "king" fruit. Minimal fruit thinning treatments varied in crop load with 90-140 fruit/m^2. Thinning treatments occurred 28 d after initial fruit set for each cultivar; after the initial natural fruit drop had occurred. Experiments were initiated in 2010 and repeated in 2011. Fruit thinning treatments were implemented on May 12 for 'AU Golden Dragon', May 17 for 'Hort16A', and May 28 for 'AU Golden Sunshine' in 2010, and on May 4, May 11, and May 25 for 'AU Golden Dragon', 'Hort16A', and 'AU Golden Sunshine' respectively, in 2011. Benefit®Kiwi applications were applied 28 d and 42 d after initial fruit set both years, which consisted of 5 $mL \cdot L^{-1}$ H_2O for 16 sec per vine.

Fruit Sampling and Analysis

Fruit were randomly sampled beginning in the first week of August in order to determine optimum harvest date. Fruit were harvested when soluble solids content (SSC) was greater than 10% and the internal hue angle was less than 103° to allow full development of the yellow flesh color (Patterson et al., 2003). 'AU Golden Dragon' was harvested on August 16, 'AU Golden Sunshine' was harvested on September 16, and 'Hort16A' was harvested on October 12, in 2010. In 2011, 'AU Golden Dragon', 'AU Golden Sunshine', and 'Hort16A' were harvested on August 30, September 6, and October 12, respectively. Total fruit yield per vine was determined at harvest. Fruit were graded at harvest into different commercial size categories, which are based on fruit weight. Any fruit ≥ 65 g was determined to be marketable fruit, while any fruit < 65 g was considered cull fruit. Ten randomly selected marketable fruit from each vine in 2011 were used to determine the effects of treatments on fruit quality. Fruit quality was determined by measuring fresh weight (FW), DMC (dry weight as a percentage of FW), SSC, titratable acidity (TA), the ratio between SSC:TA, flesh firmness, and internal flesh hue angle.

A 2 mm thick slice of skin and flesh was removed from the shoulder of each kiwifruit, and internal flesh color was determined by measuring the hue angle using a Minolta CM-2002 spectrophotometer (Minolta, Tokyo, Japan). Flesh firmness was measured on same area where the flesh color measurement was taken from each fruit. Firmness was measured with a bench top penetrometer using an 8 mm probe (model FT 327, McCormick Fruit Tech, Yakima, Washington).

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

The protocol for determining titratable acidity (TA) was as follows: twenty-five g of each composite kiwifruit sample were added to 100 mL of HPLC water from a Millipore Direct-Q5 filter system (Millipore Corp., Bedford, MA). Each composite sample was homogenized in a blender (Oster®, Sunbeam Products, Inc., Boca Raton, FL) for approximately 2 min at a setting of blend until the homogenate attained a homogenous consistency. Twenty-five g (25 g) aliquot of the homogenate was placed into clear polypropylene test tubes and centrifuged in a refrigerated centrifuge (Model J2-21; Beckman Centrifuge, San Antonio, TX) for 15 min at 15000 g_n to separate out the solids and extract the supernatant. The supernatant was filtered through grade 50 cheesecloth into 50 mL beakers. Five (5.0) mL of supernatant was added to 25 mL of HPLC Mili-Q water for a final volume of 30 mL. TA was measured using a titrimeter (Metrohm Titrino Model 719 S; Metrohm Corp., Herisau, Switzerland). The supernatant was titrated with 0.1 M solution of NaOH. Tritratable acidity was expressed as citric acid equivalent using the formula: $[(\text{mL NaOH} \times 0.1\text{ N} \times 0.064\text{ meq} \cdot \text{g of juice}^{-1}) \times 100]$.

Statistical Analysis

An analysis of variance was performed on the response data using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC). The model was a 2 by 4 factorial design of the years 2010 and 2011, and the four Benefit®Kiwi and thinning treatments. Each kiwifruit cultivar was analyzed separately. The LSMEANS statement SLICE option was used to determine simple effects significance for the year by treatment interaction. Differences among treatments within a year were determined using the LSMESTIMATE statement. Graphical methods were used to examine residuals for homogeneity of variance. Any violation of these assumptions was corrected using the RANDOM statement. All significances were at $\alpha = 0.05$.

Results

Due to irrigation failure in July, August, and September of 2011 during a severe drought, substantial fruit loss occurred that resulted in variable total and marketable fruit yields remaining on vines at harvest. Due to the variability in total and marketable fruit yields, there were no significant differences in marketable fruit number when comparing treatments within cultivars.

Hence, only the results of treatments on total, marketable, and cull fruit yields from 2010 are included in the results.

'AU Golden Dragon'

There was no effect of fruit thinning or Benefit®Kiwi on marketable fruit number of 'AU Golden Dragon' (Table 1). Marketable fruit numbers were consistent throughout all four treatments and ranged from 34-42 marketable fruit/m^2 (Table 2). There was no effect of fruit thinning or Benefit®Kiwi on marketable fruit yield (Table 1). There were more total fruit and less cull fruit due to the fruit thinning treatment compared to minimal thinning (Table 1, 2). Total yield of minimal thinning treatments were greater compared to thinning treatments (Table 1). Fruit number for fruit thinning treatments were consistently different than the minimum thinning treatments, with minimal thinning treatments averaging 122 fruit/m^2 and fruit thinning treatments averaging 70 fruit/m^2 (Table 2). There were no effects of fruit thinning or Benefit®Kiwi on fruit quality parameters of fruit from 'AU Golden Dragon' (Table 3). The DMC of fruit from the thinning treatment (19.6%) was greater than fruit that had been thinned and treated with Benefit®Kiwi (17.5%) (Table 4).

'AU Golden Sunshine'

Fruit thinning increased marketable fruit numbers and marketable fruit yield of 'AU Golden Sunshine' (Table 5). Fruit thinning treatments averaged 19 marketable fruit/m^2 (Table 6). There was no effect of Benefit®Kiwi on marketable fruit numbers or marketable fruit yield (Table 5). The total yield did not decrease due to fruit thinning treatments (Table 5). More cull fruit were present on minimal thinning treatments (82-126 m^2) compared to fruit thinning treatments (30-40 m^2) (Table 6). The greatest number of marketable fruit were due to fruit thinning, with 19 and 24 fruit/m^2 on thinning alone and Benefit®Kiwi plus thinning, respectively, compared to 8 and 13 fruit/m^2 on minimal thinning and Benefit®Kiwi plus minimal thinning, respectively (Table 6). Due to variability in fruit loads, the total fruit number for the minimal thinning treatment was not statistically different compared to the other treatments. The total fruit number for the Benefit®Kiwi plus minimal thinning treatment was greater than the thinning treatments. There were no effects of fruit thinning or Benefit®Kiwi on fruit quality parameters for 'AU Golden Sunshine' (Table 7). Treatments did not affect quality characteristics of 'AU Golden Sunshine' (Table 8).

'Hort16A'

Marketable fruit and marketable yield were greater when Benefit®Kiwi was applied to 'Hort 16A' (Table 9). Benefit®Kiwi treatments averaged 18 marketable fruit/m^2 compared to 10 fruit/m^2 without Benefit®Kiwi (Table 9). However, minimal fruit thinning treatments were not consistent in terms of total fruit number (Table 10). Minimal fruit thinning treatments averaged 157 fruit/m^2, which was greater than the total fruit number for Benefit®Kiwi plus minimal fruit thinning treatment (106 fruit/m^2) (Table 10). The significant effects of Benefit®Kiwi on marketable fruit number and marketable fruit weight (Table 9) could be misleading due to the differences in crop load between the minimal fruit thinning treatments (Table 10). Similarly, there were greater cull fruit in the minimal thinning treatment compared to vines treated with Benefit®Kiwi plus minimal fruit thinning (Table 10). There was no effect on marketable fruit number or marketable yield in response to fruit thinning (Table 9). As expected, there were more total fruit and less cull fruit due to the fruit thinning treatment compared to minimal thinning (Tables 9, 10). The TA was greater in fruit from vines treated with Benefit®Kiwi (Table 11). There were no effects of fruit thinning or Benefit®Kiwi on other fruit quality parameters (Table 11). Treatments did not affect fruit quality characteristics of 'Hort 16A' (Table 12).

Discussion

The effects of fruit thinning and Benefit®Kiwi applications yielded variable results among the three different cultivars of *A. chinensis*. Fruit thinning increased marketable yields of 'AU Golden Sunshine', but not 'AU Golden Dragon' or 'Hort16A'. Previous research with *A. deliciosa* 'Hayward' demonstrated that fruit size was increased, but total yield was reduced in response to fruit thinning (Burge, et al., 1987, Vasilakakis et al., 1997). Though a substantial number of fruit was removed when implementing fruit thinning treatments, the total yield was not reduced on 'AU Golden Sunshine', and the marketable yield was increased. Fruit thinning resulted in reduced total yield and no apparent effect on marketable yield of 'AU Golden Dragon' and 'Hort16A'. 'AU Golden Sunshine' is a very prolific fruiting cultivar, and similar results have been reported for other prolific fruiting cultivars (Lahav et al., 1989; Thakur and Chandel, 2004). Due to the great amount of fruit that 'AU Golden Sunshine' vines produced, the leaf to fruit ratio is reduced and there is likely not sufficient photo-assimilates available to produce adequate marketable yields. Fruit size of kiwifruit is greatly influenced by source-sink relationships (Boyd and Barnett, 2011; Famiani, 1997; Lai et al., 1989; Seager, 1995; Snelgar, 1988). Cooper and Marshall (1991) reported that there is an optimum balance between fruit size and yield of 'Hayward' kiwifruit; as crop load increases, total yield increases but mean fruit weight decreases. Though overall yield of 'AU Golden Dragon' was reduced due to fruit thinning applications compared to minimal thinning treatments, thinning did not have an adverse effect on total marketable fruit yields. There were no effects of fruit thinning on total yield or marketable fruit yield of 'Hort16A', therefore fruit thinning does not appear to be beneficial for these cultivars. The economic benefit of fruit thinning appears to be directly related to the fruiting habits of the cultivar. Yield loss in *A. deliciosa* 'Hayward' due to fruit thinning may not be compensated by increase in size of the remaining fruit; however, fruit thinning is warranted for the high-yielding *A. deliciosa* 'Allison' (Thakur and Chandel, 2004).

The fruit development stage when thinning treatments were applied may have been too late to achieve sufficient increases in fruit size for remaining kiwifruit on 'AU Golden Dragon' and 'Hort16A'. These cultivars do not produce (or over-produce) as much fruit compared to 'AU Golden Sunshine', which in contrast did benefit from thinning treatments. There is evidence that flower thinning, or fruit thinning at an earlier stage does increase fruit size of kiwifruit (Antognozzi, 1991, Lahav et al., 1989). Lateral removal of flowers during developmental bud-swell in 'Hayward' kiwifruit has subsequently produced a kiwifruit crop with 75% of the fruit greater than 85 g (Antognozzi, 1991).

In this study, there were no beneficial effects of Benefit®Kiwi application on marketable yield or number of marketable fruit from 'AU Golden Dragon' or 'AU Golden Sunshine'. The effect of Benefit®Kiwi on 'Hort16A' was inconclusive in this study. Marketable fruit number and marketable yield was significantly greater on vines treated with Benefit®Kiwi. The significant effects of Benefit®Kiwi on marketable fruit number and marketable fruit weight (Table 9) could be misleading due to differences in crop load between minimal fruit thinning treatments (Table 10). 'Hort16A', minimal thinning treatments (157 fruit/m^2) had more fruit left on vines compared to Benefit®Kiwi plus minimal thinning treatments (106 fruit/m^2). Due to the variation in crop load of 'Hort16A' in minimal thinning treatments (Table 10), total fruit number of the thinning treatment was not different than the Benefit®Kiwi plus minimal thinning treatment. Therefore, differences in source-sink relationships between vines treated with Benefit®Kiwi and those receiving no Benefit®Kiwi may provide a possible role in the perceived effects. Benefit®Kiwi did not appear to influence variation in crop load between the two minimal thinning treatments, as no fruit drop occurred. It is more likely that more cull/lateral fruit were present on the Benefit®Kiwi plus minimal thinning treatments causing the variation in crop loads.

Benefit®Kiwi has been shown to increase fruit size of *A. chinensis* in previous findings (Woolley and Cruz-Castillo, 2006; Brown and Woolley, 2010). ‘Hort16A’ vines treated at 0, 10, and 20 d after full bloom with Benefit®Kiwi have been shown to have a 26.4 g fruit weight increase compared to untreated vines (Brown and Woolley, 2010). Similarly Woolley and Cruz-Castillo (2006) reported a 16.9 g weight increase of an *A. chinensis* selection treated 20 d after full bloom in response to Benefit®Kiwi. Brown and Woolley (2010) have shown that Benefit®Kiwi applied at 2.5 $mL \cdot L^{-1}$ did not result in an increase fruit weight in ‘Hayward’ kiwifruit. In contrast, Costa et al. (2002) found an increase of fruit weight of ‘Hayward’ kiwifruit when Benefit®Kiwi was applied at 3$mL \cdot L^{-1}$. In this study, Benefit®Kiwi was applied at 5 $mL \cdot L^{-1}$ 28 d and 42 d after initial fruit set, which could be a limiting factor contributing to no response to Benefit®Kiwi for ‘AU Golden Dragon’ and ‘AU Golden Sunshine’. In addition, ‘AU Golden Dragon’ and ‘AU Golden Sunshine’ have shorter fruit development periods compared to ‘Hort16A’.

In a previous study, Boyd and Barnett (2011) assessed the effects on fruit quality of ‘Hort16A’, due to manipulating whole vine carbon allocation by pruning and fruit thinning. Treatments designated as the “feast” treatments maintained high leaf-to-fruit ratios by pruning fruiting shoots to approximately six leaves past the last fruit, and fruit thinning to one fruit per shoot, or ~ 28 fruit/m^2. In contrast, the “famine” treatment maintained low leaf-to-fruit ratios by the absence of fruit thinning, and pruning to one leaf past the last fruit. Although fruit were harvested at different maturities, Boyd and Barnett (2011) reported excessive pruning and increased kiwifruit loads of the famine treatment delayed maturity, and reduced the DMC. In contrast, in the present study, matured fruit of similar size were selected from each harvest of the three cultivars of *A. chinensis* to determine the effects of different treatments on fruit quality. Benefit®Kiwi and fruit thinning applications had no effect on fruit quality parameters of 'AU Golden Dragon', 'AU Golden Sunshine', and 'Hort16A'. However, thinning did result in greater DMC compared to Benefit®Kiwi + minimal thinning. Brown and Woolley (2010) found that Benefit®Kiwi treatments did result in lower DMC of 'Hort16A', however, in the present study, Benefit®Kiwi treatments did not alter DMC.

Fruit thinning and Benefit®Kiwi applications are costly management techniques used in kiwifruit production systems. The objective of this study was to determine the effects of these management techniques on marketable yield and fruit quality of three *A. chinensis* cultivars that are suitable for commercial production in the southeast. Fruit thinning is often only recommended for prolific fruiting kiwifruit cultivars. Therefore, fruit thinning may not be a cost effective management tool for many cultivars. Although, Benefit®Kiwi is often used on 'Hort16A' vines to increase fruit size in New Zealand, this study demonstrated that Benefit®Kiwi and fruit thinning is not practical for all *A. chinensis* cultivars. Thinning fruit 28 d after initial fruit set did not increase marketable yield for 'AU Golden Dragon' or 'Hort16A'. Therefore, removing fruit as much as 28 d after fruit set would likely reduce profitability in 'AU Golden Dragon' and 'Hort16A' production. Similarly, applying Benefit®Kiwi to 'AU Golden Dragon' and 'AU Golden Sunshine' is not recommended at the application frequency and rates used in this study. Fruit thinning did increase marketable yields on 'AU Golden Sunshine'. In this study, 'AU Golden Sunshine' produced an overabundance of small fruit that required fruit thinning in order for remaining fruit to attain marketable size. Besides effects on fruit size, there were no appreciable effects of fruit thinning or Benefit®Kiwi treatments on fruit quality parameters measured in this study.

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Table 1. Effect of Benefit®Kiwi[z] and fruit thinning on total fruit number, marketable fruit number, cull fruit number, total yield, and marketable yield[y] of *Actinidia chinensis* 'AU Golden Dragon', 2010.

	Benefit®Kiwi	No Benefit®Kiwi	Min Thin	Thin
Total fruit number	89ns[x]	102	122a	70b
Marketable fruit number[w]	34ns	40	36ns	38
Cull fruit number[v]	56ns	62	86a	32b
Total yield (kg)	5.2ns	5.9	6.4a	4.8b
Marketable yield (kg)	2.8ns	3.3	2.9ns	3.2

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.
[w]Marketable fruit = ≥ 65g.
[v]Cull fruit = < 65g.

Table 2. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal thinning, and Benefit®Kiwi + thinning on total fruit number, marketable fruit number, marketable yield and cull fruit number[y] of *A. chinensis* 'AU Golden Dragon', 2010.

	Total fruit number	Marketable fruit number	Marketable yield (kg)	Cull fruit number
Min Thin	128a[x]	39ns	3.16ns	90a
Thin	76b	42	3.49	35b
Benefit® Kiwi + Min Thin	116a	34	2.65	82a
Benefit® Kiwi + Thin	63b	35	2.86	29b

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$.

Table 3. Effect of Benefit®Kiwi[z] and fruit thinning on fruit quality parameters[y] of *A. chinensis* 'AU Golden Dragon', 2011.

	Benefit®Kiwi	No Benefit®Kiwi	Min Thin	Thin
Firmness (kg)	9.1ns	9.1	9.7ns	8.6
SSC (%)	10.1ns	10.4	9.9ns	10.6
IC (Hue°)	98.5ns	98.0	98.7ns	97.8
DMC (%)	18.0ns	19.0	18.3ns	18.6
TA (%)	1.6ns	1.6	1.6ns	1.6
SSC:TA (ratio)	6.4ns	6.7	6.4ns	6.7

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.

[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.

[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.

Table 4. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal fruit thinning, and Benefit®Kiwi + fruit thinning on *A. chinensis* 'AU Golden Dragon' fruit quality, 2011.

	Firmness (kg)	SSC[y] (%)	IC (Hue°)	DMC (%)	TA (%)	SSC:TA (ratio)
Min Thin	6.4ns[x]	9.8ns	98.6ns	18.4ab	1.5ns	6.5ns
Thin	7.6	10.9	97.4	19.6a	1.6	7.0
Benefit®Kiwi + Min Thin	10.9	10.0	98.8	18.4ab	1.6	6.4
Benefit® Kiwi + Thin	8.3	10.2	98.2	17.5b	1.6	6.4

[z]Benefit®Kiwi applied at $5 mL\cdot L^{-1}$.
[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.
[x]Means within columns followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.

Table 5. Effect of Benefit®Kiwi[z] and fruit thinning on total fruit number, marketable fruit number, cull fruit number, total yield, and marketable yield[y] of *A. chinensis* 'AU Golden Sunshine', 2010.

	Benefit®Kiwi	No Benefit®Kiwi	Min. Thin	Thin
Total fruit number	102ns[x]	69	115a	56b
Marketable fruit number[w]	19ns	14	11a	21b
Cull fruit number[v]	84ns	56	104a	35b
Total yield (kg)	4.7ns	3.3	4.6ns	3.4
Marketable yield (kg)	1.4ns	1.1	0.8a	1.7b

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.
[w]Marketable fruit = ≥ 65g.
[v]Cull fruit = < 65g.

Table 6. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal thinning, and Benefit®Kiwi + thinning on total fruit number, marketable fruit number, marketable yield, and cull fruit number[y] of *A. chinensis* 'AU Golden Sunshine', 2010.

	Total fruit number	Marketable fruit number	Marketable yield (kg)	Cull fruit number
Min Thin	90ab[x]	8b	0.6b	82a
Thin	48b	19a	1.5a	30b
Benefit®Kiwi+Min Thin	139a	13ab	1.0ab	126a
Benefit®Kiwi+Thin	64b	24a	1.9a	40b

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$.

Table 7. Effect of Benefit®Kiwi[z] and fruit thinning on fruit quality parameters[y] of *A. chinensis* 'AU Golden Sunshine', 2011.

	Benefit®Kiwi	No Benefit®Kiwi	Min. Thin	Thin
Firmness (kg)	9.8ns[x]	7.0	8.7ns	8.0
SSC (%)	11.6ns	12.6	12.2ns	12.1
IC (Hue°)	104.7ns	103.7	104.8ns	103.6
DMC (%)	19.3ns	18.6	19.3ns	18.7
TA (%)	1.2ns	1.2	1.3ns	1.1
SSC:TA (ratio)	9.9ns	11.2	10.0ns	11.0

[z]Benefit®Kiwi applied at $5mL \cdot L^{-1}$.

[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.

[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.

Table 8. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal fruit thinning, and Benefit®Kiwi + fruit thinning on *A. chinensis* 'AU Golden Sunshine' fruit quality, 2011.

	Firmness (kg)	SSC[y] (%)	IC (Hue°)	DMC (%)	TA (%)	SSC:TA (ratio)
Min Thin	6.4ns[x]	12.8ns	104.6ns	18.8ns	1.3ns	10.5ns
Thin	7.6	12.5	102.8	18.4	1.1	11.8
Benefit®Kiwi + Min Thin	10.9	11.6	104.9	19.7	1.2	9.6
Benefit® Kiwi + Thin	8.3	11.7	104.3	19.0	1.2	10.1

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.

[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.

[x]Means within columns followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.

Table 9. Effect of Benefit®Kiwi[z] and fruit thinning on total fruit number, marketable fruit number, cull fruit number, total yield, and marketable yield[y] of *A. chinensis* 'Hort16A', 2010.

	Benefit®Kiwi	No Benefit®Kiwi	Min. Thin	Thin
Total fruit number	87a[x]	122b	132a	77b
Marketable fruit number[w]	18a	10b	11ns	18
Cull fruit number[v]	68a	111b	120a	59b
Total yield (kg)	3.6ns	4.5	4.4ns	3.7
Marketable yield (kg)	1.4a	0.8b	0.8ns	1.4

[z]Benefit®Kiwi applied at $5mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.
[w]Marketable fruit = ≥ 65g.
[v]Cull fruit = < 65g.

Table 10. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal thinning, and Benefit®Kiwi + thinning on total fruit number, marketable fruit number, marketable yield, and cull fruit number[y] of *A. chinensis* 'Hort16A', 2010.

	Total fruit number	Marketable fruit number	Marketable yield (kg)	Cull fruit number
Min Thin	157a[x]	6b	0.5b	151a
Thin	86bc	14ab	1.1ab	72bc
Benefit®Kiwi+Min Thin	106b	16a	1.2a	90b
Benefit®Kiwi+Thin	68c	21a	1.6a	47c

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.
[y]All response data were recorded per square meter of canopy.
[x]Means within rows for Benefit® Kiwi and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$.

Table 11. Effect of Benefit®Kiwi[z] and fruit thinning on fruit quality parameters[y] of *A. chinensis* 'Hort16A', 2011.

	Benefit®Kiwi	No Benefit®Kiwi	Min. Thin	Thin
Firmness (kg)	6.3ns[x]	6.0	6.0ns	6.3
SSC (%)	15.2ns	15.2	15.6ns	14.8
IC (Hue°)	102.3ns	102.7	102.2ns	102.8
DMC (%)	21.8ns	22.0	22.0ns	21.7
TA (%)	1.2a	1.0b	1.1ns	1.1
SSC:TA (ratio)	13.2ns	14.7	14.2ns	13.7

[z]Benefit®Kiwi applied at $5mL \cdot L^{-1}$.
[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.
[x]Means within rows for Benefit and thinning followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.

Table 12. Effect of minimal fruit thinning, fruit thinning, Benefit®Kiwi[z] + minimal fruit thinning, and Benefit®Kiwi + fruit thinning on *A. chinensis* 'Hort16A' fruit quality, 2011.

	Firmness (kg)	SSC[y] (%)	IC (Hue°)	DMC (%)	TA (%)	SSC:TA (ratio)
Min Thin	5.6ns[x]	15.5ns	102.3ns	22.2ns	1.1ns	14.9ns
Thin	6.4	14.8	103.2	21.8	1.0	14.4
Benefit®Kiwi + Min Thin	6.5	15.6	102.1	21.8	1.2	13.5
Benefit®Kiwi + Thin	6.2	14.8	102.4	21.7	1.2	13.0

[z]Benefit®Kiwi applied at $5 mL \cdot L^{-1}$.

[y]SSC = Soluble solids content, IC = Internal color, DMC = Dry matter content, TA = Titratable acidity, SSC:TA = Soluble solids content: titratable acidity.

[x]Means within columns followed by different letters are significantly different based on single degree of freedom contrasts at $\alpha = 0.05$. Not significant = ns.