Impact of Harvest Maturity on Consumer Preference, Fruit Quality, and Postharvest Longevity of Two Kiwifruit Cultivars (*Actinidia chinensis* Planch.)

by

Lingbo Xie

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Approved by

James D. Spiers, Chair, Associate Professor of Horticulture
Leonard N. Bell, Professor of Poultry Science
J. Raymond Kessler, Jr., Professor of Horticulture
Floyd M. Woods, Associate Professor of Horticulture

Abstract

Harvest maturity is closely associated with postharvest performance and consumer preference of kiwifruit. This research focused on the impact of harvest maturity on consumer preference and postharvest performance of two *Actinidia chinensis* cultivars, ‘AU Golden Dragon’ and ‘AU Golden Sunshine’, grown in central Alabama. The first study focused on the effects of harvest maturity and storage time on fruit quality and postharvest performance of these two cultivars. Fruit were harvested at 7 day intervals from mid-Aug. to mid-Sept. in 2015 (four harvest dates for both cultivars) and 2016 (four harvest dates for ‘AU Golden Sunshine’; five harvest dates for ‘AU Golden Dragon). Fruit quality attributes were measured at harvest but after 64 hours curing time and subsequently every 14 days until the firmness of fruit was less than 0.5 kgf or 80% of fruit showed visual symptoms of severe chilling injury. ‘AU Golden Dragon’ harvested around 30 Aug. with 7.8– 8% soluble solids content (SSC) had a longer storage life, a more consistent market window and a relatively lower chilling injury incidence. ‘AU Golden Sunshine’ harvested 6 Sept. –13 Sept. with SSC 8.0–10.0% had a relatively longer storage life and a lower chilling injury incidence. The second study determined the effect of harvest maturity on consumer preference of these two cultivars. Sensory evaluation was conducted in 2016 using fruit harvested at 7 day intervals from mid-Aug. to mid-Sept for 5 weeks and 4 weeks, respectively, for ‘AU Golden Dragon’ and ‘AU Golden Sunshine’. Fruit quality was measured at harvest and before sensory evaluation. During sensory evaluation, 90 volunteers judged nine kiwifruit samples in three separate groups by using 9-point hedonic scales. In general, ‘AU

Golden Dragon' was rated higher with consumers than 'AU Golden Sunshine'. Harvest maturity did not affect overall consumer preference for 'AU Golden Dragon', indicating a longer harvest window for 'AU Golden Dragon', while consumer's preferred 'AU Golden Sunshine' fruit harvested on 29 Aug. 2016.

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List of Abbreviations

A.D.	Anno Domini
USDA	the United States Department of Agriculture
d	Day
%	Percent
°C	Degrees Celsius
AU	Auburn University
cv.	Cultivar
DMC	Dry Matter Content
h	hour
g	Gram
mm	Millimeter
kg	Kilogram
kgf	Kilograms of force
SSC	Soluble Solids Content
TA	Titratable Acidity
°h	Degree Hue
SSC:TA	the Ratio of Soluble Solids Content and Titratable Acidity
CI	Chilling injury
CA	Controlled atmosphere

1-MCP	1-Methylcyclopropene
RH	Relative humidity
C_2H_4	Ethylene
CO_2	Carbon dioxide
O_2	Oxygen

Chapter One

Literature Review

History

Originating from Southeast Asia, kiwifruit commonly grows wild in the forest margins of the Yangtze River Valley, especially in Ichang of China (Ferguson, 2004; LaRue, 1994). Kiwifruit was named, 'Mihoutao' during the Tang Dynasty (A.D. 618–907), as wild monkeys enjoyed the ripe fruit (Ferguson, 2004). In 1912, 'Chinese gooseberry' appeared in publications as a second kiwifruit name due to its place of origin and gooseberry flavor. In the 20th century, Isabel Fraser introduced kiwifruit seeds to New Zealand, and these seeds were given to Alexander Allison, who successfully raised kiwifruit in Wanganui (LaRue, 1994). All New Zealand kiwifruit cultivars are recognized as descendants of vines from these seeds. Now, the name "kiwifruit" is commonly used, as kiwi is a symbol of New Zealand and not because there is any similarity between the fruit and the kiwi bird. Based on the success in New Zealand, other countries, including Australia, France, Greece, Chile, Portugal, South Africa, Spain, and the United States, have imported vines for trial plantings and successfully developed commercial kiwifruit production. In the early 1930s, the United States Department of Agriculture (USDA) introduced kiwifruit into the United States, and Robert Smith, a research horticulturist of the now closed USDA Plant Introduction Station in Chico, CA, was the first to grow and produce kiwifruit in California successfully (Ferguson, 2004; La Rue, 1994). Kiwifruit plants were introduced to Alabama in the 1980's, and they have been evaluated at the Chilton Area Research and Extension Center in Thorsby, AL since then (Wall, 2006). The central portion of Alabama has the potential to develop commercial production of kiwifruit due to similarities in latitude and climate to New Zealand's Bay of Plenty and to Hubei Province of China (Wall, 2006).

Kiwifruit international trade started in the early 1950s, when New Zealand first exported kiwifruit to Europe (LaRue, 1994). Kiwifruit is currently marketed throughout the world by numerous countries. As of 2014, 3.44 million metric tons of kiwifruit were produced around the world (FAOSTAT, 2016). China was the top producer with 1.84 million metric tons, followed by Italy with 506,958 metric tons, and New Zealand with 410,746 metric tons. The United States produced 25,855 metric tons in 2014, ranking tenth in total kiwifruit production. The vast majority of kiwifruit production in the United States (98 %) was located in California (Stein, 2014).

Cultivars

Actinidia

There are approximately 76 species in the genus *Actinidia*, and *Actinidia deliciosa* is the most popular species used for the commercial market (Ferguson, 1991; Ferguson, 1999; Ferguson and Huang, 2007). Different species vary in fruit quality characteristics like size, shape, hairiness, external and internal color, juiciness, texture, and composition (Ferguson, 1999). There are two related species used commonly for international commerce: *Actinidia deliciosa* (A. Chev.) and *Actinidia chinensis* Planch. C.F. Liang et A.R. Ferguson (Ferguson and Seal, 2008).

Actinidia deliciosa

Actinidia deliciosa is the most common commercial species comprising about 96% of world kiwifruit production, and 'Hayward' is the most popular green-fleshed kiwifruit cultivar grown in the world (Ferguson, 2015). Due to its large fruit size, good flavor, superior shelf life, and reasonable yield, 'Hayward' gained popularity and has occupied a major place in international trade for at least the past 40 years. 'Hayward' was developed by Hayward Wright in New Zealand, and by 1975 it was exported worldwide (Ferguson, 1999). The harvest index for 'Hayward' grown in New Zealand was established in 1980, and fruits harvested with a minimum of 6.2% soluble solids content (SSC) could be stored and exported (Harman, 1981). The minimum harvest SSC value is constrained by growing environment and management practice. In California, it was recommended to harvest 'Hayward' when fruit reach 6.5% SSC (Crisosto and Kader, 1999).

Actinidia chinensis

It was not until 1984 that *A. chinensis* and *A. deliciosa* were separated into two species due to distinctly different fruit quality characteristics (Ferguson, 1999). *Actinidia chinensis* has larger fruit size, hairless appearance, yellow flesh, and sweeter taste, compared with *A. deliciosa* (Ferguson, 1999). *Actinidia chinensis* was selected from the wild of China, and first introduced to New Zealand in 1977 (Ferguson, 1999). After this introduction, it was believed that *A. chinensis* had the greatest commercial potential among all the *Actinidia* species (Ferguson, 1999). To produce fruit with good quality, two accessions of *A. chinensis* were crossed in 1987, and 4 years later, fruits with soft downy hair, yellow flesh, and good flavor were harvested from one seedling, named 'Hort16A' (Ferguson, 1999). 'Hort16A' was commercially released and entered into international trade in 1995, commercially sold as Zespri® Gold Kiwifruit (Patterson et al., 2003). Yellow flesh, a significant commercial characteristic of *A. chinensis*, is the result of reduction in chlorophyll and the transformation of the fruits' chloroplasts to chromoplasts during maturation and ripening (McGhie and Ainge, 2002). Thus, internal color could be used as a harvest index of yellow-fleshed kiwifruit.

After 'Hort16A' was introduced to the fresh market as Zespri® Gold, the yellow flesh and distinct sweet flavor appealed to many consumers (Ferguson, 2015). Also, 'Hort16A' attracted growers because of higher gate return (Ferguson, 2015). In the 2011–2012 season, 94,000 tons of 'Hort16A' kiwifruit were exported from New Zealand comprising 25% of the total kiwifruit export value that suggested 'Hort16A' had greater market potential (Ferguson, 2015). However, in the first week of Nov. 2010, *Pseudomonas syringae* pv. *actinidiae* (Psa), a causal agent of bacterial canker of kiwifruit, was first observed in *Actinidia chinensis* growing in Te Puke, Bay of Plenty, New Zealand (Everett et al., 2011). It multiplied and quickly spread to new areas (Vanneste et al., 2011). In 2012, there were more than 1400 orchards, 52% of the kiwifruit hectares grown in New Zealand, suffering from Psa. In the spring of 2012, the number of orchards infected by Psa increased every week (Vanneste, 2012). Psa can infect leaves, canes, trunks, buds, and flowers causing red or white liquid to ooze from cankers and wilting or death to the infected parts (Gallelli et al., 2011; Serizawa and Ichikawa 1993; Takikawa et al., 1989; Taylor et al., 2015; Vanneste et al., 2011; Vanneste et al., 2011). Because 'Hort16A' was extremely affected by Psa, exportation of 'Hort16A' from New Zealand deceased indicating that 'Hort16A' would unlikely survive as a commercial yellow-fleshed kiwifruit (Ferguson, 2015). New Zealand Plant & Food Research breeding programs identified 'Gold3' with good tolerance of Psa, which is considered the most commercially available yellow-fleshed kiwifruit cultivar nowadays and has been marketed as Zespri® SunGold Kiwifruit (Ferguson, 2010; Ferguson, 2015).

Apart from ‘Gold3’, there was another newly released, yellow-fleshed kiwifruit called ‘Gold9’ that was marketed as Zespri® Charm Kiwifruit (Ferguson, 2015). The sweeter flavor of ‘Gold9’ predicts a greater market potential in East Asia, where consumers prefer sweeter kiwifruit (Ferguson, 2015).

‘AU Golden Dragon’ and ‘AU Golden Sunshine’

‘AU Golden Dragon’ and ‘AU Golden Sunshine’ are two patented cultivars of *A. chinensis* developed by cooperation between Auburn University, Auburn, AL, USA and The Fruit and Tea Institute, Hubei province, P.R. China (Dozier et al., 2011a; Dozier et al., 2011b). They have been evaluated for fruit quality characteristics since 1995 at the Chilton Research and Extension Center in Thorsby, AL (Wall, 2006). ‘AU Golden Dragon’ fruit has an elliptical shape, smooth brown skin, and a sweet flavor, and it matures about 50 days ahead of ‘Hort16A’ (Dozier et al., 2011a; Dozier et al., 2011b). ‘AU Golden Sunshine’ fruit has cylindrical and uniform shape, smooth skin, and a sweet flavor, and it matures about 30 days ahead of ‘Hort16A’ (Dozier et al., 2011a; Dozier et al., 2011b). Both cultivars have excellent flavor and a high percent dry matter and soluble solids content that are similar to ‘Hort16A’. Compared to ‘Hort16A’, these two new cultivars have different harvest times indicating that they have potential to extend market availability of golden kiwifruit (Burnie, 2009). Psa has not been observed in these two new yellow-fleshed kiwifruit cultivars, as Psa has not been found in USA.

Maturity

During maturation, various biochemical, physiological, and structural changes occur that impart the characteristic flavor indicating that maturity at harvest is a principle factor influencing compositional quality and postharvest performance of kiwifruit (Ghasemenezhad et al., 2013).

Softening

Due to climacteric characteristics of kiwifruit, softening and compositional changes are notable during maturation and ripening (MacRae et al., 1989), and they are widely used as indicators of postharvest quality (Bonghi et al., 1996). There are two phases of softening in the kiwifruit: the first is the rapid loss of firmness from harvest firmness to a value of about 2 kgf, and the second is the slower loss of firmness from 2 kgf to eating-ripeness (Lallu et al., 1989). Physiological events including degradation of hemicellulose (Soda et al., 1987) and solubilization of polyuronide (Bonghi et al., 1996) caused fruit softening accompanied by release of galactose from pectic polymers (Redgewell et al., 1992) and starch hydrolysis (MacRae et al., 1992) resulting in increased SSC.

Firmness was recognized as a major index determining postharvest longevity that was affected by temperature, atmosphere composition, ethylene concentration, and maturity (Bonghi et al., 1996). Ethylene was an important factor influencing softening in climacteric fruit (MacRae et al., 1989). Later harvested kiwifruits are more sensitive to ethylene. Research by MacRae et al. (1989) suggested that harvest maturity mainly influenced flesh firmness, and postharvest treatments like ethylene had the most impact on firmness of the core. Harvest maturity may be associated with internal ethylene production; hence, later harvested fruit may accumulate higher levels of ethylene and exhibit higher rates of flesh softening. Without any postharvest treatment, the harder core mostly appeared in more mature fruit and resulted in a reduction of consumer acceptance when consumers chose fruit by squeezing them. Although softening of the core can be promoted by ethylene treatment, it is also related to storage period. Autocatalytic ethylene production is a typical characteristic in climacteric fruit and two key enzymes, 1-aminocyclopropane-1-carboxylic acid synthase (ACS; EC 4.4.1.14) and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO; EC 1.14.17.4), are necessary for ethylene production (Lelièvre et al., 1997). Controlling the activity of ACS and ACO is an effective way to reduce ethylene production in kiwifruit. Low temperature can inhibit ACS and ACO activity and reduce ethylene production, but rewarming can induce ACS and ACO activity (Antunes and Sfakiotakis, 2002). Rothan and Nicolas (1994) reported that a higher level of carbon dioxide can affect ACO activity and retard autocatalytic ethylene production. Application of 1-methylcyclopropene (1-MCP) is another method commonly used to restrict ethylene production and the response to exogenous ethylene during storage (Cantin et al., 2011).

Chemical composition

Kiwifruit contain high levels of biologically active components like antioxidant substances that benefit human health (Tavarini et al., 2008). Kiwifruit, marketed as a “super fruit”, contain few calories, high amounts of vitamin C, starch, sugars, acids and pigments that contribute to consumer preference (Mitra, 2014). Maturity and postharvest storage are two major factors influencing the compositional quality of fruit. During fruit ripening, chemical and physical changes take place that determine fruit quality attributes. An appropriate harvest maturity stage corresponds with optimum fruit quality and the preservation of this quality after harvest (Tavarini et al., 2008). Changes in compositional components are associated with softening.

During ripening, starch converts into soluble sugars like sucrose, glucose and fructose, resulting in increased SSC. Changes of titratable acidity (TA) in ‘Hayward’ kiwifruit at maturation vary among different growing locations. In general, kiwifruit contain 0.9–2.5% total acidity at harvest including 40–50% citrate that is highest in the inner cortex, 40–50% quinate that is mainly in the outer cortex, and 10% malate (Marsh et al., 2004). In Israel, California, and Italy, acidity of ‘Hayward’ fruit contained higher levels of acidity (2-2.5%) at harvest, and decreased sharply during storage (Ben-Arie et al., 1982; Crisosto and Crisosto, 2001; Tombesi et al., 1993), while in New Zealand, acidity of ‘Hayward’ fruit changed only slightly during ripening, and had lower levels of acidity (~1.4%) at harvest (MacRae et al., 1989). Phenolic compounds and ascorbic acid decreased during storage, and water loss of kiwifruit during storage accelerates ascorbic acid degradation (Tavarini, et al., 2008).

Pigments change during maturation results in the flesh color in ripe fruit of green-fleshed kiwifruit and yellow-fleshed kiwifruit (McGhie and Ainge, 2002). Green-fleshed kiwifruit like *A. deliciosa* ‘Hayward’ remain green during all stages of fruit development, maturation, and storage, while yellow-fleshed kiwifruit like *A. chinensis* ‘Hort16A’ are green initially and change to yellow in later stages of maturation (Montefiori et al., 2009). In green-fleshed kiwifruit, the amount of chlorophyll does not change during maturation, while in yellow-fleshed kiwifruits, chlorophyll degradation occurs during maturation and chloroplasts are converted into chromoplasts (Montefiori et al., 2009). Because of chlorophyll degradation, carotenoids contribute to the yellow flesh color. Hence, the level of chlorophyll in kiwifruit is a determining factor for the flesh color.

Chilling Injury (CI)

Chilling injury is one of the most common nonfreezing low temperature physiological disorders of kiwifruit. Typical visual symptoms of CI in kiwifruit include ring or zone granular appearance in outer pericarp area and water soaked tissues in the outer or inner pericarp (Burdon et al., 2014a; Lallu, 1997). Chilling injury appeared when kiwifruit were stored at -0.5 to 2.5 ºC for a long time (Lallu, 1997) and was associated with maturity and postharvest treatments.

Injury expression was dependent on storage temperature and duration. Kiwifruit harvested later, which have lower firmness and higher SSC, have lower susceptibility to CI (Burdon et al., 2007; Harman, 1981; Reid, 2002). Low pre-harvest temperature increased the rate of SSC accumulation (Hopkirk et al., 1989; Seager et al., 1996). SSC accumulation was observed after 150 hours at below 10 ºC in 'Hayward' kiwifruit growing in Chile (Zoffoli et al., 1999). Moreover, low pre-harvest temperature (<7 ºC) increased SSC accumulation and reduced the susceptibility of 'Tomua' fruit (*Actinidia deliciosa* (A.Chev.) C.F. Liang et A.R. Ferguson) to CI (Burdon et al., 2007). Higher SSC at harvest and lower CI incidence were found after increasing hours of low pre-harvest temperature (<7 ºC). SSC is an important osmoregulater in plant cells, and increasing SSC results in a higher intracellular solute concentration that reduces the freezing point and increases cold tolerance (Der Agopian et al., 2011).

Moreover, summer pruning was shown by Gerasopoulos and Drogoudi (2005) to increase SSC at harvest and reduced the incidence of CI. The incidence of CI of 'Hayward' was influenced by temperature, relative humidity (RH), maturity, curing time and precooling treatments (Burdon et al., 2007; Goldwater et al., 2013; Lallu, 1997). Precooling increased CI occurrence, whereas incorporating a curing time decreased CI severity and incidence (Goldwater et al., 2013; Lallu, 1997). However, Burdon et al. (2014b) pointed out that compared with at-harvest fruit characteristics, environment conditions and orchard management practices had a greater influence on CI. Chilling injury was one of the factors that can terminate postharvest longevity of kiwifruit (Lallu et al., 2011; Patterson et al., 2003), and is the main contributor to postharvest losses. Therefore, controlling CI is beneficial for reducing grower economic losses and extending the market window.

Consumer preference

All pre-harvest and postharvest treatments, for instance, cultivar, environmental, geographic cultivation conditions, postharvest storage, marketing and handling, contribute to improving or retaining fruit quality to meet consumers' satisfaction. Sensory evaluation is a method to gain knowledge about consumer acceptance of fruit including olfactory, taste and visual characteristics (McWilliams, 2005). Thus, the results of sensory evaluation could guide fruit production and postharvest treatments, and benefit the market. Appearance, aroma, texture, and flavor including sourness and sweetness are fruit characteristics often tested during a sensory evaluation (McWilliams, 2005). Sensory evaluation panels are divided into two types: trained and untrained. An untrained panel was only prepared regarding the evaluation of the product, such as a consumer panel. A trained panel is trained thoroughly, including how to use the scorecard and to describe the fruit characteristics. Trained panels are usually used for research concerning determination of human reactions to fruit characteristics in detail, whereas untrained panels are preferred for determining the general acceptance of potential consumers. Sensory evaluation tests include descriptive testing, affective tasting, and difference testing. Descriptive testing requires participants to describe or use critical scoring to judge fruit characteristics, so the panel must be trained. Affective tasting determines acceptance or preference of product, and often used an untrained consumer panel. Difference testing judges whether there is a detectable difference between products (McWilliams, 2005). Several scorecard types have been designed including descriptive scales and rating scales for difference method testing. The design of the scorecard is important for sensory evaluation, because either too much or too little detail could influence the results.

Kiwifruit is attractive to consumers in part because it is a low calorie, high amount source of antioxidants, especially vitamin C. Besides nutritive value, good flavor is another essential factor that attracts consumer acceptance and demand. Sensory evaluation of kiwifruit has been conducted for many years to determine the fruit quality attributes consumers prefer. Kiwifruit consumer preference was related to dry matter content (DMC), SSC, acidity, aroma, and firmness (Crisosto and Crisosto, 2001; Jaeger et al., 2011; Rossiter et al., 2000; Stec et al., 1989). Dry matter content is comprised of soluble solids like sugars, and insoluble solids like structural carbohydrates and starch; thus DMC is a direct indication of an indicator of total carbohydrate content of kiwifruit (Burdon et al., 2004). During fruit ripening, starch is converted into soluble solids, resulting in changes in juice color and influencing SSC in the ripe stage, which reflects eating fruit quality (Beever and Hopkirk, 1990; Mitchell et al., 1990; Richardson et al., 1997). Burdon et al. (2004) indicated that higher DMC at harvest improved flavor at the ripening stage and was more popular with consumers. Sweetness and sourness are two major factors influencing consumer preference of fruit, and were commonly used as attributes in sensory evaluation. Crisosto and Crisosto (2001) reported that consumers preferred ‘Hayward’ kiwifruit with higher SSC value at harvest. Rossiter et al. (2000) similarly reported that consumers preferred ‘Hayward’ kiwifruit more as the soluble solids content:titratable acidity ratio (SSC:TA) increased, indicating that consumers prefer sweeter ‘Hayward’ kiwifruit. Higher DMC of

‘Hort16A’ were more popular with consumers (Jaeger et al., 2011), and consumers preferred ‘Hort16A’ with 14% ripe SSC (Harker et al., 2009). Above all, consumer preference is associated with fruit characteristics affected by harvest maturity, indicating that determining the appropriate harvest indices for new cultivars is important for consumer acceptance.

Harvest index

Postharvest performance is related to the physiological state of the fruit at harvest, and harvest index is generally recognized as an indicator of the stage of fruit development appropriate to harvest for desired use (Burdon et al., 2014a). Harvesting at less than optimal stage of ripeness resulted in postharvest physiological damage and thereby limited storage life (Burdon et al., 2016). Thus, it is necessary to determine cultivar-specific harvest indices that are appropriate for the desired market in terms of consumer acceptance and postharvest life. Three harvest indices are commonly used for yellow-fleshed kiwifruit: SSC, DMC, and flesh color. ‘Hayward’ kiwifruit were harvested at a minimum of 6.2% SSC in New Zealand or at least 6.5% according to University of California recommendations (Burdon et al., 2014a; Crisosto and Crisosto, 2001). For yellow-fleshed kiwifruit, 8% SSC serves as a harvest index (New Zealand Kiwifruit Grower Incorporated, 2016). Moreover, DMC had a significant impact on postharvest performance, which can indicate the level of SSC in ripe fruit (Burdon et al., 2004). As for yellow-fleshed kiwifruit, flesh color had a potential to be an indicator of postharvest performance (Burdon et al. 2014a).

Soluble Solids Content

Because SSC increases (up to a point) as kiwifruit develop, a critical SSC value could be found to indicate a physiological state and potential postharvest performance; hence, SSC was considered a candidate for harvest index (Burdon, 2015). In 1980, a 6.2% SSC value was determined to serve as the harvest index of 'Hayward' kiwifruit growing in New Zealand, which would be stored and exported (Harman, 1981). For yellow-fleshed kiwifruit, an 8% SSC value was considered as the harvest index (New Zealand Kiwifruit Grower Incorporated, 2016). The selection of this value was based on the rate of SSC accumulation (Harman, 1981). Accumulation of SSC during fruit development could be described as a simple sigmoidal curve; a slow increase in the initial period followed by a rapid increase, and a slow increase again in the final period (Burdon, 2015). The 6.2% SSC value corresponds to the point in which slow accumulation rate transitions into fast accumulation associated with the physiological change from starch accumulation to starch hydrolysis (Harman, 1981). Various researches suggested that the initial phase of increased SSC accumulation rate could occur without a marked decline in starch content (Reid et al., 1982; Sawanobori and Shimura, 1990; Richardson et al., 2011). Finally, starch starts to break down resulting in a rapid increase in SSC accumulation rate (Burdon, 2015). Thus, variable periods between the cessation of starch accumulation and starch breakdown could lead to differences in the changeover period from slow to rapid SSC accumulation.

The SSC accumulation pattern may be influenced by many factors such as climate, cultivars, fruit development, and growing condition, such as cold night temperature increasing SSC accumulation (Burdon et al., 2007; Burdon, 2015; Burdon et al., 2013; Hopkirk et al., 1989; Seager et al., 1991). Therefore, the indicated value of 6.2% SSC may not be appropriately reflect accurately growing conditions and cultivars. Although SSC is commonly used as a harvest index for kiwifruit, SSC has its limitations. Burdon (2015) indicated that postharvest performance of kiwifruit was variable, even though the SSC is similar. Hence, there are challenges associated with using a single harvest index to predict postharvest performance, and additional harvest indices may be warranted.

Dry Matter Content

Dry matter content (DMC) was proposed as a candidate harvest index for kiwifruit due to associated change in soluble and insoluble solids content (Crisosto et al., 2011). Therefore, DMC may predict ripe SSC and final soluble sugars after ripening (Crisosto et al., 2008; Harker et al., 2009; Jordan et al., 2000). This approach could provide an accurate fruit physicochemical assessment for SSC limitation caused by postharvest starch conversion to soluble sugars (Crisosto et al., 2011). Because DMC can be used to predict ripe SSC, which is associated with consumer preference, DMC can indicate consumer acceptance at harvest. A minimum of 16.1% DMC is recommended as a harvest index to meet consumers' satisfaction (Crisosto et al., 2011). Satara Co-Operative Group Ltd (2012) recommended that a minimum of 15% DMC and 15.2% DMC could be harvest indexes for 'Hort16A' and 'Gold3', respectively. Additionally, kiwifruit DMC could be influenced by the season, orchard location, vineyard management, and harvest date (Mowat and Maguire, 2007; Taylor et al., 2007).

Flesh color

Flesh color was used to determine harvest time for yellow-fleshed kiwifruit and was anticipated to provide an accurate indicator of postharvest performance (Burdon et al., 2014a; Burdon et al., 2014b). During maturation, reduction in chlorophyll content and the transformation of the fruit's chloroplasts to chromoplasts contributed to the development of yellow flesh, which is considered an important commercial factor of yellow-fleshed kiwifruit (Burdon et al., 2014a; McGhie and Ainge, 2002). Thus, flesh color indicates harvest maturity of yellow-fleshed kiwifruit. Based on Burdon et al. (2014a) research, 103 °h flesh color may accurately reflect horticultural maturity for 'Hort16A' cultivated in New Zealand. At this hue angle, full flesh degreening was achieved, DMC was in 18–21%, SSC was 9–10% accompanied by increased rate of SSC accumulation, and firmness was 6.12–7.14 kgf not followed by rapid softening (Burdon et al., 2014a; Patterson et al., 2003). However, when kiwifruit were cultivated in other locations, the relationship between compositional factors like SSC, firmness, and flesh color was altered indicating a certain value of flesh color was difficult to apply in all circumstances. Therefore, flesh color does not accurately reflect all postharvest physiological changes associated with 'Hort16A'. For 'Gold3', a hue angle of 110 °h was used as harvest index (Satara Co-Operative Group Ltd, 2012). Flesh color was recognized as an important harvest index for 'Gold9', and a color of 103 °h served as harvest index for 'Gold9' (Lallu et al., 2012). At this stage, flesh was fully degreened, SSC was 12% and fruit firmness was 4.0-4.5 kgf.

Postharvest Storage

Kiwifruit harvested at the optimal harvest maturity may remain commercially viable for approximately 4–6 months in postharvest storage (Cheah and Irving, 1997). Dependent on preharvest conditions and cultivar, the storage life was reported 3–6 months for ‘Hayward’ kiwifruit (Nishiyama, 2007), or 3–4 months for ‘Hort16A’ (Patterson et al., 2003). Optimum storage conditions for kiwifruit are 0 ºC, 90–95% RH, and postharvest ethylene (C_2H_4) concentration below 0.01 ppm (Cheah and Irving, 1997; Crisosto and Kader, 1999). Kiwifruit is a climacteric fruit that continues to ripen after harvest. Hence, chemical and physical changes occur during storage. Because firmness is a key factor related to postharvest longevity, minimizing softening after harvest is a common way to extend the storage life.

Controlled atmosphere storage

Controlled atmosphere (CA) storage is commonly used to maximize storage life and minimize storage disorders of vegetables and fruits (Bishop, 1997). Typical characteristics of CA are accurate temperature, and precise levels of oxygen (O_2) and carbon dioxide (CO_2). Previous studies have successfully utilized CA as a method to prolong storage life of kiwifruit. The kiwifruit softening process is characterized by two distinct phases: a period of rapid firmness loss followed by a period of progressive slow loss in firmness (Harman and McDonald, 1983). Appropriately low O_2 concentrations and high CO_2 concentrations can retard the softening and extend kiwifruit postharvest longevity. A 4% atmospheric CO_2 concentration may retard initial softening, whereas 8-10% atmospheric CO_2 had a greater impact on reduced fruit softening. However, when the CO_2 level was above 8%, postharvest storage disorders were observed and kiwifruit developed off-flavors indicating anaerobic respiration thereby reducing consumer acceptance. Ethylene in CA storage also has significant effects on softening. Harman and McDonald (1983) reported that the rate of kiwifruit softening increased when stored at 0 ºC and 6% CO_2 in 0.1 ppm C_2H_4 atmospheric conditions. Therefore, maintenance of appropriate postharvest C_2H_4 concentration during kiwifruit storage is necessary, because of characteristic autocatalytic climacteric fruit ripening. 1-Methylcyclopropene (1-MCP) is usually used to block C_2H_4 action and $KMnon_4$ is commonly used to absorb C_2H_4 within storage atmosphere (Ben-Arie and Sonego, 1985; Cantin et al., 2011). In general, 5–8% CO_2, 1–2% O_2, and reduced C_2H_4 concentration in postharvest atmosphere may provide optimum storage conditions (Harman and McDonald, 1983).

Since harvest maturity had a great impact on postharvest performance and consumer preference of kiwifruit, it is important to determine the effect of harvest maturity on new kiwifruit cultivars to ensure good postharvest performance of fruit. Thus, my research focused on determining the effects of harvest maturity and storage time on postharvest performance and determining the impact of harvest maturity on consumer preference of two new yellow-fleshed kiwifruit cultivars 'AU Golden Dragon' and 'AU Golden Sunshine'.

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Chapter Two

Impact of Harvest Maturity on Fruit Quality and Postharvest Longevity of 'AU Golden Dragon' and 'AU Golden Sunshine'

Introduction

Gold-fleshed kiwifruit (*Actinidia chinensis* Planch. C.F. Liang et A.R. Ferguson) became commercially available internationally in 1995, and have since occupied an important place in the kiwifruit international market (Patterson et al., 2003). However, gold kiwifruit remains relatively unknown globally, but the market potential appears promising. In 2015, ~1.2 million kg of gold kiwifruit at a value of over NZ $500 million were exported from New Zealand, accounting for 26% of New Zealand's total kiwifruit exportation – or approximately twice the gold kiwifruit exported in 2014 (USDA Foreign Agriculture Service, 2016).

Postharvest performance of kiwifruit is closely associated with harvest maturity, as harvest maturity reflects the physiological state of the fruit and has a direct impact on fruit characteristics at harvest like firmness, soluble solids content (SSC), dry matter content (DMC), color and titratable acidity (TA) (Crisosto et al., 2011; MacRae et al., 1989). Later harvested kiwifruit have greater SSC and DMC (Burdon et al., 2014a), which may influence postharvest performance and fruit quality. Improper harvest maturity will result in poor fruit quality, shorter storage life and reduced consumer acceptance (Burdon et al., 2016).

Suitable postharvest longevity is essential for fruit exportation, and increasing postharvest longevity can effectively expand the global market and extend the supply of seasonal fruits. Firmness and chilling injury (CI) are two crucial factors of postharvest longevity of kiwifruit (Lallu et al., 2011; Patterson et al., 2003). Chilling injury, a common nonfreezing low temperature physiological disorder observed in kiwifruit, occurs when kiwifruit are stored at -0.5 ºC to 2.5 ºC for an extended time and symptoms include ring or zone granular appearance in the outer pericarp and water soaked tissues in the outer or inner pericarp (Burdon et al, 2014a; Lallu, 1997). These symptoms are caused by peroxidation of membrane lipids and cell wall breakdown (Yang et al., 2011).The rate of fruit softening and CI can be affected by the physiological status of fruit at harvest (Costa et al., 1997; Jabbar et al., 2014; MacRae et al., 1989). Softening rate in storage could be influenced by harvest time and storage condition (Burdon et al., 2014a). Higher SSC at harvest was observed to reduce fruit susceptibility to CI in ‘Tomua’ kiwifruit (Burdon et al., 2007). Likewise, research has demonstrated that later harvested kiwifruit typically exhibit a lower risk of CI (Burdon et al., 2007; Harman, 1981; Reid, 2002).

Soluble solids content (SSC), DMC, and flesh color have been recognized as potential harvest indices for gold kiwifruit (Burdon, 2015; Burdon et al., 2004; Burdon et al., 2014a; Burdon et al., 2014b). Soluble solids content increases to a critical level as kiwifruit develop and accurately reflect physiological state and potential postharvest performance (Burdon, 2015). Gold kiwifruit cultivated in New Zealand, typically is harvested using a harvest index of 8% SSC (New Zealand Kiwifruit Grower Incorporated, 2016). Dry matter content (DMC) consists of soluble and insoluble solids content (Burdon et al., 2004), which is indicative of what the SSC will be in the ripe stage. Since DMC is associated with consumer acceptance, it has also been proposed to be a potential harvest index (Crisosto, et al., 2011). In California, a minimum of 16.1% DMC was required to satisfy consumers (Crisosto et al., 2011). For ‘Hort16A’, a minimum of 15% DMC is recommended to be a harvest index in New Zealand (Satara Co-Operative Group Ltd, 2012). For ‘Gold3’, a 15.2% DMC is recognized as a harvest index in New Zealand (Satara Co-Operative Group Ltd, 2012). One of the distinct characteristics of gold kiwifruit is the flesh color, which is considered an important commercial factor (Burdon et al., 2014a). During fruit ripening, the green flesh color of gold kiwifruit turns to yellow because of the degradation of chlorophyll and unmasking of fruit carotenoid content (McGhie and Ainge, 2002). 'Gold3' cultivated in New Zealand, a hue angle of a maximum of 110 °h is recommended as a harvest index (Satara Co-Operative group Ltd, 2012). A hue angle of 103 °h is recommended as a harvest index for 'Gold9' and 'Hort16A' in New Zealand (Burdon et al., 2014a; Lallu et al., 2012). Thus, one or more of these attributes may serve as the harvest index for new kiwifruit cultivars.

Postharvest performance depends greatly on postharvest handling and storage. Recommended storage conditions for kiwifruit are approximately 0 °C for the air temperature, 90-95% relative humidity (RH), and ethylene (C_2H_4) concentration below 0.01 ppm (Cheah and Irving, 1997; Crisosto and Kader, 1999). Kiwifruit is a climacteric fruit, therefore, the goal during postharvest storage is to reduce the climacteric rate of respiration and associated C_2H_4 production. Low temperature storage typically provides viable means to reduce kiwifruit respiration rate and C_2H_4 production for kiwifruit (Antunes and Sfakiotakis, 2002). Meanwhile, lowering oxygen (O_2) concentrations (1-2%) and increasing carbon dioxide (CO_2) concentrations (5-8%) are recommended in a controlled atmosphere (CA) storage system to ensure good quality kiwifruit after long-term cold storage (Harman and McDonald, 1983). Applications of 1-methylcyclopropene (1-MCP) and $KMnon_4$ could also be used to reduce opportunities that plants get in touch with C_2H_4 (Cantin et al., 2011).

After harvesting, curing before placing kiwifruit in cold storage has a significant role in their postharvest performance. Holding kiwifruit at 22- 25°C and 95% RH for 2 to 3 days (curing) has effectively reduced the incidence of stem-end rot (Pennycook and Manning, 1992;

Tonini et al., 1989). There is a higher risk of stem-end rot, caused by *Botrytis cinerea*, to occur with rapid cooling, but curing effectively reduces this problem (Retamales et al., 1997). Additionally, a beneficial reduction in C_2H_4 concentration was noted with curing (Retamales et al., 1997), suggesting that curing has a positive effect on storage life. Curing could also reduce the susceptibility of CI (Goldwater et al., 2013).

'AU Golden Dragon' and 'AU Golden Sunshine' are two cultivars of *A. chinensis* developed in cooperation between Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Hubei Province, P.R. China (Dozier et al., 2011a; Dozier et al., 2011b). Both cultivars have been evaluated for fruit quality characteristics since 1995 at the Chilton Research and Extension Center in Thorsby, AL (Wall, 2006), and in 2014, a golden kiwifruit industry growing 'AU Golden Sunshine' was initiated in central Alabama. As the effects of harvest maturity on postharvest performance of these two cultivars is unclear, the objective of this study was to determine harvest index based on harvest date for optimum postharvest performance of 'AU Golden Dragon' and 'AU Golden Sunshine'.

Materials and Methods

Kiwifruit were harvested from mature vines of 'AU Golden Dragon' and 'AU Golden Sunshine' planted at the Chilton Research and Extension Center in Clanton, AL, USA. In 2015, fruit from each cultivar were harvested from specified vines at 7 d intervals for a total of four harvest dates (25 Aug. – 14 Sept.). In 2016, 'AU Golden Dragon' fruit were harvested from specified vines at 7 d intervals for a total of 5 harvest dates (15 Aug. – 12 Sept.) and 'AU Golden Sunshine' fruit were harvested similarly for a total of four harvest dates (22 Aug. – 12 Sept.). Each harvest consisted of approximately 300 marketable fruit per cultivar. After harvest, fruit were kept at room temperature (20 °C) for 64 hours of curing prior to initial fruit quality measurements. After curing, ten fruit per cultivar from each harvest date were evaluated for initial fruit quality and the remaining fruit were placed into polyethylene liners inside kiwifruit boxes and placed in cold storage at 0 °C and 95% RH. Two data loggers (Model A150, Spectrum® Technologies Inc., IL, USA) were placed in the cooler to monitor the temperature and the RH. In 2015, the temperature was maintained at 1 ± 1.1 ºC and the RH was at 90 ± 5%; however in 2016, a cooler malfunction occurred during experiment. On 15 Sept. 2016, because of a frost problem on the cooler fans, the temperature increased to 5.6 ºC, so all the fruit were subsequently moved into an adjacent cooler with temperature at 2.2 ºC. Two days later, the current cooler's temperature also went up to 8.3 ºC. The same day, fruits were removed to the original cooler with temperature at 1.1 ºC. However, on 9 Nov. 2016, the same cooler problem recurred, with the temperature reaching 11.7 ºC. Again, all the fruit were moved into a new cooler with temperature at 1.1 ºC. Five days later, the new cooler's temperature went up to 6.1 ºC; once again all the fruits were moved to the previous cooler, which had been fixed. Except on the days when the cooler problems occurred, the temperature was maintained at 1.1 ± 1.1 ºC, and during the whole experiment the RH was maintained at 90 ± 5%. An ethylene filter (Transprotekt ethylene extend F100 filter ethylene, Bioconservacion, S.A., Spain) was placed in the cooler. Fruit quality of ten fruits per cultivar was determined initially for each harvest and subsequently every 14 d for the duration of the experiment. Each individual fruit was considered a replicate.

Fruit quality analysis

Fruit quality data collected included: weight (g), length (mm), width (mm), DMC, TA, SSC, internal color, external color, firmness (kgf) and SSC: TA. Fruit quality analysis continued until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed visual symptoms of severe CI.

Fruit weight was measured with a scale (A&D EJ-610, A&J Corp., San Jose, CA, USA). Length and width were measured using a digital caliper (Mitutoyo Corp., Kawasaki, Japan). Fruit DMC was only measured at harvest because previous research demonstrated that DMC did not change in cold storage for kiwifruit (Burdon et al., 2004; Crisosto et al., 2011). Fruit DMC was determined by drying a 3 mm transverse slice from the middle section of both halves in food dehydrator (Excalibur products, Sacramento, California, USA) at 65 °C for approximately 24h (Burdon et al., 2014a). Both slices were weighed before and after drying to determine DMC, and the average value was reported. External color (°hue) was measured twice at the equator of each fruit, with two measurements taken 90° in relation to each other, using a spectrophotometer (Minolta CM-2002, Konica Minolta Ins., Tokyo, Japan). Internal color was measured after removal of skin to a depth of approximately 2 mm at the same location as external color measurement. The average of two measurements was used to determine the external color and internal color. Firmness was measured twice in kg of force needed to insert an slightly rounded 8 mm probe 1 cm into the flesh of the fruit after removal of skin (1 mm) at the equator of each fruit, with the two measurements taken 90° adjacent to each other, by using a penetrometer (McCormick Fruit Pressure Tester FT327, McCormick Fruit Tech, Yakima, WA, USA). Fruit firmness was reported as the average of the two measurements. A 10 mm section was cut from both the flower and the vine end of the fruit to measure the percent SSC. Percent SSC for both fruit ends were determined using a refractometer (Leica Mark II Abbe, Leica Inc., Buffalo, NY, USA), and the average of the top and bottom SSC was used to determine fruit SSC. Titratable acidity of ten fruits per cultivar was measured with a titrator (Mettler Toledo DL15, Mettler-

Toledo LLC, Columbus, OH, USA). Ten fruit per cultivar at each harvest date were weighed at harvest and the same ten fruit were weighed after 10 weeks storage time to determine the kiwifruit moisture loss in the cooler during the experiment.

Kiwifruit with CI exhibited several symptoms including a ring or zone of granular appearance in the outer pericarp and/or water soaked tissues in the outer or inner pericarp (Burdon et al., 2014a; Lallu, 1997). In 2015, the first incidence of CI was observed at the end of October, and severity was assessed at the end of experiment. In 2016, CI severity was assessed every week from the end of October until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit suffered from chilling injury. Thirty-five fruit in 2015 and ten fruit in 2016, from each cultivar per harvest date were removed from cold storage and held at room temperature for 6 days prior to examining outer and inner pericarp for CI symptoms (Goldwater et al., 2013). Chilling injury severities were divided into 4 categories based upon the area of water soaked tissue apparent in the outer or inner pericarp: 1) normal, 2) moderate, 3) severe, and 4) very severe (Fig. 2.1).

Statistics

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). Kiwi cultivars and experimental runs (years) were analyzed separately. The studies were split-plots with harvest date in the main plot and storage time in the sub-plot. All responses were analyzed using the normal probability distribution, except chilling injury rating. Where residual plots and a covariance test indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Chilling injury ratings were analyzed using the multinomial probability distribution with a cumulative logit link. Linear and quadratic trends over storage time for each harvest date and over harvest date for each storage time were determined using qualitative-quantitative regression models in cases of significant interactions. Simple model regressions were used in cases of significant harvest date main effects. All significance levels were at α = 0.05 unless otherwise indicated in the tables.

Results

'AU Golden Dragon'

In 2015 and 2016, the fruit weight and fruit size index did not change or changed slightly, indicating uniform fruit samples as harvest date increased across storage duration (Table 2.1, Table 2.2).

Postharvest longevity is defined as the duration from the harvest date to the time when the fruit was unmarketable. In 2015, fruit harvested on 31 Aug. and 7 Sept. had longer postharvest longevity compared with other harvest dates (Fig. 2.2), while in 2016 fruit harvested on 29 Aug. had the longest postharvest longevity (Fig. 2.3). The market window was determined by harvest date and postharvest longevity of kiwifruit. In 2015, fruit harvested on 7 Sept. had the longest market window (Fig. 2.4), while in 2016 fruit harvested on 29 Aug. and 12 Sept. had longer market windows (Fig. 2.5).

As harvest date increased, there was a quadratic increase in initial firmness in 2015 and there was a linear decrease in initial firmness in 2016 (Table 2.3, Table 2.4). Lower fruit firmness was observed on the later harvest dates across storage weeks. Firmness decreased quadratically during storage across harvest date in both years. Comparing two years' data, fruit harvested in 2016 had a shorter storage life than in 2015 because of the cooler malfunction in 2016. Between 15 Sept. and 17 Sept. 2016, temperature increased drastically from 1 to 8.3ºC causing a sharp decline in firmness, and the percent reduction in firmness was 83.8%, 58.2%, 72.9%, 76.9%, and 62.2% for fruit harvested on 15 Aug., 22 Aug., 29 Aug., 5 Sept. and 12 Sept., respectively (Table 2.4). Only fruit harvested on 29 Aug. and 12 Sept. were damaged due to cooler malfunction that occurred on 9 Nov., but firmness was not affected at this time (Table 2.4).

As harvest date increased, internal and external color hue at harvest decreased linearly, which means later harvested fruit had a darker external appearance and more yellow flesh (Table 2.3, Table 2.4). For many harvest dates in both 2015 and 2016, internal color hue did not change during storage.

Harvest date also affected SSC, TA and SSC: TA. In 2015, as the harvest date increased, there was a quadratic increase in SSC at harvest and a linear increase in SSC:TA at harvest, whereas there was a quadratic decrease in TA at harvest (Table 2.5). In 2016, there was a quadratic change in SSC and SSC:TA at harvest with minimum value on 22 Aug. in response to increasing harvest date, while there was a quadratic decrease in TA at harvest as harvest date increased (Table 2.6). Soluble solids content and SSC:TA increased quadratically in response to the length of time in cold storage across harvest dates in both years except for fruit harvested on 25 Aug. 2015, when SSC: TA increased linearly with increasing the length of time in cold storage (Table 2.5, Table 2.6). Titratable acidity decreased quadratically in response to cold storage duration in both years except for fruit harvested on 12 Sept. 2016 when TA did not change during storage (Table 2.5, Table 2.6).

Harvest date influenced DMC at harvest and moisture loss during storage. As harvest date increased, there was a linear increase in DMC at harvest in both years (Table 2.7). In both years, there was a quadratic change in moisture loss as harvest date increased with minimum values on 25 Aug. 2015 and 29 Aug. 2016 (Table 2.8).

In 2015, there was a quadratic effect of harvest date on CI severity indicating that CI was more severe on the first and last harvest dates (Table 2.9). In 2016, harvest date and storage duration affected CI severity (Table 2.10). A similar quadratic trend indicating that CI was greater in earlier and later harvested fruit was observed. Although in 2016 the median of CI severity were the same from 15 Aug. to 5 Sept., there was a quadratic change in the means of CI severity as harvest date increased with the least severe CI observed on fruit harvested on 29 Aug. (not shown in the table). There was a linear increase in CI severity in response to a longer duration of cold storage (Table 2.10).

'AU Golden Sunshine'

In 2015 and 2016, the fruit weight and fruit size did not change or changed slightly, indicating uniform fruit samples as harvest date increased across storage duration (Table 2.11, Table 2.12).

In 2015, fruit harvested on 31 Aug. and 7 Sept. had extended postharvest longevity (Fig. 2.2), whereas in 2016, fruit harvested on 5 Sept. had the longest postharvest longevity (Fig. 2.3). In 2015 fruit harvested on 14 Sept. had the longest market window (Fig. 2.4), while in 2016 fruit harvested on 5 Sept. had the longest market window (Fig. 2.5).

As the harvest date increased in 2015, there was a linear decrease in fruit firmness at harvest, and a linear or quadratic decrease in firmness with increasing cold storage duration

(Table 2.13). In 2016, there was no effect of harvest maturity on firmness at harvest, but there was a quadratic decrease in firmness in response to cold storage duration (Table 2.14). Comparing two years' data, fruit harvested in 2016 had a shorter storage life because of a cooler malfunction. Between 15 Sept. and 17 Sept., temperature increased drastically from 1 to 8.3ºC causing a sharp drop in firmness and the percent reduction in firmness was 35.6%, 34.4%, 34.7%, and 70.3% for fruit harvested on 22 Aug., 29 Aug., 5 Sept. and 12 Sept., respectively (Table 2.14). The cooler malfunction on 9 Nov. likely affected firmness on 12 Sept., whereas firmness levels remained stable for fruit harvested on other dates (Table 2.14).

In 2015, there was no effect of harvest date on internal color hue at harvest, while as harvest date increased, there was a quadratic change in external color hue with maximum value on 7 Sept. (Table 2.14). In 2016, as harvest date increased, there was a linear decrease in internal and external color hue at harvest (Table 2.15). The internal color of fruit harvested on 29 Aug. and 5 Sept. 2016 did not change during cold storage (Table 2.13). Moreover, external color hue decreased linearly during cold storage except for fruit harvested on 12 Sept. 2016 (Table 2.13).

In both years, SSC at harvest increased linearly with increasing harvest date, and SSC increased quadratically with increasing cold storage duration (Table 2.15, Table 2.16). In 2015, there was no effect of harvest date on TA and SSC:TA at harvest, but there was a linear or quadratic decrease in TA and a linear or quadratic increase in SSC:TA with increasing cold storage duration (Table 2.15). In 2016, as harvest date increased, there was a linear decrease in TA at harvest and a quadratic increase in SSC:TA at harvest (Table 2.16). During cold storage, there was a linear or quadratic decrease in TA and a quadratic increase in SSC: TA in 2016 (Table 2.16).

In 2015, DMC increased linearly as harvest date increased, whereas in 2016 there was no effect of harvest date on DMC (Table 2.17). In 2015, there was a quadratic change in moisture loss with increasing harvest date with a maximum value on 7 Sept., while in 2016 as harvest maturity increased there was a cubic change in moisture loss with a maximum value on 5 Sept. (Table 2.18).

In 2015, a quadratic effect of harvest date on CI severity was observed indicating that fruit harvested on 7 Sept. had less CI compared to other harvest dates (Table 2.19). Harvest date and storage duration affected CI severity in 2016 (Table 2.20). A linear decrease in CI severity was observed with increasing harvest date, and a linear increase in CI severity was found with increasing cold storage duration (Table 2.20).

Discussion

The effects of harvest maturity on postharvest longevity and market window varied between these two gold kiwifruit cultivars. 'AU Golden Dragon', fruit harvested around 30 Aug. consistently had longer postharvest longevity and market window. These fruit had a firmness of approximately 4.0 kgf, internal color of 98.2–99 °h, a SSC of 7.8–8.0%, and a DMC of 17.1–17.2%. For 'AU Golden Sunshine', fruit harvested around 6 Sept. –13 Sept. had relatively longer storage life and market window, and these fruit had a SSC of 8.0–10.0% and DMC above18%.

Firmness and CI are two primary factors determining postharvest longevity (Lallu, 1997). Interactions of harvest maturity and storage days on firmness were significant in this study. Later harvested fruit had lower initial firmness, but they did not necessarily have a shorter storage life than fruit with higher initial firmness. Except 'AU Golden Sunshine' harvested in 2015, the pattern of fruit softening was divided into two phases: an initial period with rapid softening followed by a slow softening after about 6 weeks in storage. The softening pattern of 'AU Golden Sunshine' harvested in 2015 was sigmoidal including three phases: an initial rapid softening, followed by a slow softening after 6 weeks and finally a rapid softening starting at 11 weeks after harvest. Compared with 'Hort16A', although the softening pattern was sigmoidal, the three phases were: an initial period of slow softening, followed by a rapid softening and finally a second slow softening (Burdon et al., 2014a). Burdon et al. (2014a) attributed the sigmoidal softening pattern in storage to the influence of fruit softening on the vine. Thus, early harvested fruit may have an initial slow period at harvest leading to an initial slow softening during storage. In contrast, later harvested fruit may have already begun softening on the vine and exhibited rapid softening early on in storage. In 2016, increasing cooler temperature resulted in shorter storage lives than those in 2015 for both cultivars at each harvest time. Abrupt unanticipated alterations in postharvest conditions influenced postharvest longevity. Firmness is an obvious fruit characteristic that responds to temperature change Fluctuations in cooler temperature may have provoked tissue rewarming process and possibly promoted C_2H_4 production by enhanced 1-aminocyclopropane-a-carboxylic acid synthase (ACS; EC 4.4.1.14) and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO; EC 1.12.17.4) activity (Antunes and Sfakiotakis, 2002). Additionally, when these fruit were repetitively moved from one cooler to another, fluctuating ambient internal atmosphere within storage boxes may have altered fruit respiration and C_2H_4 production.

Chilling injury is another factor influencing postharvest longevity, and in this study, harvest maturity did have effects on CI severity for the two cultivars. There was a quadratic change in CI severity in 'AU Golden Dragon' with increasing harvest date with less severe or no CI observed on fruit harvested around 6 Sept., whereas for 'AU Golden Sunshine', later harvested fruits had less severe or no CI. The symptoms of CI were most severe on less mature fruit and fully ripened fruit were less susceptible with the exception of over ripened fruit that were equally susceptible to CI. Previous research demonstrated that later harvested ‘Hort16A’ and ‘Tomua’ kiwifruit were less susceptible to CI than early harvested fruit (Burdon et al, 2007; Burdon et al., 2014a).

Changes of internal color hue were variable during this study. In the study, internal color generally changed slightly during storage, but for some harvest dates, internal color showed no change during cold storage duration. Ben-Arie et al. (1982) demonstrated that degradation of chlorophyll was observed in yellow-fleshed kiwifruit during storage, indicating that there was color development during storage. Moreover, other researchers also identified the pattern of color development in yellow-fleshed kiwifruit on the vine. Previous findings of ‘Hort16A’ suggested that the pattern of yellow-fleshed kiwifruit internal color development from green to yellow was sigmoidal, in which hue angle decreased slowly from 115 °h to 113 °h followed by a rapid decline to 102 °h and finally a slow decrease below 102 °h (Burdon et al., 2014a). A similar pattern of color development in yellow-fleshed kiwifruit was demonstrated by Minchin et al. (2003) as well. Compared with color development on the vine, color developed slowly in storage, if at all, in this study.

The later harvested fruit with higher DMC at harvest increased ripe SSC. In this study, fruit harvested on the last harvest date (14 Sept. 2015 and 12 Sept. 2016) had the highest SSC at the ripe stage. The ratio of SSC and TA (SSC:TA) is commonly used as the sweetness index of fresh horticultural produce (Beckles, 2012). At the ripe stage, ‘AU Golden Dragon’ had lower SSC:TA (10.0–16.4) than ‘AU Golden Sunshine’ (16.8–26.9), indicating ‘AU Golden Sunshine’ likely had a sweeter taste than ‘AU Golden Dragon’.

Moisture loss of fruit accompanied by shriveling caused rapid deterioration in fruit quality, and even altered metabolism and accelerated ripening (Burdon et al., 1994). Thus, lower moisture loss during storage may result in superior fruit quality. Comparing two years' data, the fruit harvested during the last week of Aug. had lowest moisture loss for both cultivars. 'AU Golden Sunshine' harvested on the first week of Sept. had the highest moisture loss among harvest times. Ghasemnezhad et al. (2013) stated that later harvested 'Hayward' kiwifruit had higher moisture loss after four months of storage.

Potential harvest indices of gold kiwifruit are SSC, DMC and internal color. Higher SSC and DMC and lower internal color hue were observed in later harvested fruit of 'AU Golden Dragon' and 'AU Golden Sunshine' in 2015 and 2016. In present study, 'AU Golden Dragon' harvested around 30 Aug. with a SSC of ~8% had a longer postharvest life and market window, and relatively low CI severity. Therefore, a SSC value of 7.8–8% could serve as a harvest index of 'AU Golden Dragon'. At that point, the firmness was around 4 kgf, internal color hue was 98–99 °h and DMC was 17–17.3%. AU Golden Sunshine', fruit harvested 6 Sept. –13 Sept. were observed to have DMC in excess of 18.0 %, SSC of 8.0 –10%, and initial firmness of 4 kgf which appeared to result in an extended postharvest longevity, extended market window, and less CI severity. Additionally, 'AU Golden Sunshine' fruit harvested with higher SSC levels and initial firmness of least 4 kgf had reduced chilling injury severity. Due to variable fruit maturity at harvest of 'AU Golden Sunshine', specific harvest indices were difficult to determine. However, a SSC value of 8.0–10.0% may be a possible harvest index for 'AU Golden Sunshine'. Variable fruit maturity at harvest was the result of lateral flowers that opened later than terminal flowers (Lawes et al., 1990) and premature fruit drop occurred prior to anticipated planned harvesting. Hydrogen cyanamide, a chemical growth regulator used to coordinate concentrated flower initiation and fruit thinning is frequently used to regulate variability in fruit maturity at harvest (Henzell and Briscoe, 1986; McPherson et al., 2001). Therefore, it is necessary to conduct additional research on ‘AU Golden Sunshine’ with stable fruit maturity at harvest to obtain integrated information of fruit harvest characteristics.

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Table 2.1. Effect of harvest date and cold storage duration on average weight and fruit size index of *Actinidia chinensis* ‘AU Golden Dragon’ in 2015[z].

Attribute	Date[x]	Storage weeks[y] 0	2	4	6	8	10	12	14	16	18	Sign.[w]
Weight[v] (g)	8/25	103.9	98.0	99.6	94.9	101.3	87.5	100.2	95.5	–	–	L*
	8/31	117.6	112.1	110.6	110.4	114.4	106.2	109.8	110.1	109.4	128.6	NS
	9/7	106.5	88.9	91.2	98.7	97.0	96.7	99.4	99.2	101.3	99.1	NS
	9/14	95.2	92.0	84.2	95.1	99.3	96.9	–	–	–	–	NS
	Sign.	Q***	L**	L***	Q*	NS	Q*	Q*	Q**	NS	L***	
Fruit size index[u] (mm)	8/25	55.7	54.2	55.4	54.1	55.1	53.2	55.4	54.6	–	–	NS
	8/31	57.7	57.5	56.8	57.2	57.5	55.1	57.3	57.2	57.3	58.8	NS
	9/7	55.7	53.4	53.2	53.9	54.5	54.8	54.2	55.5	53.9	55.7	L***
	9/14	55.8	53.1	52.5	54.1	55.0	55.2	–	–	–	–	Q*
	Sign.	Q*	L*	L***	NS	NS	L**	Q**	Q*	NS	NS	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Weight measured with a scale.
[u]Fruit size index= $\frac{length+wide\ width+short\ width}{3}$. Length and width were measured using a digital caliper. Wide width was measured as the major width 90° from length measurement, and short width was measured as the minor width 90° from wide width across horizontal plane.

Table 2.2. Effect of harvest date and cold storage duration on average weight and fruit size index of *Actinidia chinensis* 'AU Golden Dragon' in 2016[z].

		Storage weeks[y]							
Attribute	Date[x]	0	2	4	6	8	10	12	Sign.[w]
Weight[v] (g)	8/15	116	105.7	99.3	106.5	97.7	94	–	L**
	8/22	95.6	91.5	94.5	92.7	–	–	–	L*
	8/29	106.9	107.6	87.9	101.7	90.2	99.4	96.2	Q**
	9/5	112.2	108.7	105.1	–	–	–	–	NS
	9/12	109.5	97.7	97.6	95.5	109.8	102.3	–	NS
	Sign.	Q*	NS	NS	Q***	L***	L*	–	
Fruit size index[u] (mm)	8/15	58.7	56.9	55.7	56.7	55.1	54.9	–	Q*
	8/22	54.7	54.0	54.8	63.8	–	–	–	L**
	8/29	57.3	57.2	53.6	55.5	54.1	55.5	55.3	Q**
	9/5	59.2	56.7	56.0	–	–	–	–	Q*
	9/12	57.3	54.3	54.9	54.8	57.1	55.7	–	NS
	Sign.	NS	NS	NS	NS	Q**	NS	–	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Weight measured with a scale.
[u]Fruit size index=$\frac{length+wide\ width+short\ width}{3}$. Length and width were measured using a digital caliper. Wide width was measured as the major width 90º from length measurement, and short width was measured as the minor width 90º from wide width across horizontal plane.

Table 2.3. Effect of harvest date and cold storage duration on average firmness, external color and internal color of *Actinidia chinensis* 'AU Golden Dragon' in 2015[z].

Attribute	Date[x]	Storage weeks[y] 0	2	4	6	8	10	12	14	16	18	Sign.[w]
Firmness[v] (kg)	8/25	3.96	3.78	3.93	2.11	1.25	1.25	0.58	0.55	–	–	Q**
	8/31	3.97	3.67	2.16	0.92	1.01	0.84	0.85	0.89	0.88	0.87	Q***
	9/7	3.45	2.53	1.33	0.94	0.94	0.66	0.75	0.75	0.89	0.54	Q***
	9/14	2.05	2.35	0.95	0.72	0.68	0.81	–	–	–	–	Q***
	Sign.	Q***	L***	Q**	Q**	L***	Q**	Q**	Q**	NS	L*	
Internal color[u] (hue°)	8/25	100.1	99.9	98.6	98.7	99.0	98.9	99.2	101.5	–	–	L***
	8/31	98.2	99.3	99.1	98.3	98.4	98.8	98.4	97.4	97.7	96.7	L***
	9/7	100.2	99.0	96.0	97.6	97.9	96.9	97.8	96.8	96.7	96.6	L***
	9/14	95.6	95.8	95.8	96.2	96.0	96.8	–	–	–	–	NS
	Sign.	L**	L***	L***	L***	L***	L**	L***	L***	L*	NS	
External color[t] (hue°)	8/25	83.4	82.6	81.1	79.7	79.0	79.9	78.8	69.8	–	–	L***
	8/31	77.5	77.7	81.1	79.0	79.6	74.6	72.4	74.1	72.1	73.1	Q***
	9/7	70.5	82.6	82.8	80.4	78.8	80.8	71.6	74.9	76.1	77.1	Q***
	9/14	75.7	81	76.9	74.1	67.5	73.4	–	–	–	–	Q**
	Sign.	L***	NS	Q*	L**	Q***	Q***	L***	NS	NS	NS	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.
[u]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.
[t]External color measured with spectrophotometer.

Table 2.4. Effect of harvest date and cold storage duration on average firmness, external color and internal color of *Actinidia chinensis* 'AU Golden Dragon' in 2016[z].

		Storage weeks[y]							
Attribute	Date[x]	0	2	4	6	8	10	12	Sign.[w]
Firmness[v] (kg)	8/15	5.41	5.28	4.43	0.72	0.75	0.63	–	Q***
	8/22	4.44	2.61	1.09	0.55	–	–	–	Q***
	8/29	4.05	3.14	0.85	0.85	0.59	0.52	0.53	Q***
	9/5	4.28	0.99	0.98	–	–	–	–	Q***
	9/12	3.54	1.34	0.64	0.60	0.57	0.56	–	Q***
	Sign.	L***	Q*	Q***	NS	NS	NS	–	
Internal color[u] (hue°)	8/15	100.9	104.7	103.6	103.4	102.4	101.5	–	Q**
	8/22	101.9	100.6	100.0	100.6	–	–	–	NS
	8/29	99.0	100.1	97.8	100.5	100.0	97.7	98.0	Q*
	9/5	98.3	97.1	97.3	–	–	–	–	NS
	9/12	96.6	96.5	96.7	97.3	97.0	96.7	–	NS
	Sign.	L***	L***	Q**	L***	L***	L***	–	
External color[t] (hue°)	8/15	86.0	83.6	82.5	77.8	78.5	74.0	–	L***
	8/22	82.9	80.6	83.6	73.9	–	–	–	L***
	8/29	85.1	86.2	79.2	82.7	79.2	75.7	78.5	L***
	9/5	78.9	80.0	73.1	–	–	–	–	Q*
	9/12	78.3	75.7	77.4	68.6	70.3	75.7	–	L***
	Sign.	L***	Q*	L***	Q**	L**	NS	–	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.
[u]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.
[t]External color measured with spectrophotometer.

Table 2.5. Effect of harvest date and cold storage duration on average SSC, TA and SSC:TA of *Actinidia chinensis* ‘AU Golden Dragon’ in 2015[z].

Attribute	Date[x]	Storage weeks[y] 0	2	4	6	8	10	12	14	16	18	Sign.[w]
SSC[v] (%)	8/25	7.0	9.7	11.6	13.0	14.3	14.7	14.9	14.5	–	–	Q***
	8/31	8.0	10.3	12.0	14.5	15.6	15.4	15.4	15.3	14.8	14.2	Q***
	9/7	9.9	11.0	13.2	14.6	14.3	15.1	14.6	14.3	13.9	12.4	Q***
	9/14	12.9	12.3	14.1	16.7	17.1	16.7	–	–	–	–	Q***
	Sign.	Q**	L***	L***	Q**	Q***	L***	L**	Q*	L*	NS	
TA[u] (%)	8/25	1.72	1.82	1.72	1.61	1.26	1.08	0.90	0.96	–	–	Q**
	8/31	1.70	1.77	1.47	1.37	1.03	0.99	1.04	0.98	1.11	0.87	Q***
	9/7	1.84	1.73	1.30	1.25	1.09	0.95	0.94	0.91	0.86	0.89	Q***
	9/14	1.56	1.48	1.48	1.16	0.96	1.06	–	–	–	–	Q***
	Sign.	Q***	L***	Q***	L***	L***	Q**	L***	NS	L***	NS	
SSC:TA[t]	8/25	4.1	5.4	6.8	8.2	11.6	13.7	16.6	15.2	–	–	L***
	8/31	4.7	5.9	8.3	10.7	15.4	15.7	14.8	15.6	13.6	16.4	Q***
	9/7	5.4	6.4	10.3	11.8	13.3	16.1	15.6	15.9	16.4	14.1	Q***
	9/14	8.4	8.4	9.7	14.5	17.9	15.9	–	–	–	–	Q**
	Sign.	L**	Q*	Q*	L***	L***	L*	L*	NS	L*	NS	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***). Sign.= Significance.
[v]SSC= Soluble solids content measured with refractometer.
[u]TA= Titratable acidity measured with titrator.
[t]SSC:TA= the ratio of soluble solids content and titratable acidity.

Table 2.6. Effect of harvest date and cold storage duration on average SSC, TA and SSC:TA of *Actinidia chinensis* 'AU Golden Dragon' in 2016[z].

		Storage weeks[y]							
Attribute	Date[x]	0	2	4	6	8	10	12	Sign.[w]
SSC[v] (%)	8/15	7.3	7.9	10.3	12.5	13.1	13.7	–	Q***
	8/22	6.3	9.7	12.6	14.1	–	–	–	Q***
	8/29	7.8	9.6	13.9	13.7	14.3	14.7	13.8	Q***
	9/5	7.8	13.2	14.1	–	–	–	–	Q***
	9/12	11.5	13.6	14.2	15.6	15.2	14.8	–	Q***
	Sign.	Q***	L***	Q***	L***	L***	L***	–	
TA[u] (%)	8/15	1.92	1.76	1.67	1.18	1.33	1.33	–	Q*
	8/22	1.96	1.62	1.37	1.23	–	–	–	Q***
	8/29	1.70	1.50	1.10	1.15	1.31	1.15	1.13	Q***
	9/5	1.71	1.08	1.35	–	–	–	–	Q**
	9/12	1.39	1.22	1.23	1.36	1.22	1.19	–	NS
	Sign.	Q*	L***	Q***	L**	NS	NS	–	
SSC:TA[t]	8/15	3.8	4.5	6.3	10.8	10.0	10.4	–	Q*
	8/22	3.2	6.2	9.3	11.6	–	–	–	Q***
	8/29	4.6	6.5	12.9	12.2	11.0	13.1	12.3	Q***
	9/5	4.7	12.3	10.5	–	–	–	–	Q***
	9/12	8.7	11.3	11.7	11.7	12.7	12.6	–	Q**
	Sign.	Q***	L***	Q***	NS	L**	Q**	–	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***). Sign.= Significance.
[v]SSC= Soluble solids content measured with refractometer.
[u]TA= Titratable acidity measured with titrator.
[t]SSC:TA= the ratio of soluble solids content and titratable acidity.
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Table 2.7. Effect of harvest date on average DMC of *Actinidia chinensis* 'AU Golden Dragon' in 2015 and 2016[z].

Harvest date	8/25/15	8/31/15	9/7/15	9/14/15		Sign.[x]
DMC[y] (%)	16.72	17.23	17.96	18.73		L***
Harvest date	8/15/16	8/22/16	8/29/16	9/5/16	9/12/16	
DMC (%)	16.61	16.69	17.12	17.00	17.98	L***

[z]Only the harvest date main effect was significant at α=0.05.

[y]DMC = Dry matter content= $\frac{fresh\ weight - dry\ weight}{fresh\ weight} \times 100$. Dry weight of ten fruit at each harvest date was measured after kiwifruit slice was dehydrated in dehydrator at 65 °C for approximately 24h.

[x]Significant (Sign.) linear (L) trends using model regression at α=0.001(***).

Table 2.8. Effect of harvest date on average moisture loss of *Actinidia chinensis* ‘AU Golden Dragon’ in 2015 and 2016[z].

Harvest date	8/25/15	8/31/15	9/7/15	9/14/15		Sign.[x]
Moisture loss[y] (%)	0.57	1.40	1.75	1.47		Q***
Harvest date	8/15/16	8/22/16	8/29/16	9/5/16	9/12/16	
Moisture loss (%)	2.48	1.37	0.91	1.42	1.04	Q***

[z]Only the harvest date main effect was significant at α=0.05.

[y]Moisture loss= $\frac{Weight\ (before\ storage) - Weight\ (after\ 10\ weeks\ storage)}{Weight\ (before\ storage)} \times 100$. Fruit moisture loss of ten fruit at each harvest date was measured after 10 weeks storage time.

[x]Significant (Sign.) quadratic (Q) using model regression at α=0.001(***).

Table 2.9. Effect of harvest date on chilling injury rating of *Actinidia chinensis* 'AU Golden Dragon' in 2015[z].

Harvest	Normal	Moderate	Severe	Very severe
8/25/15	0[y]	0	22	12
8/31/15	0	12	15	7
9/7/15	14	16	2	2
9/14/15	0	0	15	19
Sign.[x]				Q***

[z]Only the harvest date main effect was significant at α=0.05.
[y]Chilling injury ratings of thirty–four fruit at each harvest time were assigned when the average firmness of fruit was less than 0.5kgf (Patterson et al., 2003) . Counts of fruit exhibit chilling injury at each injury category.
[x]Significant (Sign.) quadratic (Q) trend using model regressions at $\alpha = 0.001$ (***).

Table 2.10. Effect of harvest date and cold storage duration on chilling injury of *Actinidia chinensis* ‘AU Golden Dragon’ in 2016[z].

Harvest	Chilling injury rating[y]	Measure date	Chilling injury rating
8/15/16	1.0[x]	10/20/16	1.0
8/22/16	1.0	10/27/16	1.0
8/29/16	1.0	11/3/16	1.0
9/5/16	1.0	11/10/16	1.0
9/12/16	2.0	11/10/16	1.0
Sign.[w]	Q***	11/17/16	2.0
		11/24/16	1.0
		Sign.	L***

[z]Only the harvest date by storage weeks main effects were significant at α=0.05
[y]Chilling injury rating: 1= Normal, 2= Moderate, 3= Severe, 4= Very Severe. Chilling injury was measured every week from the end of Oct. 2016 until the firmness of fruit was less than 0.5 kg of pressure (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Reported are medians.
[w]Significant (Sign.) linear (L) or quadratic (Q) trends using model regressions at α = 0.001 (***).

Table 2.11. Effect of harvest date and cold storage duration on average weight and fruit size index of *Actinidia chinensis* 'AU Golden Sunshine' in 2015[z].

		Storage weeks[y]									
Attribute	Date[x]	0	2	4	6	8	10	12	14	16	Sign.[w]
Weight[u] (g)	8/25	87.6	97.0	83.0	93.9	92.2	86.5	94.3	–	–	NS
	8/31	110.5	85.5	92.9	112.3	95.5	96.8	92.4	94.2	–	NS
	9/7	115.9	89.1	107.6	103.2	102.4	103.4	100.8	103.7	–	NS
	9/14	99.3	81.5	78.1	84.2	87.8	79.4	87.6	96.2	85.2	Q***
	Sign.	Q***	L***	Q***	Q***	Q*	Q***	Q*	Q**	–	
Fruit size index[v] (mm)	8/25	52.1	54.6	51.6	53.5	52.8	52.4	53.5	–	–	NS
	8/31	55.8	51.5	53.4	56.5	53.9	54.2	53.5	53.4	–	NS
	9/7	57.2	52.8	55.6	54.6	53.4	55.0	54.8	55.4	–	L**
	9/14	54.3	50.9	50.2	51.4	52.3	50.8	51.8	47.9	51.4	Q***
	Sign.	Q***	L***	Q***	Q***	NS	Q***	Q**	Q***	–	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Weight measured with a scale.
[u]Fruit size index= $\frac{length+wide\ width+short\ width}{3}$. Length and width were measured using a digital caliper. Wide width was measured as the major width 90° from length measurement, and short width was measured as the minor width 90° from wide width across horizontal plane.

Table 2.12. Effect of harvest date and cold storage duration on average weight and fruit size index of *Actinidia chinensis* 'AU Golden Sunshine' in 2016[z].

		Storage weeks[y]						
Attribute	Date[x]	0	2	4	6	8	10	Sign.[w]
Weight[u] (g)	8/22	90.4	90.7	94.4	80.6	75.5	75.6	L*
	8/29	108.2	116.8	107.8	108.8	110.0	112.2	Q**
	9/5	111.5	108.4	105.2	89.6	96.8	115.3	Q***
	9/12	138.7	123.0	128.6	108.5	124.0	–	L**
	Sign.	L***	L***	L***	L**	L***	Q***	
Fruit size index[v] (mm)	8/22	52.8	53.1	53.9	51.1	50.3	50.3	L*
	8/29	56.3	57.7	55.9	55.9	57.3	57.1	Q*
	9/5	56.8	56.4	55.4	52.7	54.0	57.8	Q***
	9/12	61.1	58.5	59.3	56.6	59.1	–	L**
	Sign.	L***	L***	L***	L***	L***	Q***	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Weight measured with a scale.
[u]Fruit size index=$\frac{length+wide\ width+short\ width}{3}$. Length and width were measured using a digital caliper. Wide width was measured as the major width 90º from length measurement, and short width was measured as the minor width 90º from wide width across horizontal plane.

Table 2.13. Effect of harvest date and cold storage duration on average firmness, external color and internal color of *Actinidia chinensis* 'AU Golden Sunshine' in 2015[z].

		Storage weeks[y]									
Attribute	Date[x]	0	2	4	6	8	10	12	14	16	Sign.[w]
Firmness[u] (kg)	8/25	4.29	3.16	2.25	2.01	1.9	1.92	1.19	–	–	L***
	8/31	4.08	3.52	2.08	1.83	1.57	1.43	1.32	0.8	–	Q***
	9/7	4.03	2.83	1.87	1.49	1.79	1.19	1.32	0.81	–	Q***
	9/14	3.25	1.52	1.07	1.47	1.16	1.27	1.20	0.94	0.7	L***
	Sign.	L*	Q**	L***	L*	L**	L*	NS	L**	L**	
Internal color[v] (hue°)	8/25	102.9	101.7	103	103.7	100.8	102.8	100.5	–	–	L***
	8/31	98.7	99.6	99.5	99.6	100.1	99.7	99.3	99.1	–	Q***
	9/7	100.6	101.2	99.1	98.6	100.0	90.6	98.7	99.1	–	Q***
	9/14	97.9	97.1	96.5	97.3	98.4	98.0	98.1	98.0	97.5	L***
	Sign.	NS	Q**	L**	NS	L***	Q***	NS	NS	L*	
External color[t] (hue°)	8/25	71.0	82.1	75.4	63.9	77.1	72.2	74.3	–	–	L**
	8/31	71.9	79.4	73.2	75.3	67.2	70.1	74.3	68.7	–	Q***
	9/7	76.7	77.9	76.9	79.2	76.8	89.8	71.3	71.3	–	Q***
	9/14	68.6	73.1	69.0	72.8	60.5	66.1	64.4	58.1	67.6	L***
	Sign.	Q***	L**	Q*	Q***	Q***	Q***	L***	Q***	L***	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.
[u]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.
[t]External color measured with spectrophotometer.

Table 2.14. Effect of harvest date and cold storage duration on average firmness, external color and internal color of *Actinidia chinensis* ‘AU Golden Sunshine’ in 2016[z].

Attribute	Date[x]	Storage weeks[y] 0	2	4	6	8	10	Sign.[w]
Firmness[u] (kg)	8/22	4.21	3.06	1.97	1.14	1.33	0.86	Q***
	8/29	3.87	2.15	1.41	1.20	0.70	1.06	Q***
	9/5	3.78	2.47	1.64	0.77	0.85	0.70	Q***
	9/12	4.11	1.22	0.61	0.78	0.78	–	Q***
	Sign.	NS	Q*	Q*	NS	NS	L*	
Internal color[v] (hue°)	8/22	105.6	104.5	105.1	101.5	103.1	102.6	Q*
	8/29	101.5	103.8	101.1	100.2	103.2	100.1	NS
	9/5	101.5	98.9	101.8	98.3	100.7	99.8	NS
	9/12	100.4	100.7	98.3	99.5	99.1	–	L**
	Sign.	L*	Q***	L***	Q*	L***	L***	
External color[t] (hue°)	8/22	84.9	82.3	84.1	78.3	74.2	78.7	L***
	8/29	82.0	79.6	77.1	76.3	75.4	74.0	L***
	9/5	80.8	76.7	77.1	72.5	73.5	78.3	L**
	9/12	75.0	75.8	72.2	73.0	76.7	–	NS
	Sign.	L**	L*	L***	L*	NS	NS	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***).
[v]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.
[u]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.
[t]External color measured with spectrophotometer.

Table 2.15. Effect of harvest date and cold storage duration on average SSC, TA and SSC: TA of *Actinidia chinensis* 'AU Golden Sunshine' in 2015[z].

		Storage weeks[y]									
Attribute	Date[x]	0	2	4	6	8	10	12	14	16	Sign.[w]
SSC[u] (%)	8/25	7.2	11.8	11.6	12.5	13.7	13.5	13.9	–	–	Q***
	8/31	8.5	11.5	12.7	14.0	14.6	15.1	14.8	15.3	–	Q***
	9/7	7.8	11.2	13.8	14.0	14.0	14.2	14.6	14.2	–	Q***
	9/14	10.1	13.8	15.2	15.2	15.2	16.1	15.5	15.3	15.6	Q***
	Sign.	L***	Q***	L***	L***	L**	L**	L**	L*	L**	
TA[v] (%)	8/25	1.32	1.26	1.21	0.93	0.99	0.84	0.69	–	–	L***
	8/31	1.41	1.33	1.09	0.92	0.86	0.67	0.76	0.71	–	Q***
	9/7	1.44	1.22	1.25	0.87	0.85	0.67	0.65	0.71	–	Q***
	9/14	1.41	1.08	1.04	0.88	0.67	0.81	0.74	0.71	0.59	L***
	Sign.	NS	L***	L**	NS	L***	Q***	NS	NS	L*	
SSC:TA[t]	8/25	5.6	9.5	9.7	13.5	14.0	16.2	20.4	–	–	L***
	8/31	6.1	8.8	11.8	15.4	17.2	22.6	19.6	21.6	–	Q***
	9/7	5.4	9.4	11.1	16.3	16.8	21.7	22.8	20.7	–	Q***
	9/14	7.3	12.9	14.7	17.4	22.8	20.0	21.1	21.6	26.9	Q***
	Sign.	NS	Q*	L***	L*	L***	Q***	NS	NS	L*	

[z]The harvest date by storage weeks interaction was significant at α=0.05.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003).
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynumerals at α=0.05(*), 0.01(**) or 0.001(***). Sign.= Significance.
[v]SSC= Soluble solids content measured with refractometer.
[u]TA= Titratable acidity measured with titrator.
[t]SSC:TA= the ratio of soluble solids content and titratable acidity.

Table 2.16. Effect of harvest date and cold storage duration on average SSC, TA and SSC: TA of *Actinidia chinensis* 'AU Golden Sunshine' in 2016[z].

		Storage weeks[y]						
Attribute	Date[x]	0	2	4	6	8	10	Sign.[w]
SSC[v] (%)	8/22	7.8	9.9	12.5	13.7	13.2	13.8	Q***
	8/29	10.3	11.2	14	14.8	14.3	15	Q***
	9/5	8.3	12.7	13.7	15.3	14.4	14.9	Q***
	9/12	10.7	14.5	15.3	14.8	15.4	–	Q***
	Sign.	L*	L***	L***	Q*	L***	L***	
TA[u] (%)	8/22	1.51	1.27	1.05	0.94	0.83	0.84	Q***
	8/29	1.23	1.01	0.87	0.89	0.85	0.78	Q**
	9/5	1.27	1.26	0.98	0.81	0.8	0.81	Q***
	9/12	1.05	0.86	0.82	0.9	0.78	–	L***
	Sign.	L***	L***	L**	Q**	L***	NS	
SSC:TA[t]	8/22	5.2	7.9	12.2	13.8	14.0	16.8	Q**
	8/29	8.2	11.7	16.2	17.0	16.9	19.5	Q*
	9/5	6.6	10.2	14.1	20.2	18.3	18.6	Q***
	9/12	10.3	17.3	18.9	16.6	19.8	–	Q*
	Sign.	Q*	Q*	L**	Q*	L***	L*	

[z]The harvest date by storage weeks interaction was significant at $\alpha=0.05$.
[y]Fruit quality data of ten fruit at each harvest date were recorded until the firmness of fruit was less than 0.5 kgf (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Harvest dates.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynumerals at $\alpha=0.05(^{*})$, $0.01(^{**})$ or $0.001(^{***})$. Sign.= Significance.
[v]SSC= Soluble solids content measured with refractometer.
[u]TA= Titratable acidity measured with titrator.
[t]SSC:TA= the ratio of soluble solids content and titratable acidity.

Table 2.17. Effect of harvest date on average DMC of *Actinidia chinensis* ‘AU Golden Sunshine’ in 2015 and 2016[z].

Harvest date	8/25/15	8/31/15	9/7/15	9/14/15	Sign.[x]
DMC[y] (%)	17.10	17.89	17.92	18.42	L***
Harvest date	8/22/16	8/29/16	9/5/16	9/12/16	
DMC (%)	17.40	17.65	18.20	18.28	NS

[z]Only the harvest date main effect was significant at α=0.05.

[y]DMC = Dry matter content= $\frac{fresh\ weight - dry\ weight}{fresh\ weight} \times 100$. Dry weight of ten fruit at each harvest date was measured after kiwifruit slice was dehydrated in dehydrator at 65 °C for approximately 24h.

[x]Not significant (NS) or significant (Sign.) linear (L) trends using model regression at α=0.001(***). Sign= Significance.

Table 2.18. Effect of harvest date on average moisture loss of *Actinidia chinensis* 'AU Golden Sunshine' in 2015 and 2016[z].

Harvest date	8/25/15	8/31/15	9/7/15	9/14/15	Sign.[x]
Moisture loss[y] (%)	0.41	0.89	1.48	0.93	Q***
Harvest date	8/22/16	8/29/16	9/5/16	9/12/16	
Moisture loss (%)	1.93	0.88	2.10	0.98	C***

[z]Only the harvest date main effect was significant at α=0.05.

[y]Moisture loss= $\frac{Weight\ (before\ storage) - Weight\ (after\ 10\ weeks\ storage)}{Weight\ (before\ storage)} \times 100$. Fruit moisture loss of ten fruit at each harvest date was measured after 10 weeks storage time.

[x]Significant (Sign.) quadratic (Q) or cubic (C) trends using model regression at α=0.001(***).

Table 2.19. Effect of harvest date on chilling injury rating of *Actinidia chinensis* ‘AU Golden Sunshine’ in 2015[z].

Harvest	Normal	Moderate	Severe	Very severe
8/25/15	0[y]	0	0	34
8/31/15	0	0	0	34
9/7/15	0	24	7	3
9/14/15	0	0	15	19
Sign.[x]				Q***

[z]Only the harvest date main effect was significant at α=0.05.
[y]Chilling injury ratings of thirty–four fruit at each harvest time were assigned when the average firmness of fruit was less than 0.5kgf (Patterson et al., 2003) . Counts of fruit exhibit chilling injury at each injury category.
[x]Significant (Sign.) quadratic (Q) trend using model regressions at $\alpha = 0.001$ (***).

Table 2.20. Effect of harvest date and cold storage duration on chilling injury of *Actinidia chinensis* ‘AU Golden Sunshine’ in 2016[z].

Harvest	Chilling injury rating[y]	Measure date	Injury rating
8/22/16	4.0	10/20/16	1.0
8/29/16	3.0	10/27/16	2.0
9/5/16	2.5	11/3/16	2.0
9/12/16	1.0	11/10/16	3.0
Sign.[x]	L***	11/17/16	3.0
		11/24/16	4.0
		Sign.[x]	L***

[z]Only the harvest date by storage weeks main effects were significant at α=0.05
[y]Chilling injury rating: 1= Normal, 2= Moderate, 3= Severe, 4= Very Severe. Chilling injury was measured every week from the end of Oct. 2016 until the firmness of fruit was less than 0.5 kg of pressure (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.
[x]Reported are medians.
[w]Significant (Sign.) linear (L) or quadratic (Q) trends using model regressions at α = 0.001 (***).

1- Normal 2- Moderate 3-Severe 4-Very Severe

Fig 2.1. Chilling injury severity rating scales of the outer or inner pericarp. Chilling injury severity was rated after fruit were held at room temperature for six days. The rating scale was: 1) normal, 2) moderate, 3) severe, and 4) very severe.

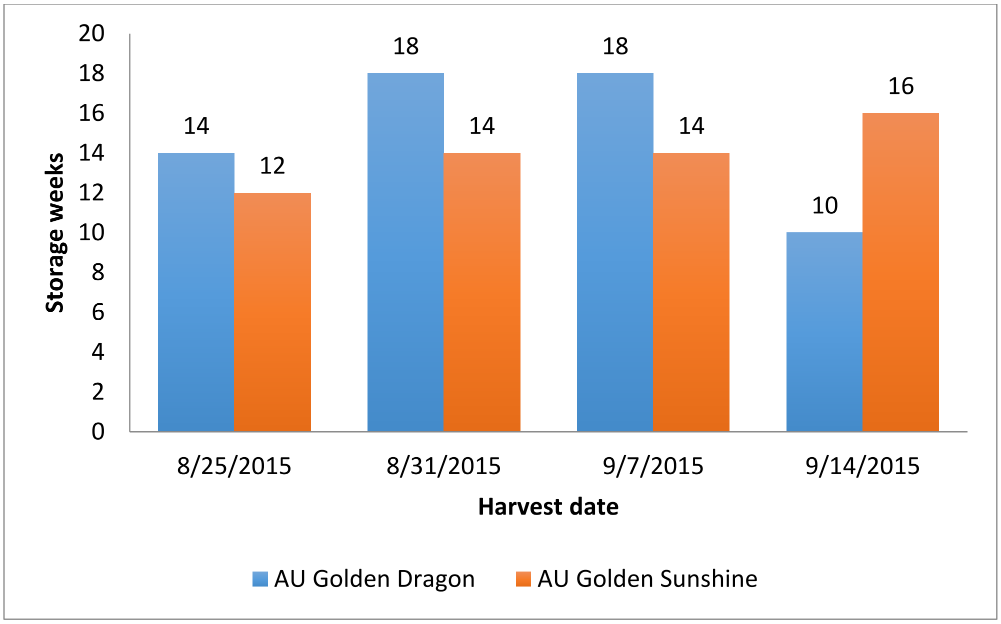

Fig. 2.2. Postharvest longevity of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine' at each harvest date in 2015. Fruit were considered unmarketable when firmness was < 0.5 kg of pressure (Patterson et al., 2003) or 80% of fruit showed symptoms of severe chilling injury.

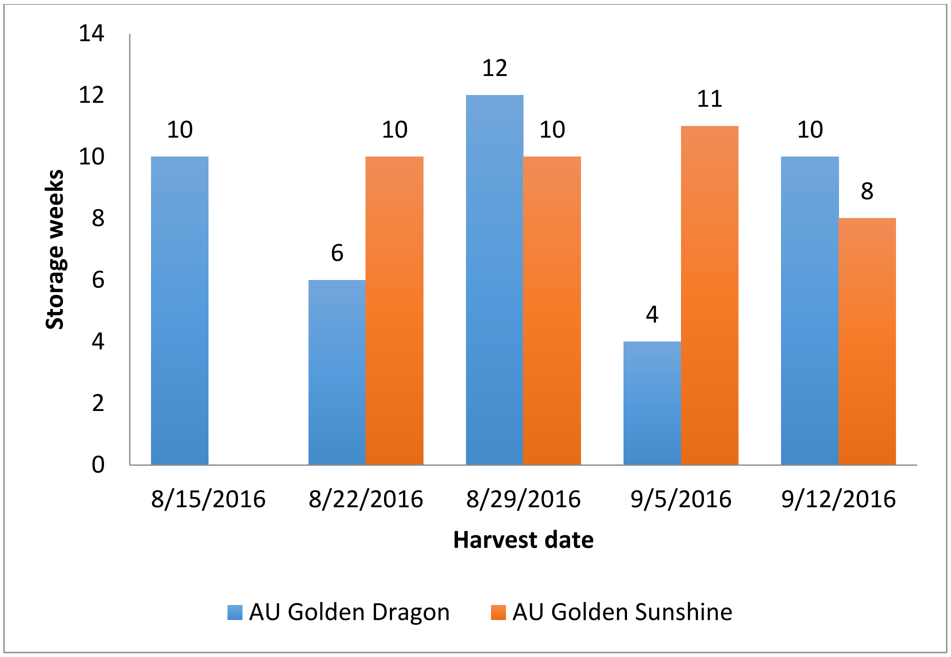

Fig. 2.3. Postharvest longevity of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine' in relation to harvest date in 2016. Fruit were considered unmarketable when firmness was < 0.5 kg of pressure (Patterson et al., 2003) or 80% of fruit showed symptoms of severe Chilling injury.

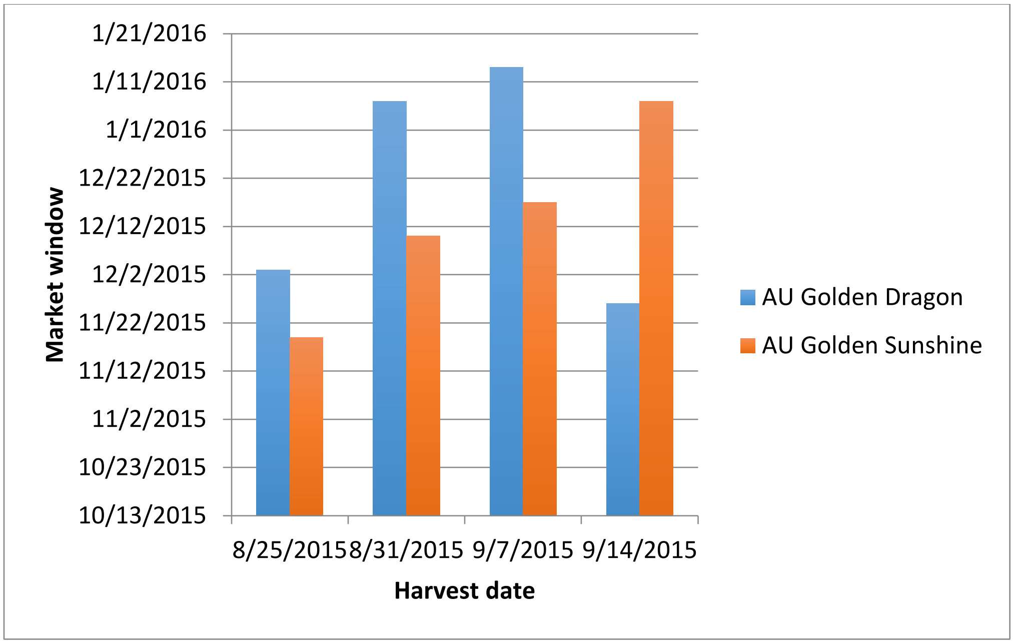

Fig. 2.4. Market window for *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine' at each harvest date in 2015. Market window was determined by harvest date and storage life.

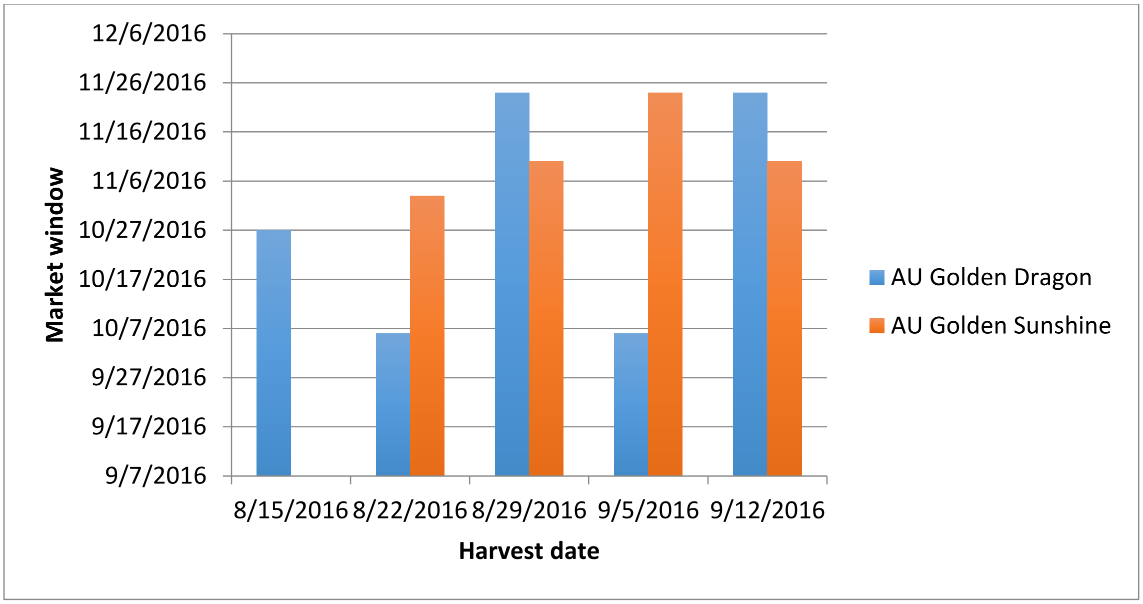

Fig. 2.5. Market window of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine' in relation to harvest date in 2016. Market window was determined by harvest date and storage life.

Chapter Three

Impact of Harvest Maturity on Consumer Preference of 'AU Golden Dragon' and 'AU Golden Sunshine'.

Introduction

Kiwifruit first appeared on the international market in the 1970s, and became a mainstream commercial crop on most western markets by the mid-1990s (HortResearch, 2000). Consumer demand and preference dramatically influence the kiwifruit market and product development (Jaeger et al., 2003). It is important for the kiwifruit industry to retain competitive advantages of new cultivars (Jaeger et al., 2003). Hence, it is essential to provide sensory evaluation in order to accurately assess consumer concerns and acceptance of fruit characteristics (McWilliams, 2005), and provide important information pertaining to fruit cultivation and postharvest treatments.

Kiwifruit appeals to many consumers because of its high content of vitamin C and other nutrients. Apart from nutritive value, excellent flavor is another essential factor attracting consumers. Flavor is a combination of taste and aroma, which are related to fruit characteristics like soluble solids content (SSC), titratable acidity (TA), and SSC:TA (McWilliams, 2005; Shewfelt, 2009). Additionally, texture and appearance are important sensory attributes (Colaric et al., 2005). Sensory evaluations of kiwifruit have been conducted for many years, and have demonstrated that fruit characteristics like dry matter content (DMC), SSC, TA, aroma and firmness greatly influence consumer preference of kiwifruit (Crisosto and Crisosto, 2001; Jaeger et al., 2011; Rossiter et al., 2000; Stec et al., 1989). Dry matter content, comprised of soluble and insoluble solids content, is an indicator of the total carbohydrate content of kiwifruit, and can be used to predict SSC in the ripe stage (Beever and Hopkirk, 1990; Burdon et al., 2004; Mitchell et al., 1990; Richardson et al., 1997). Consumers have demonstrated preference towards higher DMC at harvest in 'Hayward' (*Actinidia deliciosa*) and 'Hort16A' (*A. chinensis*) (Burdon et al., 2004; Jaeger et al., 2011). 'Hayward' kiwifruit growing in New Zealand with > 17% DMC at harvest (14% ripe SSC) and 'Hort16A' kiwifruit growing in New Zealand with > 16% DMC at harvest (14% ripe SSC) were preferred by consumers (Jaeger et al., 2011). Interactions of DMC and TA in the ripe stage also play a role in consumer acceptance (Crisosto et al., 2011). In California, when ripe TA was above 1.2%, 'Hayward' kiwifruit harvested with above 16.1% DMC was well received, whereas consumers preferred lower DMC fruit, ~15.1%, when ripe TA was below 1.2% (Crisosto et al., 2011). Soluble solids content (SSC) and TA are two major factors influencing sweetness and sourness of fruits. Higher SSC at harvest and higher SSC:TA in the ripe stage of 'Hayward' kiwifruit were preferred, indicating that sweeter 'Hayward' kiwifruit was more popular with consumers (Crisosto and Crisosto, 2001; Rossiter et al., 2000).

Green-fleshed kiwifruit entered into the international trade as early as the 1970s, while yellow-fleshed kiwifruit did not appear commercially until 1995 (Ferguson, 1999; Patterson et al., 2003). Compared with familiar green-fleshed kiwifruit with a sweet-tart taste, yellow-fleshed kiwifruit with sweet and fruity flavor had a lower overall preference (Jaeger et al., 2003), due to food neophobia, a phenomenon where humans initially reject or are unwilling to eat novel food (Pliner and Hobden, 1992). Consumer outreach programs designed to increase awareness of novel food can effectively assist consumers to overcome their initial food neophobia (Launchbaugh et al., 1997).

An informed knowledge and understanding of kiwifruit preference will enhance future breeding efforts and consumer attitudes to purchasing fresh and nutritionally enriched cultivars. Optimal harvest maturity of kiwifruit dramatically impact consumer demand, preference and overall fruit quality. Therefore, sensory evaluation is a critical instrument in determining consumer appeal, demand and optimal harvest index. AU Golden Dragon' and 'AU Golden Sunshine' are relatively new cultivars and with minimal information provided concerning consumer preference. Determining consumer preference and fruit attributes associated with these cultivars would critically assist in determining harvest indices, as well as developing fruit quality standards for commercial production. Thus, the goals of this study were to determine the effects of harvest maturity on consumer preference and the fruit quality attributes that consumers prefer.

Materials and methods

'AU Golden Dragon' were harvested from specified vines every 7 d for a total of five harvest times (15 Aug. – 12 Sept. 2016), while 'AU Golden Sunshine' were harvested from specified vines every 7 d for a total of four harvest times (22 Aug. – 12 Sept. 2016), from the Chilton Research and Extension Center, Clanton, AL. After harvest, fruit were kept at room temperature (20 °C) for 64 hours to cure prior to initial fruit quality measurement and then being placed into polyethylene liners inside kiwifruit boxes and placed in cold storage at 0 °C and 95% relative humidity (RH). Two data loggers (Model A150, Spectrum® Technologies Inc., IL, USA) were placed in the cooler to monitor the temperature and RH. On 15 Sept. 2016, because of a frost problem on cooler fans, temperature went up to 5.6 ºC, so all the fruits were moved into a new cooler with temperature at 2.2 ºC. Two days later, the new cooler's temperature went up to 8.3 ºC. The same day fruit were moved back to the previous cooler with temperature at 1.1 ºC. Except on the days when the cooler problems occurred, the temperature was maintained at 1.1±1.1 ºC, and during the whole experiment RH was maintained at 90±5%. An ethylene filter

(Transprotekt ethylene extend F100 filter ethylene scrubber; Bioconservacion, S.A., Spain) was placed in the cooler.

Prior to sensory evaluation, the length of time that fruit were exposed at room temperature was determined by moving ten fruits per cultivar at each harvest time from cold storage and placing the two cultivars into separate boxes with 2.7 kg 'Golden Delicious' apples at room temperature. The process was repeated twice to determine the length of time that needed to soften the fruits to eating quality (0.5-1.0 kgf firmness; Patterson et al., 2003). Fifty 'AU Golden Dragon' and fifty 'AU Golden Sunshine' at each harvest time were removed from cold storage and exposed at room temperature (20 ºC) with 'Golden Delicious' apples for 2 d and 3 d respectively, ahead of sensory evaluation.

Fruit quality analysis

Ten fruit from each cultivar per harvest were used to determine fruit quality at harvest after curing and after 'AU Golden Dragon' and 'AU Golden Sunshine' held at room temperature (20 ºC) with 'Golden Delicious' apples for 2 d and 3 d respectively, but before sensory evaluation. The following data were collected for each fruit: weight (g), length (mm), width (mm), TA, SSC, internal color, firmness (kgf) and SSC: TA. Dry matter content was only measured at harvest.

Fruit weight was measured with a scale (A&D EJ-610, A&J Cprp., San Jose, CA, USA). Length and width were measured using a digital caliper (Mitutoyo Corp., Kawasaki, Japan). The DMC was measured at harvest and determined by drying a 3–mm transverse slice from the middle section of both halves of the fruit in food dehydrator (Excalibur products, Sacramento, California, USA) at 65 ºC for approximately 24 h (Burdon et al., 2014a). External color (ºhue) was measured twice at the equator of each fruit, with two measurements taken 90º to each other, using a spectrometer (Minolta CM-2002, Konica Minolta Ins., Tokyo, Japan). Internal color was measured after removal of skin to a depth of approximately 2 mm at the same location as external color measurements. The average of the two measurements was external and internal color. Firmness was measured twice in kg of force needed to insert a 8 mm slightly rounded probe 1 cm into the flesh of the fruit after removal of skin 1 mm at the equator of each fruit, with two measurements taken 90º adjacent to each other, by using a penetrometer (McCormick Fruit Pressure Tester FT327, McCormick Fruit Tech, Yakima, Washington). Fruit firmness was the average of the two measurements. A 10 mm section was cut from both the calyx and the vine end of the fruit to measure the percent SSC. Percent SSC for both fruit ends were determined using a refractometer (Leica Mark II Abbe, Leica Inc., Buffalo, NY, USA), and the average of the top and bottom SSC were fruit SSC. Titratable acidity of ten fruits per cultivar was measured with a titrator (Mettler Toledo DL15, Mettler-Toledo LLC, Columbus, OH, USA).

Sensory evaluation

Prior to sensory evaluation, an invitation email was sent to all students, faculty and staff of the College of Agriculture, Auburn University and invitation posters were posted in front of College of Agriculture buildings. Sensory evaluation was conducted on 18 Oct. 2016 in the Research Kitchen & Sensory Laboratory, Poultry Science Building, Auburn University, AL. There were 90 volunteers who participated in this sensory evaluation. The basic information about the participants is shown in Table 3.1. A random three-digit code for each cultivar at each harvest date was created. Three codes were randomly chosen and assigned to be one of three groups. A 3 mm transverse slice from the middle section from both halves of kiwifruit was divided into two pieces/slice to serve as samples for the sensory evaluation. During the sensory evaluation, each participant was served nine kiwifruit samples in three separate groups with crackers and a bottle of water and asked to write down the sample code shown on the plate and complete the survey. Participants were instructed to cleanse their palates between samples using water and a cracker. Each panelist was asked to rate the following attributes: sweetness, sourness, aroma, firmness, overall liking and desire to buy using a nine-point hedonic scale (1=dislike very strongly, 2=dislike strongly, 3=dislike, 4=dislike a little, 5=neither like nor dislike, 6=like a little, 7=like, 8=like strongly, 9=like very strongly).

The current project was given approval to proceed as Auburn University Institutional Review Board for Research Involving Human Subjects (16-203 EX 1606) and participants provided their appropriate informed consent. Approval letter and sensory evaluation survey are provided in Appendices.

Statistics

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.4 (SAS Institute, Cary, NC). The studies were split-plots with kiwi cultivar in the main plot and harvest date in the sub-plot. All fruit quality responses were analyzed using the normal probability distribution. Where residual plots and a significant covariance test indicated heterogeneous variance among treatments, a RANDOM statement with the GROUP option was used to correct heterogeneity. Least squares means comparisons between cultivars for each date were determined using F-tests. All sensory evaluation responses were analyzed using the normal probability distribution with analysis of variance (Taylor et al., 2008). Comparisons between cultivars for each date were estimated. Linear and quadratic trends harvest dates for each cultivar were determined using qualitative-quantitative regression models in cases of significant interactions. Simple model regressions were used in cases of significant harvest date main effects. Reported are least squares means. All significances were at $\alpha = 0.05$ unless otherwise indicated in the tables.

Results

Fruit quality of kiwifruit at harvest

Harvest maturity affected fruit harvest characteristics for ‘AU Golden Dragon’. There was a linear decrease in firmness and internal color hue with increasing harvest date, whereas DMC increased linearly (Table 3.2). Moreover, SSC and SSC:TA changed quadratically with minimum values on 22 Aug. with increasing harvest date, whereas TA changed quadratically with the maximum value on 22 Aug. as harvest date increased (Table 3.2).

Maturity at harvest influenced ‘AU Golden Sunshine’ fruit characteristics. There was no effect of harvest date on firmness or DMC (Table 3.3). As harvest date progressed, internal color hue and TA decreased linearly, while SSC increased linearly and SSC:TA increased quadratically (Table 3.3).

Fruit quality of ripe kiwifruit

There were interactions between harvest date and cultivar for some fruit quality attributes. As harvest date increased, there was a linear increase in SSC of ‘AU Golden Dragon’ and ‘AU Golden Sunshine’ (Table 3.4). Except for fruit harvested on 22 Aug. 2016, ‘AU Golden Dragon’ had lower SSC than ‘AU Golden Sunshine’ at each harvest date (Table 3.4). There was a quadratic change with increasing harvest date in TA with a maximum value on 5 Sept. for ‘AU

Golden Dragon', but no change of 'AU Golden Sunshine' (Table 3.4). 'AU Golden Dragon' had a higher level of TA than 'AU Golden Sunshine' at each harvest date (Table 3.4). Harvest date and cultivar had no impact on firmness (Table 3.4).

The harvest maturity and cultivar main effects were significant for SSC:TA and the harvest date main effect was significant for internal color (Table 3.5). As harvest date increased, there was a quadratic change in SSC:TA with maximum value on 29 Aug. (Table 3.5). 'AU Golden Dragon' had a much lower SSC:TA than 'AU Golden Sunshine' (Table 3.5). Internal color hue decreased linearly with increasing harvest date (Table 3.5).

Sensory evaluation

Cultivar by harvest date interactions affected sensory evaluation scores for sweetness, sourness, firmness and flesh color (Table 3.6). Consumers consistently preferred 'AU Golden Dragon' over 'AU Golden Sunshine' for each of the above-mentioned attributes, with the exception of color on 29 Aug. and 5 Sept. where no differences were observed (Table 3.6). There was a linear negative relationship between sweetness liking scores and increasing harvest date of both cultivars (Table 3.6). Liking scores of sourness were not affected by increasing harvest date for 'AU Golden Dragon', whereas there was a linear decrease in liking scores of 'AU Golden Sunshine' (Table 3.6). As harvest date increased, there was a linear decrease in liking scores for firmness of 'AU Golden Dragon', while there was a quadratic change in firmness with the highest scores for fruit harvested on 29 Aug. of 'AU Golden Sunshine' (Table 3.6). Increasing harvest date resulted in a linear decrease in liking scores for color of 'AU Golden Dragon' and a quadratic change in color of 'AU Golden Sunshine' with a maximum liking score for fruit harvested on 29 Aug. (Table 3.6). Only the main effect cultivar influenced consumer evaluation of aroma and desire to buy (Table 3.7). ‘AU Golden Dragon’ had higher scores in aroma and desire to buy than ‘AU Golden Sunshine’ (Table 3.7).

Harvest date had no significant effect on overall liking scores of ‘AU Golden Dragon’ (Table 3.8). A quadratic trend was observed for overall liking scores of ‘AU Golden Sunshine’, with the highest scores for fruit harvested on 29 Aug. (Table 3.8).

Discussion

Sweetness is a desirable attribute of many fruits (Terry et al., 2005), which is related to SSC and TA. The SSC:TA is commonly used as an indicator of sweetness of fresh horticultural produce (Beckles, 2012). However, in the current study, different liking scores were observed for fruit with similar values of SSC:TA. Jordan et al. (2001) demonstrated that SSC:TA did not consistently correlate well with the perception of sweetness, because similar values of SSC:TA may be derived from different concentrations of SSC and TA causing variability in flavor perceptions for the same ratio. Therefore, similar SSC:TA may result in different liking scores. Another possible reason is that different concentrations of fructose can interact greater than glucose and sucrose in a similar SSC:TA, and thereby influence consumers’ perception to sweetness. Comparisons of the two cultivars, ‘AU Golden Dragon’ had higher liking scores in sweetness than ‘AU Golden Sunshine’ at each harvest date, while ‘AU Golden Dragon’ had a lower SSC: TA than ‘AU Golden Sunshine’ in the ripe stage. Additionally, ‘AU Golden Dragon’ had a higher TA level at harvest and in the ripe stage than ‘AU Golden Sunshine’ at each harvest date. These results indicated that consumers preferred the level of sweetness of ‘AU Golden Dragon’ and perceived ‘AU Golden Sunshine’ as too sweet, likely due to the absence of TA. Moreover, as shown in the Table 3.3, harvest maturity of ‘AU Golden Sunshine’ had no significant effect on DMC and the value of SSC on 29 Aug. was much higher than that on 5 Sept., indicating variable fruit maturity at harvest. Variable fruit maturity at harvest associated with ‘AU Golden Sunshine’ could be caused by lateral fruit and a fruit drop observed near the end of Aug., which may have contributed to the lack of cultivar by harvest date effects on SSC:TA.

For the yellow-fleshed kiwifruit, the internal color is an essential commercial characteristic. Interestingly, for ‘AU Golden Dragon’, as internal color hue decreased linearly (more yellow flesh), liking scores of internal color decreased linearly over harvest date. This suggested that consumers like the traditional green color better than the yellow flesh color. But for ‘AU Golden Sunshine’, fruit with a hue angle of 100º were more popular with consumers.

For ‘AU Golden Dragon’, harvest date did not affect overall liking scores, but for ‘AU Golden Sunshine’, overall liking scores changed quadratically with a maximum value on 29 Aug. Burdon et al. (2004) and Jaeger et al. (2011) indicated that higher DMC were more popular with consumers. However, in this study, DMC was not tightly correlated with consumer preference in either cultivar. This could be partly due to the variable maturity observed in ‘AU Golden Sunshine’ that contributed to lack of differences for DMC. The observed DMC values for ‘AU Golden Dragon’ increased linearly with harvest date but only slightly (~1.3%).

Above all, ‘AU Golden Dragon’ was more popular with consumers than ‘AU Golden Sunshine’. Harvest date did not greatly influence consumer perception of ‘AU Golden Dragon’, which suggests that ‘AU Golden Dragon’ could have a long harvest window. Moreover, because consumers were unfamiliar with yellow-fleshed kiwifruit, ‘AU Golden Dragon’ kiwifruit with higher internal color hue (more green) were more popular with consumers. For ‘AU Golden Sunshine’, fruit harvested on 29 Aug. had a relatively higher score than other harvest dates in most fruit quality attributes. Consumers tended to prefer the sweetness of earlier harvested 'AU Golden Sunshine', which had lower SSC:TA. Additionally, for 'AU Golden Sunshine', compared with fruit harvested on 22 Aug., consumers preferred the firmness and internal color of fruit harvested on 29 Aug., although there was no effect of harvest maturity on firmness. Combining these factors, the fruit harvested on 29 Aug. were popular with consumers.

Variable fruit maturity at harvest of 'AU Golden Sunshine' made it difficult to get clear information about the relationship between harvest date and consumer preference. Lateral flowers that opened later than terminal flowers (Lawes et al., 1990) and fruit dropping before harvesting are two major factors influencing fruit maturity at harvest. Hydrogen cyanamide, a chemical compound, is applied to advance the date of budbreak and concentrate the flowering, and thus harvest maturity, of kiwifruit (Henzell and Briscoe, 1986; McPherson et al., 2001). Fruit thinning is also a useful method to remove lateral fruit, increase fruit size and improve fruit quality (Pescie and Strik, 2004; Thakur and Chandel, 2004). Hence, hydrogen cyanamide and thinning could be used to minimize differences in fruit maturity at harvest. Because this study was only conducted in 2016, additional insight could be gained by repeating this study to explore the relationship between harvest maturity and consumer preference of these two yellow-fleshed kiwifruit cultivars.

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Table 3.1. Demographic characteristics of the 90 consumers who participated in the kiwifruit sensory evaluation.[z]

Demographic	Segment	Percent
Sex	Female	45%
	Male	55%
Age	19 to 29	81%
	30 to 39	6%
	40 to 49	6%
	50 to 59	6%
	60 and older	1%
Ethnicity	White	82%
	Hispanic or Latino	3%
	Asian/ Pacific islander	15%
Consumption of kiwifruit	> 3 times a week	2%
	1 to 2 times a week	4%
	1 to 2 times a month	39%
	A few times a year	45%
	Never	10%

[z]Sensory evaluation was conducted on 18 Oct. 2016 at the Research Kitchen & Sensory Laboratory, Poultry Science Building, Auburn University, AL.

Table 3.2. Effect of harvest date on fruit harvest characteristics of *Actinidia chinensis* ‘AU Golden Dragon’.[z]

	Harvest date[y]					
Attributes	8/15/2016	8/22/2016	8/29/2016	9/5/2016	9/12/2016	Sign.[y]
Firmness[x] (kg)	5.41	4.44	4.05	4.28	3.54	L***
Internal color[w] (°hue)	100.9	101.9	99.0	98.3	96.6	L***
SSC[v] (%)	7.3	6.3	7.8	7.8	11.5	Q***
TA[u] (%)	1.92	1.96	1.70	1.71	1.39	Q*
SSC:TA[t]	3.8	3.2	4.6	4.7	8.7	Q***
DMC[s] (%)	16.61	16.69	17.12	17.00	17.98	L***

[z]Only the harvest date main effect was significant at α=0.05. Fruit quality analysis was conducted at harvest after 64 hours curing at room temperature (20 °C).

[y] Significant (Sign.) linear (L) or quadratic (Q) trends using model regression at α=0.05(*), 0.01(**) or 0.001(***).

[x]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.

[w]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.

[v]SSC= Soluble solids content measured with refractometer.

[u]TA= Titratable acidity measured with titrator.

[t]SSC:TA= the ratio of soluble solids content and titratable acidity.

[s]DMC = Dry matter content= $\frac{fresh\ weight - dry\ weight}{fresh\ weight} \times 100$. Dry weight was measured after kiwifruit slice was dehydrated in dehydrator at 65 °C for approximately 24h.

Table 3.3. Effect of harvest date on fruit harvest characteristics of *Actinidia chinensis* 'AU Golden Sunshine'.[z]

	Harvest date[y]				
Attributes	8/22/2016	8/29/2016	9/5/2016	9/12/2016	Sign.[y]
Firmness[x] (kg)	4.21	3.87	3.78	4.11	NS
Internal color[w] (°hue)	105.6	101.5	101.5	100.4	L*
SSC[v] (%)	7.8	10.3	8.3	10.7	L*
TA[u] (%)	1.51	1.23	1.27	1.05	L***
SSC:TA[t]	5.2	8.2	6.6	10.3	Q*
DMC[s] (%)	17.40	17.65	18.20	18.28	NS

[z]Only the harvest date main effect was significant at α=0.05. Fruit quality analysis was conducted at harvest after 64 hours curing.

[y]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using model regression at α=0.05(*) or 0.001(***).

[x]Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.

[w]Internal color measured with spectrophotometer after removal of skin to a depth of approximately 2 mm.

[v]SSC= Soluble solids content measured with refractometer.

[u]TA= Titratable acidity measured with titrator.

[t]SSC:TA= the ratio of soluble solids content and titratable acidity.

[s]DMC = Dry matter content= $\frac{fresh\ weight - dry\ weight}{fresh\ weight} \times 100$. Dry weight was measured after kiwifruit slice was dehydrated in dehydrator at 65 °C for approximately 24h.

Table 3.4. Effect of harvest date and cultivar on average SSC, TA, firmness and internal color of *Actinidia chinensis* ‘AU Golden Dragon’ and ‘AU Golden Sunshine’.[z]

		Harvest date					
Attribute[y]	Cultivar[x]	8/15/16	8/22/16	8/29/16	9/5/16	9/12/16	Sign.[w]
SSC (%)	GD	13.2	14.2ns[v]	13.1b	14.6b	14.4b	L***
	GS	-	14.3	15.7a	15.7a	16.6a	L**
TA (%)	GD	0.98	1.22a	0.97a	1.32a	1.13a	Q**
	GS	-	0.84b	0.77b	0.84b	0.81b	NS
Firmness (kg)	GD	0.51	0.27ns	0.48ns	0.59ns	0.47ns	NS
	GS	-	0.52	0.43	0.59	0.54	NS

[z]The cultivar by harvest date interaction was significant at $\alpha = 0.05$. Prior to sensory evaluation, fruit quality attributes were measured after fruit held at room temperature (20 ºC) with ‘Golden Delicious’ apples for 2 or 3 d for ‘AU Dragon’ and ‘AU Golden Sunshine’, respectively.
[y]SSC= Soluble solids content measured with refractometer, TA= Titratable acidity measured with titrator. Firmness measured with a bench top penetrometer using an 8 mm probe after removal of skin to a depth of approximately 1 mm.
[x]GD= ‘AU Golden Dragon’, GS= ‘AU Golden Sunshine’.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trend using model regression at $\alpha = 0.01$ (**) or 0.001 (***). Sign.= Significance.
[v]Least squares means comparisons between cultivars for each date using F-tests at $\alpha = 0.05$.

Table 3.5. Effect of harvest date and cultivar on SSC: TA of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine'.

Cultivar	SSC: TA[z]	Harvest date	SSC:TA	Internal color (°hue)[y]
AU Golden Dragon	12.66b[x]	8/15/16	16.93	103.77
AU Golden Sunshine	19.49a	8/22/16	14.57	102.87
		8/29/16	17.22	100.97
		9/5/16	15.17	98.6
		9/12/16	16.79	96.96
Sign.[w]			Q***	L***

[z]Only the cultivar and harvest date main effects were significant $\alpha = 0.05$. Prior to sensory evaluation, SSC:TA were measured after fruit held at room temperature (20 ºC) with 'Golden Delicious' apples for 2 or 3 d for 'AU Dragon' and 'AU Golden Sunshine', respectively
[y]Only the harvest date main effect was significant at $\alpha = 0.05$. Internal color was measured with spectrophotometer after removal of skin to a depth of approximately 2 mm before sensory evaluation but after fruit held at room temperature (20 ºC) with 'Golden Delicious' apples for 2 or 3 d for 'AU Dragon' and 'AU Golden Sunshine', respectively
[x]Least squares means comparisons between cultivars using the main effect F-tests at $\alpha = 0.05$.
[w]Significant (Sign.) linear (L) or quadratic (Q) trends using model regression at $\alpha = 0.001$ (***).

Table 3.6. Effect of harvest date and cultivar on average consumer liking scores for sweetness, sourness, firmness and color of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine'.[z]

		Harvest date					
Attribute	Cultivar[y]	8/15/16	8/22/16	8/29/16	9/5/16	9/12/16	Sign.[x]
Sweetness	GD	6.5[w]	6.4a[v]	6.6a	6.6a	6.9a	L*
	GS	-	5.5b	6.0b	5.2b	5.0b	L*
Sourness	GD	6.3	6.2a	6.1a	6.3a	6.3a	NS
	GS	-	5.2b	5.4b	4.8b	4.7b	L**
Firmness	GD	6.2	6.2a	5.7ns	5.9a	5.4a	L**
	GS	-	4.5b	5.2	5.1b	4.5b	Q**
Flesh Color	GD	6.3	6.2a	6.2ns	5.4ns	5.9a	L**
	GS	-	5.6b	6.1	5.6	5.1b	Q**

[z]The cultivar by harvest date interaction was significant at $\alpha = 0.05$. Ninety participants were served with nine samples (half of a 3-mm transverse slice from the middle section from both halves) in three separate groups.
[y]GD= 'AU Golden Dragon', GS= 'AU Golden Sunshine'.
[x]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using qualitative-quantitative regression models at $\alpha = 0.05$ (*) or 0.01 (**)..
[w]Liking scores were rated on 9-point hedonic scale from 1= 'dislike very strongly' to 9= 'like very strongly'.
[v]Least squares means comparisons between cultivars for each date used F-tests at $\alpha = 0.05$.

Table 3.7. Effect of harvest date and cultivar on average consumer liking scores for aroma and desire to buy of *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine'.[z]

Cultivar	Aroma	Desire to buy
Golden Dragon	6.2a[x]	6.0a
Golden Sunshine	5.5b	4.7b

[z]Only the cultivar main effect was significant at $\alpha = 0.05$. Ninety participants were served with 9 samples (half of a 3-mm transverse slice from the middle section from both halves) in three separate groups.

[y]Liking scores were rated on 9-point hedonic scale from 1= 'dislike very strongly' to 9= 'like very storngly'.

[x]Least squares means comparisons between cultivars used F-test at $\alpha = 0.05$.

Table 3.8. Effect of harvest date and cultivar on consumer overall liking on *Actinidia chinensis* 'AU Golden Dragon' and 'AU Golden Sunshine'.[z]

	Harvest date					
Cultivar[y]	8/15/16	8/22/16	8/29/16	9/5/16	9/12/16	Sign.[x]
GD	6.5[w]	6.4a[v]	6.6a	6.4a	6.6a	NS
GS	-	5.2b	5.9b	5.1b	4.7b	Q**

[z]The cultivar by harvest date interaction was significant at α = 0.05. Ninety participants were served with 9 samples (half of a 3-mm transverse slice from the middle section from both halves) in three separate groups.
[y]GD= AU Golden Dragon, GS= AU Golden Sunshine.
[v]Not significant (NS) or significant (Sign.) quadratic (Q) trend using model regression at α = 0.01 (**).
[x]Liking scores were rated on 9-point hedonic scale from 1= 'dislike very strongly' to 9= 'like very strongly'.
[w]Least squares means comparisons between cultivars for each date used F-tests at α = 0.05

Chapter Four

Conclusions and Recommendations

The results of the two studies reported above allowed for some conclusions and recommendations to be derived for *Actinidia chinensis* ‘AU Golden Dragon’ and ‘AU Golden Sunshine’.

‘AU Golden Dragon’ had a longer harvest window, and a soluble solids content (SSC) value of 7.8–8% was recommended to serve as a harvest index, with around 99 °h internal color hue and approximately 17.2% dry matter content (DMC) to ensure good postharvest performance.

Variable fruit maturity at harvest for ‘AU Golden Sunshine’ in 2016 made it difficult to get a specific harvest index that ensures better postharvest and higher consumer acceptance. A SSC value of 10% could be a possible harvest index for ‘AU Golden Sunshine’. Moreover, when the firmness of ‘AU Golden Sunshine’ fruit remained at or above 4 kgf at harvest, higher SSC at harvest enhanced postharvest longevity and lowered susceptibility to chilling injury (CI). Hence, if fruit remains firm, then allowing fruit to increase SSC would improve postharvest performance. Future research would facilitate determining more specific harvest indices and the effects on postharvest performance and consumer acceptance of ‘AU Golden Sunshine’. Meanwhile, fruit thinning and hydrogen cyanamide could be used to reduce variable fruit maturity at harvest in future study.

Consumers tend to prefer ‘AU Golden Dragon’ to ‘AU Golden Sunshine’ in the sensory evaluation. Educating consumers on the differences between green-fleshed kiwifruit and yellow-fleshed kiwifruit prior to sensory evaluation might improve scores in future research, particularly such as color.

Appendices

Golden kiwifruit 'AU Golden Dragon' and 'AU Golden Sunshine' Survey

'AU Golden Dragon' and 'AU Golden Sunshine' were developed by a joint effort between Auburn University, Auburn, Alabama, USA and The Fruit and Tea Institute, Hubei province, P.R. China. Kiwifruit are known to contain high levels of vitamin C, vitamin E, beta-carotene, and polyphenols. The purpose of this study is to determine consumer acceptance of these two kiwifruit cultivars harvested at different levels of maturity. Hence, this research can provide growers with recommended harvest indices based on consumer preferences and markets.

This survey will remain confidential and no names or identifiers will be used. If you are interested in a copy of the results or have any questions, please e-mail Lingbo Xie at lzx0013@auburn.edu.

Directions

1. During the survey, you will be served with 9 kiwifruit samples in three separate groups.
2. After tasting each sample, you are asked to write down the sample code shown on the plates and complete the table.
3. Please cleanse your palate between samples using water and crackers.
4. When you complete one group of samples, please close the window to notify the researcher to serve you another group of samples.
5. After you complete tasting the 9 kiwifruit samples in three separate groups, you will be asked to provide background information that will critically assist me in my research.
6. Finally, when you complete all requested information on the survey, please close window and return the survey sheets back to the research.

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Sample Code

Please check the box within the table that most accurately describes how much you like the corresponding attribute for each sample and then how likely you would be to purchase the sample.

Attribute	1 Dislike Very Strongly	2 Dislike Strongly	3 Dislike	4 Dislike a little	5 Neither like nor dislike	6 Like a little	7 Like	8 Like Strongly	9 Like Very Strongly
Sweetness									
Sourness									
Aroma									
Firmness									
Color									
Overall liking									
Desire to buy									

Additional comments (optional)

Background information:

1. What is your gender?
A. Male
B. Female

2. What is your age?
A. 19~29
B. 30~39
C. 40~49
D. 50~59
E. 60 and over

3. What is your ethnicity?
A. White.
B. Hispanic or Latino.
C. Black or African American.
D. Native American or American Indian.
E. Asian / Pacific Islander.
F. Other.

4. Frequency of fresh kiwifruit consumption
A. More than 3 times a week
B. 1~2 times a week
C. 1~2 times a month
D. A few times a year
E. Never

AUBURN UNIVERSITY INSTITUTIONAL REVIEW BOARD for RESEARCH INVOLVING HUMAN SUBJECTS

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For Information or help completing this form, contact: **THE OFFICE OF RESEARCH COMPLIANCE**, 115 Ramsay Hall
Phone: 334-844-5966 **e-mail:** IRBAdmin@auburn.edu **Web Address:** http://www.auburn.edu/research/vpr/ohs/index.htm

Revised 2/1/2014 **Submit completed form to IRBsubmit@auburn.edu or 115 Ramsay Hall, Auburn University 36849.**

Form must be populated using Adobe Acrobat / Pro 9 or greater standalone program (do not fill out in browser). Hand written forms will not be accepted.

Project activities may not begin until you have received approval from the Auburn University IRB.

1. PROJECT PERSONNEL & TRAINING

PRINCIPAL INVESTIGATOR (PI):

Name Lingbo Xie **Title** MS. **Dept./School** Horticulture
Address 122 Funchess Hall, Auburn University **AU Email** lzx0013@auburn.edu
Phone 3344443973 **Dept. Head** Dave Williams

FACULTY ADVISOR (if applicable):

Name James D. Spiers **Title** Dr. **Dept./School** Horticulture
Address 111 Funchess Hall, Auburn University
Phone 3347281888 **AU Email** jds0017@auburn.edu

KEY PERSONNEL: **List Key Personnel (other than PI and FA).** Additional personnel may be listed in an attachment.

Name	Title	Institution	Responsibilities
Leonard Bell	Dr.	Auburn University	Assist to design project

KEY PERSONNEL TRAINING: **Have all Key Personnel completed CITI Human Research Training (including elective modules related to this research) within the last 3 years?** ☑ YES ☐ NO
TRAINING CERTIFICATES: **Please attach CITI completion certificates for all Key Personnel.**

2. PROJECT INFORMATION

Title: The Effect of maturity on consumer preference of two kiwifruit cultivars ' AU Golden Dragon' and 'AU Golden Sunshine'

Source of Funding: ☐ Investigator ☑ Internal ☐ External

List External Agency & Grant Number:

List any contractors, sub-contractors, or other entities associate with this project.

List any other IRBs associated with this project (including those involved with reviewing, deferring, or determinations).

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The Auburn University Institutional Review Board has approved this Document for use from 06/15/2016 to 06/14/2019
Protocol # 16-203 EX 1606

3. PROJECT SUMMARY

a. **Does the research involve any special populations?**

- ☐ YES ☑ NO **Minors (under age 19)**
- ☐ YES ☑ NO **Pregnant women, fetuses, or any products of conception**
- ☐ YES ☑ NO **Prisoners or Wards**
- ☐ YES ☑ NO **Individuals with compromised autonomy and/or decisional capacity**

b. **Does the research pose more than minimal risk to participants?** ☐ YES ☑ NO

Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests. 42 CFR 46.102(i)

c. **Does the study involve any of the following?**

- ☐ YES ☑ NO **Procedures subject to FDA Regulation** Ex. Drugs, biological products, medical devices, etc.
- ☐ YES ☑ NO **Use of school records of identifiable students or information from instructors about specific students**
- ☐ YES ☑ NO **Protected health or medical information when there is a direct or indirect link that could identify the participant**
- ☐ YES ☑ NO **Collection of sensitive aspects of the participant's own behavior, such as illegal conduct, drug use, sexual behavior or use of alcohol**
- ☐ YES ☑ NO **Deception of participants**

If you checked "YES" to any response in Question #3 STOP. It is likely that your study does not meet the "EXEMPT" requirements. Please complete a PROTOCOL FORM for Expedited or Full Board Review.
You may contact IRB Administration for more information. (Phone: 334-844-5966 or Email: IRBAdmin@auburn.edu)

4. PROJECT DESCRIPTION

a. **Subject Population** (Describe, include age, special population characteristics, etc.)

Subjects will include staff, faculty and students on campus. All the subjects in the research are 19 years old or older than 19 years old. Pregnant women are not allowed to participate project.

b. **Describe, step by step, all procedures and methods that will be used to consent participants.**

☐ **N/A (Existing data will be used)**

At first the invitation email regarding basic information of project will be sent to potential participates on campus. Before the the participants participates research, they will be asked to read and sign the informed consent.

c. **Brief summary of project.** (Include the research question(s) and a brief description of the methodology, including recruitment and how data will be collected and protected.)

The objective of this study will be to determine how fruit maturity at harvest affects consumer preference. Consumer preference tests will be held in fall, 2016 at Sensory Analysis Lab of Auburn University and students, faculty and staff, who are 19 or older than 19, on campus will be invited by sending email. Two cultivars are harvest at four different times in the Chilton Research and Extension Center in Clanton, AL, USA, and stored in a cooler (95% RH and 0° C). Consumer preference studies will be done separately for the two cultivars. Participants will be presented with four ripe kiwifruit samples from the same cultivar, each kiwifruit derived from four different harvest dates in random order. Before the sensory evaluation, kiwifruit samples will be removed from cold storage and exposed to room temperature for a determined length of time to allow fruit to soften to approximately 0.9~1.4 kg firmness level, that is best for consumer consumption. When determined ready for consumption, 10 fruit/harvest will be analyzed for fruit quality (SSC, TA, Firmness, internal color, external color). Preliminary studies will be conducted to determine the length of time to store kiwifruit prior to sensory evaluation. A 3-mm transverse slice from the middle section from both halves of kiwifruits will be divided into four pieces/slice to serve as samples for the sensory evaluation. The sensory tests begin with three demographic questions: gender, age and frequency of fresh kiwifruit consumption. Each participants is asked about 'how much you like or dislike the attributes: sweetness, sourness, aroma, firmness, overall flavor and overall liking using a nine-point hedonic scale (1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like very much, 9=like extremely). All the data in the research will be collected anonymously with no direct or indirect coding, link, or awareness of who participated in the study by using questionnaire and only kept by investigator in paper and electronic format.

d. **Waivers. Check any waivers that apply and describe how the project meets the criteria for the waiver.**

- ☐ **Waiver of Consent (Including existing de-identified data)**
- ☑ **Waiver of Documentation of Consent (Use of Information Letter)**
- ☑ **Waiver of Parental Permission (for college students)**

No identifiers are being collected in the survey.

All the subjects in the research are 19 or older than 19 years old.

e. **Attachments.** Please attach Informed Consents, Information Letters, data collection instrument(s), advertisements/recruiting materials, or permission letters/site authorizations as appropriate.

Signature of Investigator *lingbo xie* Date 6/9/2016

Signature of Faculty Advisor [signature] Date 6/9/2016

Signature of Department Head [signature] Date 6/9/2016

AUBURN
UNIVERSITY

COLLEGE OF AGRICULTURE

DEPARTMENT OF HORTICULTURE

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER

For a Research Study entitled

"The effect of maturity on consumer preference of 'AU Golden Dragon' and 'AU Golden Sunshine" kiwifruit cultivars."

You are invited to participate in a research study to measure consumer acceptance of a golden kiwifruit harvested at different levels of maturity. This study is being conducted by Ms. Lingbo Xie, under the direction of Dr. James Spiers in the Auburn Univ. Dept. of Horticulture. You are invited to participate because you are staff, faculty or students of Auburn University and are age 19 or older.

If you decide to participate in this research study, you will be asked to taste different kiwifruit samples, complete a short survey and return it at the end of the tasting. Your total time commitment will be approximately 10 minutes. The results of the survey will be used to determine gold kiwifruit quality and maturity indices that consumers prefer. Your answers are completely confidential and anonymous. Reports from this survey will only be released in summary form, preventing any individual's answers from being identified. Information collected through your participation may be published in a professional journal and/or presented at a professional meeting.

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06/15/2016 to 06/14/2019
Protocol # 16-203 EX 1606

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the Department of Horticulture.

If you have questions about this study, please ask them now or contact Lingbo Xie at lzx0013@auburn.edu or Dr. James D. Spiers at jds0017@auburn.edu.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE IF YOU WANT TO PARTICIPATE IN THIS RESEARCH PROJECT. THE DATA YOU PROVIDE WILL SERVE AS YOUR AGREEMENT TO DO SO. THIS LETTER IS YOURS TO KEEP.

____

Investigator's signature   Date

_____Lingbo Xie__________________________

Printed Name

____

Co-Investigator   Date

____

Printed Name

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