A DISSERTATION FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Evaluation of Wind Damage Affecting Vine Regrowth, Abnormal Flowering, Fruit Quality, and Return Bloom by Artificial Defoliation in 'Jecy Gold' Kiwifruit

'제시골드' 참다래에서 인위적엽에 의한 신초 재생장, 불시개화, 과실품질

및 익년개화에 영향하는 바람 피해의 평가

Witchaya Srisook

August, 2016

DEPARTMENT OF HORTICULTURAL SCIENCE

GRADUATE SCHOOL

JEJU NATIONAL UNIVERSITY

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(Supervised by Professor **Kwan Jeong Song**, Ph.D)

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Agriculture

August, 2016

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ABSTRACT

Kiwifruit was introduced to Korea in late 1970s and has been cultivated in southern coastal areas including Jeju Island. The Jeju Island is battered by typhoons every year which the strong wind always damage, especially kiwifruit's leaves due to their large size and long petiole. Artificial defoliation has been applied to stimulate the effects of unfavorable weather conditions like gusty wind on kiwifruit vine growth. This study was intended to evaluate the effects of defoliation levels and times on vine regrowth, fruit quality, and flower production on 'Jecy Gold' kiwifruit during three years (2013 to 2015). Five-year-old 'Jecy Gold' kiwifruit vines grown in a plastic house were demonstrated in the study. Artificial defoliation was applied by hand with different levels, i.e., 0 (control), 50, 75, and 100% on August 23, 2013 by removing leaves including petioles at the petiole junction with canes. Leaves were removed at regular intervals. Further, 100% defoliation was applied in the different times as follow July 28 and August 29, 2014. Vine regrowth by axillary bud burst, cane bark carbohydrate reserve, fruit quality, and yield, and flowering were investigated.

The 50, 75, and 100% defoliation induced axillary budburst during the first week after leaf removal. The axillary budburst in 75 and 100% defoliation vines were significantly higher than those in the control and 50% defoliation vines. Furthermore, vines treated with 100% defoliation produced a few off-season flowers. The significant reduction of starch and sucrose concentration was observed in 75 and 100% defoliation during two weeks after defoliation. 100% defoliation significantly increased fruit drop and fruit firmness. However, mean fruit weight, soluble solid content, and dry matter content were significantly decreased by 75 and 100% defoliation. The severe defoliation caused a large reduction in flowering in subsequent years. Return bloom in 2014, expressed as the number of flowers per shoot was reduced about 19.2 and 50.0% while the number of flowers per florescence were reduced about 37.5 and 58.3% with 75 and 100% defoliation, respectively. Especially, the reduction of the number of flowers per florescence was remained in 2015, about 17.9 and 25.0% with 75 and 100% defoliation, respectively. Fruit quality parameters, i.e., fruit length, width, firmness, soluble solid content, acidity, and dry matter content, were not significantly different in both years, 2014 and 2015.

The off-season flowers were produced on vines defoliated on August 29, but not on July 28. Vine regrowth was not significantly different between July 28 and August 29 defoliation. Starch and soluble sugars of cane bark were not significantly different except for

60 days after defoliation and sucrose content on August 29 was higher than that on July 28. At harvesting time, fruit firmness was increased and soluble solid content was decreased on August 29 defoliation. Further, July 28 and August 29 defoliations did not affect fruit quality in the following year (2015) compared to the control. The number of flowers per florescence was significantly decreased by 29.2% and 37.3% on July 28 and August 29 defoliation, respectively while the number of flowers per shoot was not significantly affected by July 28 and August 29 defoliation compared to the control vines. The results indicated that the shortage of starch and sucrose concentration, particularly by severe defoliation, might affect a reduction of fruit quality in the growing season but not in the following season. Defoliation also affects a reduction of flower production in subsequent years, even though the defoliation was done on the different time (July 28 and August 29). Also, the occurrence of off-season flowering in late August defoliation could be explained floral evocation of 'Jecy Gold' kiwifruit vine and floral evocation might be completed during July 28 and August 29. Moreover, 100% defoliation on August 29 more affect fruit quality, especially fruit firmness, and soluble solid content than those on July 28 defoliation.

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INTRODUCTION

Kiwifruit was introduced to Korea in late 1970s, was cultivated in southern coastal areas including Jeju Island. The Jeju Island is battered by typhoons every year which the strong wind always damage kiwifruit's leaves due to their large size and long petiole (Kwack et al., 2012, 2013). Gusty wind might be affected to either the physical damage including fruit yield and quality in the current season or the flowering in the following season.

Artificial defoliation has been applied to simulate the effects of unfavorable weather conditions on kiwifruit vine growth. Loss of leaves leads to the imbalance of carbohydrate supply between source and sink and consequently caused the competition for carbohydrate supply among the starve sinks. Buwalda and Smith (1990) reported the rank of competitive strengths of sinks as shoots, fruit, roots, and flowering in *Actinidia deliciosa* cv.'Hayward'. Flowering is the most sensitive sink to the shortage of carbohydrate supply. Hopping (1990) described that floral evocation in kiwifruit occurs in the current season and complete the flowering process in the following season. Though, lack of carbohydrate availability during floral evocation caused the reduction of the number of flowers in the subsequent year (Snelga and Clearwater, 2007). Moreover, the reduction of flowering might be remain more than one year after defoliation. However, the amount of carbohydrate supply was recovered during the growing season of defoliation and fruit quality was not affected by defoliation in the following season nevertheless the negative impact on flowering in subsequent years after defoliation might be affected to fruit yield due to the reduction of flowering.

Kiwifruit vine produced a flower within two seasons which are separated by the period of winter dormancy. Floral evocation occurs in the first season as the meristematic tissue in axillary buds changed to the reproductive state. Consequently, the flower primordia was developed to the floral organs in the second season. Defoliation has been used as the method to evaluate the time of evocation in kiwifruit vine through defoliation prevent floral evocation. (Hopping, 1990; Snelgar et al, 1992). The negative impact of defoliation on floral evocation and flower reduction are related to the severity of leaves losses.

Two species in the genus *Actinidia* are economically important, i.e., *A. deliciosa* 'Hayward' and *A. chinensis*. There are variation in morphology and physiology between both of this species. Generally, *A. deliciosa* 'Hayward' is the green flesh kiwifruit and they are hexaploids while *A. chinensis* is the yellow flesh kiwifruit and they are diploids or tetraploids (Zhen et al, 2004). Several studies have been reported the effects of defoliation on vine growth, fruit quality and return bloom in the green flesh kiwifruit nevertheless, few studies were done in the yellow flesh kiwifruit (Buwalda and Smith, 1990; Cruz-Castillo et al., 2010; Kwack et al., 2012, 2013; Richardson et al., 2011). However, the responses of vines to defoliation might be different among the cultivars of genus *Actinidia* and also it is not well understood in the yellow flesh cultivars. Thus, this study was undertaken to better understanding how defoliation affects vegetative and reproductive growth either in the growing season or the following season after defoliation in 'Jecy Gold' kiwifuit. The specific aims of this study were to evaluate the effect of wind damage affecting vine regrowth, abnormal flowering, fruit quality, and return bloom by artificial defoliation in 'Jecy Gold' kiwifruit.

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LITERATURE REVIEW

History, Taxonomy, and Vine Morphology of Genus *Actinidia*

Kiwifruit is one of the most interesting fruits present in the world due to its health attributed and great flavor (Cruzat, 2014). The seeds of kiwifruit (*Actinidia deliciosa*) were collected from China then sent to Europe and North America in 1900. At about that time, kiwifruit was produced as the ornamental plant but not as a commercial production. Subsequently, the seeds of green flesh kiwifruit were introduced to New Zealand in 1904 and they were developed as a industry in New Zealand (Ferguson, 2004). In 1959, the name 'Kiwifruit' has been given by New Zealand fruit handling firm, Turners and Growers Ltd. while replacing the old name 'Chinese gooseberry' (Bano and Scrimgeour, 2012; Ferguson, 2013). The commercial orchards in New Zealand started producing kiwifruit to export in 1976 and also developed a new variety as *Zespri*® *Gold*, the yellow flesh kiwifruit by Zespri brand which started exportation in 1998 (Bano and Scrimgeour, 2012). At the present, there are only two species of *Actinidia* have been growing as the major economically important kiwifruit, i.e., *A. deliciosa* cv. 'Hayward' which is the green flesh kiwifruit whereas *A. chinensis* cv. 'Hort16A' is the yellow flesh kiwifruit and both of them developed in New Zealand (Ferguson, 1990a; Ferguson, 2013).

Kiwifruit belongs to the genus *Actinidia*, family *Actinidiaceae*. The genus *Actinidia* comprises more than 50 species and 100 taxa. The most of species originated from temperate forest of south-western China while some other of species range from Siberia to Indonesia. (Ferguson, 1990a). A widespread geographical distribution and natural hybridization caused a wide genetic variation within the genus *Actinidia*. At the geographical extremes, the difference between species are quite distinct and easily distinguished. *A. delisiosa* is closely related to *A. chinensis*, they both were classified together under the name of *A. chinensis*. However, recently, the differences between these two species can be consistently separated (Ferguson, 1990b). There is a good botanical reason for separating the two species, especially their fruits are distinctly different. The fruits of *A. chinensis* are generally much smaller, more rounded, and less cylindrical than those of *A. deliciosa*. Further, the skin of *A. chinensis* fruits are almost hairless due to an early shedding of downy hairs. Flesh color vary greatly from bright green to intense yellow (Ferguson, 1999). Moreover, the variation in fruits characteristics such as fruit hairs, fruit flesh color, and fruit weight are related to the distinction of a ploidy levels. The mostly of yellow or golden yellow fruit flesh cultivars are diploid or tetraploid whereas the mostly of green fruit flesh cultivars are hexaploid (Li et al., 2010). However, the diploid and hexaploid may have arisen from their adaptation to the differential climate, diploid is usually found in the warm area in the warmer region whereas hexaploid is found in the colder region. Though, the coexistene of cytotypes might be the result of reproductive between ploidy race (Ferguson, 1990b; Li et al., 2010).

Vine Morphology of *Actinidia deliciosa* and *A. chinensis*

All *Actinidia* species are perennial, climbing, and scrambling plants. In a commercial orchard, female vines were subjected to a training system, the mature vine usually has trunk with two leaders trained in opposite directions. A number of canes were trained perpendicularly from each leader and buds on each cane produce shoots (Walton et al., 1997; Ferguson, 1999).

In *Actinidia*, shoots of the current season arise from axillary buds of the previous season's growth. Axillary bud on kiwifruit canes start breaking in spring while also the proportion and time of bud break depending on the cultivars. In addition, the mean shoot length in different *Actinidia* species vary between 31 and 100 cm except in *A. polygamma*, the mean shoot length is 124 cm and it is in *A. chinensis* is 18 cm (Snowball, 1997). Shoots of *Actinidia* can be identified as terminating shoots or 'spur' and this shoot type variable in length including the number of nodes and node interval. Short shoots were defined having nine or less nodes with 9 mm of node interval, whereas the medium shoot as having at more than nine nodes with 27 mm of internode length. Also, non-terminating shoots type are continue growing during a season, shoot length can reach 3-5 m with the total number of nodes is up to 90 nodes per shoot and 47 mm in node interval. Nevertheless, the non-terminating shoots that develop from the latent bud on older wood or the center of the vine are the 'water shoots' which do not bear fruits (Ferguson, 1990c; Seleznyova et al., 2002).

Leave of *Actinidia* are alternate and simple, usually with long petiole. Leaves shape and leaves size are variable between species or even in one plant. In some species of *Actinidia*, leaves are covered with hairs, especially on the lower surface. *A. chinensis* has obovate leaves which the lower side covered by short and greyish-white hair. Leaves of *A. deliciosa* are larger and thinner than leaves of *A. chinensis*. The lower surface of the leaf is covered with long, greyish-brown and stellate hairs. However, the characteristic of leaf hairs is useful in taxonomy and also leaf thickness and leaf surface morphology can be used in sex determination (Ferguson, 1990a; Ferguson, 1990b; Olah et al., 1997).

All species in genus *Actinidia* appear to be functionally dioecious, male vines produce viable pollen while ovary, ovule, or styles are not available for development, whereas the performance of female vines are perfect but the pollen is shriveled or not existed (Ferguson, 1999). Generally, kiwifruit flowers initiate in the leaf axil of current year shoots. The flowers are cup-shape and usually consist of five or more thin petals, which can be white, yellow, or pinkish. The sepal shapes are mostly slight variation of the ovate form. The superior ovary can be ovoid, cylindrical, or bottle shape. The styles are strongly curved outwards and generally stigmatic at their tips. The ovules of *Actinidia* flowers are anatropous, unitegma, and tenuinucellate (Jie and Thorp, 1986; Ferguson 1990a). However, the details of flower morphological description in genus *Actinidia* are variable among the species and gender. For example, flowers of *A. chinensis*, pistillate flowers are usually larger than staminate flowers, whereas the flowers of *A. chinensis* are smaller than flowers of *A. deliciosa* (Ferguson, 1990b).

The fruit of *Actinidia* is a berry, which develops from a multicarpellate ovary. Single fruit containing a number of dark seeds embedded in the juicy flesh. The fruit consists of four distinct tissue types, i.e., a central core joined to the fruit stalk, an inner pericarp containing locules and seed, a dense outer pericarp lying beneath the epidermis, and the skin. There are the plastids containing chlorophyll in both outer and inner pericarp give the green color of the internal tissue. However, the *Actinidia* fruits are varying among cultivars with several different traits such as fruit size, fruit shape, and hairyness of the skin. They also offer a wide variation in sensory attributes such as flesh color, flavor, and taste, including the nutritional attributes such as vitamin C and carotenoid content. (Beever and Hopkirk, 1990; Ferguson, 1990a; Nishiyama, 2007; Richardson, 2011). Most fruits of *A. chinensis*, are spherical with short, soft, and greyish-white hair. Fruit skin is smooth due to the early shedded downy hairs and revealing single, scattered, and yellowish-brown spots. The fruit pulp is yellow, greenish-yellow, or green (Ferguson, 1990b).

Annual Growth Cycle

The annual growth cycle of kiwifruit has been reported in *A. deliciosa* cultivar 'Hayward' under the temperate climatic conditions in New Zealand. The kiwifruit vines initiate new growth in spring with warming temperatures that cause buds to break dormancy. Bud swell occurs in late August (equivalent to February in Korea) subsequently to bud break. At the bud break stage, shoots have rapid growth, and flower bud development and enlargement occur concurrently. The flowering is in November to early December (equivalent to May to early July in Korea). After pollination and fruit set, the rate of fruit growth and development is gradually increased. The expansion of young fruitlets in both length and circumference is very high in the first two months, then it is much slower and almost constant subsequently. Fruits maturity occurs in early May (equivalent to November in Korea). Leaf fall normally occurs during May to early June (equivalent to November to December in Korea) and vine dormancy generally occurs from the end of leaf fall to until late August (Fig. 1) (Davison, 1990).

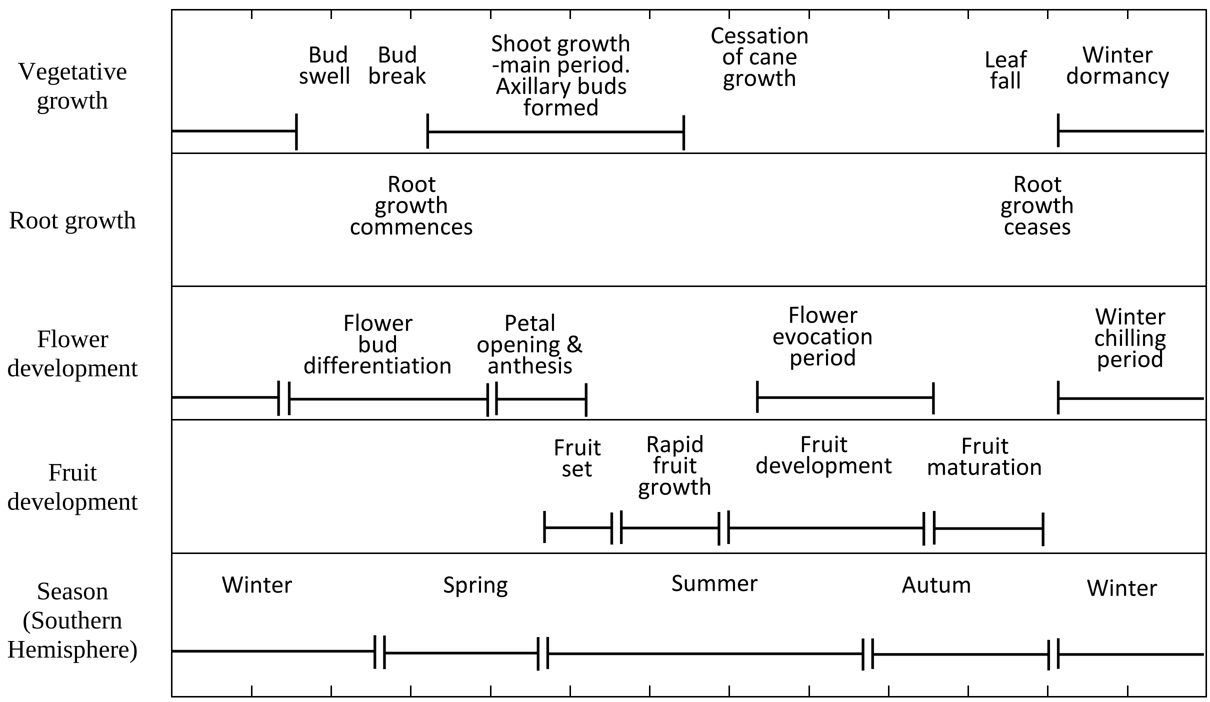

Fig. 1. The annual growth cycle for *Actinidia deliciosa* cv. ‘Hayward’ (Davidson, 1990).

Flowering in Kiwifruit

Flower development of genus *Actinidia* is occured over two growing seasons, which may be separated with varying amounts of time. In the first growing season, the meristematic tissue in axillary buds undergoes the process of evocation by changing to the reproductive stage. There is no a visible change occurs in the bud at this time. Also, floral evocation appears to occur at about the time that the subtending leaf ceases expansion (Snelgar and Manson, 1992). The floral evocation in *A. deliciosa* 'Hayward' is initiated at the beginning of spring. At this time, the meristem in axillary bud at 13^{th} node from the basal of shoot perceived the floral stimulus from the lateral leaves. Consequently, meristems at 5^{th} to 12^{th} nodes within the bud changed from vegetative to reproductive tissue without any morphological changes until the time of bud movement in the following spring (Hopping, 1990). Floral evocation in the genus *Actinidia* is varying among the species. The defoliation technique has been used to evaluate the time of evocation in *Actinidia* species (Walton et al., 1997). Snelgar and Manson (1992) reported that floral evocation in *A. deliciosa* 'Hayward' in the Bay of Plenty, New Zealand occurs during December and January. Also, the shoot tipped technique was used to investigate floral evocation time by Walton (1995) and described that evocation in *A. eriantha* occurred during last spring and early summer. However, the floral evocation can be affected by the factors associated with the condition of the whole vine, or individual shoots (Fig. 2) (Hopping, 1990; Snelgar and Manson, 1992).

Flower development is also the key factors in kiwifruit cropping cycle to achieve a maximum fruit production. Generally, flower bud has undergone evocation in the previous season and remain in dormancy through winter season. In the spring of the following season, the reproductive meristems of flower buds rapidly increase their size. The swollen reproductive meristems developed into acropetal order and a pair of protuberances become bracts and lateral flowers. The first primordia developed into sepals, and then primordia between and inside sepal bases subsequently developed into petals. The petals of *A, deliciosa* cultivar 'Hayward'were initiated, approximately five days after shoot bud burst. At this stage the colour of developing flower buds changed from a translucent white to opaque light green and covered with dense red hairs. At the time of petals differentiation, the stamen appeared on the meristem as two whorls for pistillate and three whorls for staminate flowers. Thereafter, a whorl of stigma initials around the periphery of the meristematic dome has been developed in both pistillate and staminate flowers. In the pistillate flower, the stigma whorls rise to form a superior ovary above the stigmas and styles. Whereas, the staminate flowers the stigma whorl fails to developed into the ovary. Ovules become apparent in the ovary approximately 45 days after bud burst. By this time stamens expand slowly and differentiate into anthers and filaments about 35 days after bud burst. Anther head develop into two-lobes, four-loculed structure, and pollen grains soon form while the ovary develop into locule. The sepals begin separate to reveal the petals, the pollen grains separate in the anther heads, and the stamen filaments expand rapidly, especially over the last 5 days after bloom (Fig. 2) (Brundell, 1975; Hopping, 1990).

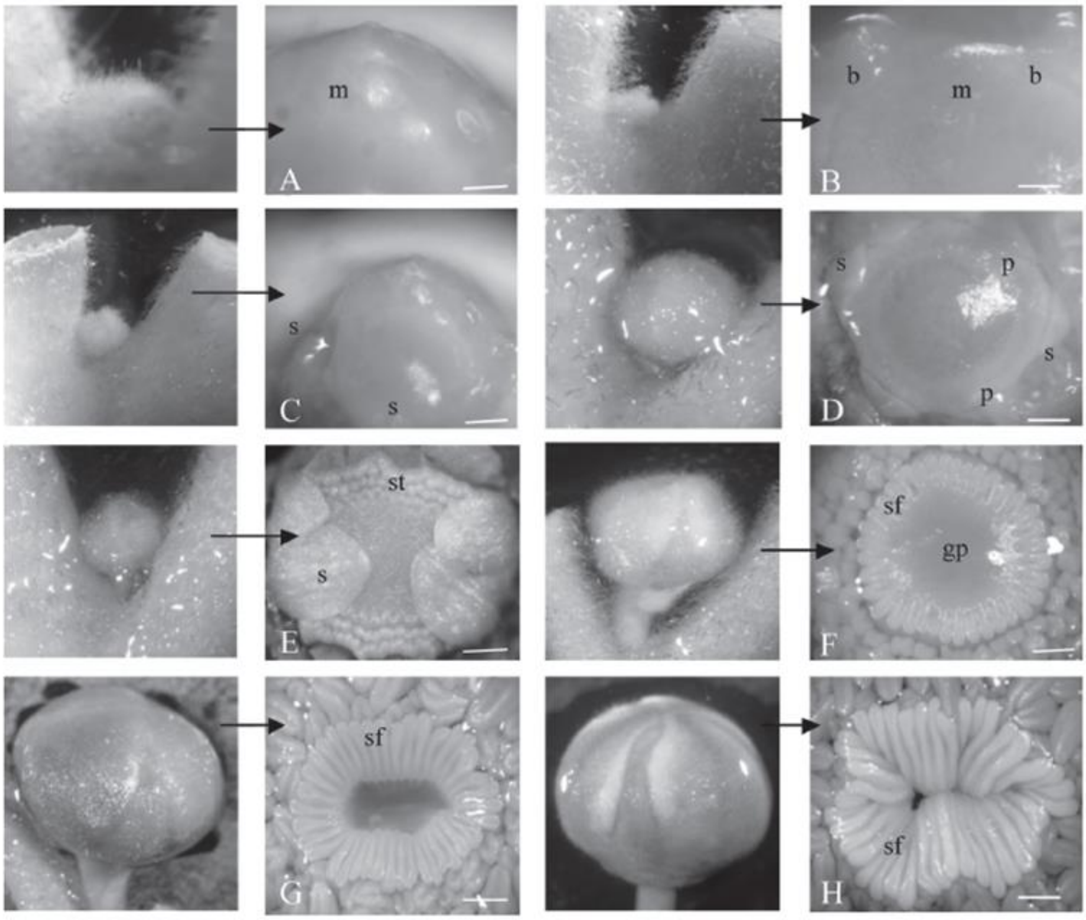

Fig. 2. Flower development of *Actinidia deliciosa* cv. 'Hayward', A) initial phase of stage meristematic tissue (m) change from vegetative to reproductive stage, B) flower primodia enlarged and initiation of bracts (b), C) sepal (s) priodia initiation, D) petal (p) primodia initiation in pentagonal whorl, E) stamen (st) primodia, F) stigma formation (sf) and gynoecial plateau (gp), G) pistil enlargement and differentiation, H) pistil continuing to develop, stigma developing, and ovule formation (Engin et al., 2010).

Factors Affecting Flower Evocation and Development

Previous Crop Level and Biennial Bearing. Floral evocation occurs approximately during the way of fruit growth cycle. At that time a heavy crop level might cause the competition for assimilate supply between fruit growth and floral evocation. Although, the various hormone factors associated with fruit development might cause the competition for metabolites, or that specific compound suppresses flower development (Davidson, 1990; Hopping, 1990).

Leaf Area. Loss of leaves or part of leaves through the damage by wind, water stress, pests, or diseases affected to the reduction of the number of flowers due to the decreasing of leaf-derived floral stimulus (Davidson, 1990). However, Snowball (1996) reported that floral evocation might not be occured in the previous summer but could occur immediately prior to flower differentiation in spring due to the loss of photosynthates.

Time of Cane Initiation and Shoot Growth. Shoot productivity was affected by time of cane initiation in the previous season. Shoots that developed from canes initiated early in the growing season were longer and had larger basal diameters than shoots that developed from late canes due to the subtending leaves on early cane having photosynthate for longer period and buds have a greater supply of photosynthates which results high production of flowers and fruits (Walton et al., 2000). Further, Snelgar et al. (1992) also reported that shoots which grow late in the growing season may evocate flower later in the season due to a high competition for carbohydrate supply between fruit growth and vegetative growth.

Photoperiod. The degree of exposure of vines to light might affect to floral evocation in kiwifruit (Davidson, 1990). Snelgar et al. (2007) reported that long duration of photoperiod affected to floral evocation which caused the reduction of flowering in the following season in *A. deliciosa*. Also, shading reduces the percentage of shoots bearing flowers and the number of flowers per flowering (Snelgar et al., 1991).

Temperature. Temperature has a strong influence on the regression of the rate of development from bud break to flowering (Mcpherson et al., 1992). Low temperature delays bud break, a 1°C drop in main daily temperature delays flowering by 10-12 days and reduced the proportion of flowering shoots (Davidson, 1990).

Fruit Growth and Development

Physical Development. The important commercial characteristics of fruits, i.e., shape and size depend on cell multiplication and enlargement of fruits. The fruit growth of *Actinidia* was observed in cultivar 'Monty' and 'Hayward'. The kiwifruit growth curve from full flowering to maturity is a double sigmoid curve (Hopping, 1976; Jao, 1990; Richardson, 2011) or a triple sigmoid curve (Pratt and Reid, 1974). Hopping (1976) described a double sigmoid growth curve for the fruit growth of 'Monty'. At 0-58 DAA, fruit growth rate has rapidly increased due to cell division and cell enlargement initiated in the outer pericarp, inner pericarp, and central core for 23, 33, and 111 DAA, respectively. At 58-76 DAA, the fruit growth curve was characterized by reducing rate due to a slowing of cell enlargement in both inner pericarp and central core. At 76-160 DAA, the fruit growth curve is increasing again due to cell enlargement in the inner pericarp. Richardson et al. (2011) reported a sigmoid fruit growth curve for *A. chinensis* cv. 'Hort16A' the slower growth curve was observed at 60-140 DAA. At about 155 DAA, the fruit weight has slowly increased and remain constant at about 237 DAA and over 95% of seeds have turned into black at this time. Seed change in color, firstly from white to brown then finally to black as the fruit approach maturity. However, there are no changes observed in the appearance of either the vine or the fruit except only few changes in internal appearance as flesh and seed color (Beever and Hopkirk, 1990).

Chemical Changes. Change in the component concentration in fruit appears to be related to the changes in fruit growth. The most marked change occurs in carbohydrate, especially the starch and sugar components. Fruit accumulates large quantities of starch that are converted to soluble sugars during the latter part of the growing season. At 15-44 days after anthesis, the fruit starch content constantly remains, whereas glucose and fructose contents are increased while the sucrose content is decreased. During 112 days after anthesis (DAA), starch content reached 50% of the total dry matter while glucose content decreased slowly while fructose and sucrose content slightly increased. Then, the starch content rapidly decreased during 119 and 140 DAA resulted an increasing in glucose, fructose and sucrose contents. Between 161 and 210 DAA, the sugars content increased by about 50% and a decreasing in starch content was observed at this time (Beever and Hopkirk, 1990; Antognozzi et al., 1996).

Few changes in the concentrations of other components during fruit growth also were reported. Richardson et al. (2011) reported an accumulation of quinic acid and citric acid during the early stage of fruit growth following a rapid decreasing of quinic acid content before the fruit maturation and it remain constant until fruit maturation and citric acid content remain constant until fruit maturation. Moreover, according to Ferguson (1980), during kiwifruit growth the calcium content was highest until fruit maturation while potassium and phosphorus did not show a marked pattern whereas potassium is proportionately higher in the flesh than other.

Carbohydrate Reserve

The annual growth cycle of temperate woody plants was adapted to accommodate seasonal changes in environmental conditions. The accumulation of reserves within the perennial organs of a woody plant might be used throughout the plant and over the season (Loescher et al., 1990). Kiwifruit plants store carbohydrate reserve in bark, wood and root tissues for sustain the vine during winter and provide substrate for the intense growth activity in the spring which occurs before the new leaves perform their functions in photosynthesis (Beever and Hopkirk, 1990). Generally, starch is the main storage reserve and other materials such as nitrogenous compounds, proteins and fats are also stored (Davdson, 1990). Ryugo (1994) demonstrated the amount and pattern of starch storage depend on cropping and sunlight exposure. Kiwifruit shoots begin to store starch as the basal leaves reach one-half to three-fourths of full size. As the rate of shoot elongation diminishes in late fall the starch level usually reaches a maximum value. Starch is stored in summer and early fall in kiwifruit shoot in converted to sugar in late September and early October as nights become cooler. The interconversion of starch to sugar proceeds so that minimum starch and maximum sugar contents were attained by January. In kiwifruit canes starch reaches the second maximum at bud break then both starch and sugar contents are at a minimum by full bloom due to the soluble carbohydrates are consumed for growth and for respiratory substrate (Fig. 3). Following the explanation given by Smith et al. (1992), the starch content in stem of kiwifruit was greatest at the period of fruit harvesting and approximately 30% of the total starch content decreased during winter and early spring. Also, Piller and Meeking (1997) described that shoot elongation progresses from budburst to constant rate until about 7 weeks after budburst then the rate start to decline, whereas the first 3-4 week after budburst shoots utilize carbohydrate reserve to promote shoot growth. The limitations in carbohydrate reserves during this time might have a negative impact on floral evocation and fruit weight, and fruit size, thus bud break in spring was depended on mobilization and utilization of carbohydrate reserve metabolites synthesized during the previous season.

Factors influence the balance between photosynthesis and the use of photosynthates directly influence the level of carbohydrate reserves. Leaf area is one of the most important factors of carbohydrate reserve content. Factors affecting the leaf area, such as defoliation, leaf loss by water stress, and excessive pruning directly influence the reserve of the vine (Davison, 1990). Tombesi et al. (1994) reported that at the condition of low leaf area index, the sink strength of fruit was greater and more extended so that vine growth and the plants reserves were restricted. In addition, the presence of the reproductive organs such as flowers and fruits decreases carbohydrate reserve in all vegetative tissues (Monerri et al., 2011).

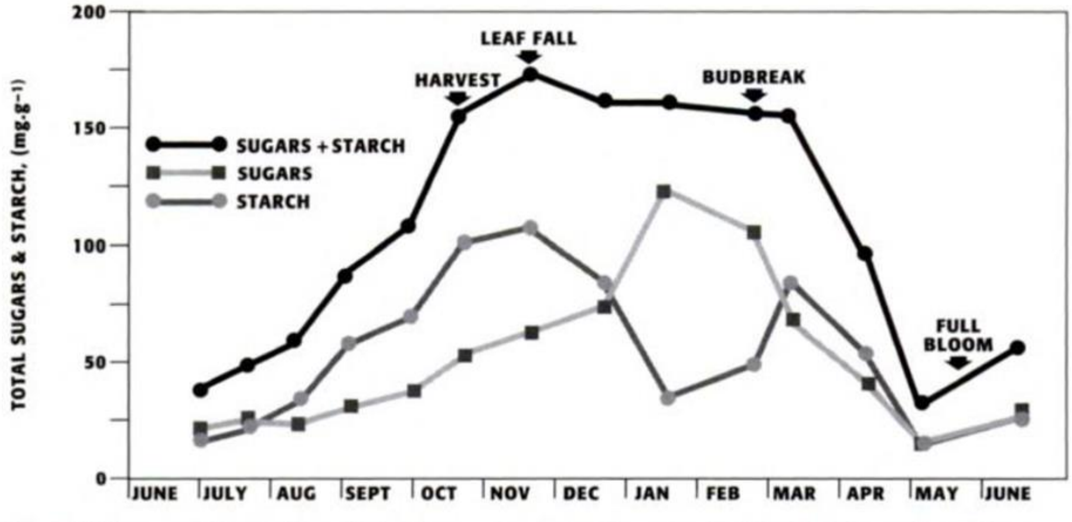

Fig. 3. Seasonal fluctuations in total starch and sugar content in kiwifruit branches (Ryugo, 1994).

Impact of Defoliation on Plant Growth

Defoliation affects to plants by eliminating their carbohydrate production capability. The severity of leaf loss depends on the number of leaves loss, ontogenic stage of plant, and the effects of any additional stress factors which influence the tree (Smith, 1972). There are two types of defoliation, i.e., natural defoliation and artificial defoliation. Natural defoliation usually caused by diseases, insects, animals, and unfavorable weather, whereas the artificial defoliation is often used to simulate defoliation by nature and is usually considered a good indicator of a plant's response to a given type of damage due to the direction of response to artificial defoliation and natural defoliation is very similar (Quentin et al., 2010).

Plant response to defoliation by producing a new leaves as the regrowth for replacing of plant biomass loss. The regrowth occurs immediately following defoliation and they also utilize carbohydrate reserve in plant for their development, whereas the capacity of regrowth strongly related to the different pattern of defoliation (Boege, 2005; Pankoke and Muller, 2013). Gazzoni and Moscardi (1998) reported that any level of defoliation applied at vegetative stage in soybeans cv. 'Parana' can recovery to potential LAI while leaf area recovery could not reach their potential LAI up to the end of the plant cycle in reproductive stage application. Although, 75% defoliation at the both periods of fruit set and veraison including 50% defoliation at fruit set stage caused the reduction in total cane length and average internode length of 'Thompson seedless' grapevines (Kliewer and Fuller, 1973). Howerver, plant was applied with some level of defoliation can be compensated photosynthates losses by increasing the photosynthetic rate of remaining leaves (Yuan et al., 2005).

The initiation of shoot growth and young expanding leaves after defoliation appear to be a powerful metabolic sink which can influence the pattern of metabolic movement in plant and also influence the other sinks development such as fruit and flowering (Brundell, 1975). In the condition of source limitation, there is the competition for carbohydrate supply among the sinks. Vegetative sink had a greater ability to attract carbohydrate supply than other sinks such as fruit and flowering. Minchin et al. (2010) described sink priority as their ability to compete for carbohydrate supply when it was limited. The differences of sink priority type explained by Michaelis-Menton kinetics, the parameter km that describes carrier binding and Vmax that describes flow resistance of sinks. Sinks utilize the same carrier, then the effective of km will be the same. Though, the km of the sinks was assumed to be the same, then the sink with the lower Vmax had higher priority for the limited carbohydrate supply. Buwalda and Smith (1990) reported the rank of sink priority in kiwifruit in descending order as, shoots, fruit, roots, and flowering. Several studies have reported the effects of defoliation on kiwifruit. Cruz-Castillo et al. (2010) reported that the severe defoliation in the summer season on ‘Hayward’ kiwifruit vines caused the reduction of carbohydrate reserve, especially starch in the trunk bark due to the intense competition for carbohydrate supply among the tissues where the starch is accumulating (i.e. shoots and trunk) and the growing fruit. The fruit sink has a minor effect on fruit size and final fruit yield, whereas bud fertility in the following year was much more marked by the severe defoliation. Kwack et al. (2013) demonstrated on non-bearing fruit of ‘Goldrush’ kiwifruit, the number of flowers per floral shoot in the following year was reduced by defoliation where the reduction was more severe in the higher level defoliation. The high level defoliation initiated the marked reduction of carbohydrate supply, especially starch and sucrose in cane bark tissue and even though they can recover by about one month after defoliation, the fruit quality was decreased at the harvesting time (Srisook et al., 2015). The results also supported by Tombesi et al. (1993) as the flower sink is the most sensitive to a lack of carbohydrate supply among vegetative sink and fruit sink.

The sequentially defoliation was also used to determine the time of floral evocation in kiwifruit (Davison, 1990). Buds from shoots defoliated in the previous growing season were considered to have been evoked if they produce at least one flower in the current season. However, there is the limitation in using defoliation technique to determine floral evocation time in kiwifruit, hence floral evocation can be nullified when the vines were defoliated for long periods after evocation has occurred (Snelgar and Manson, 1992).

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CHAPTER Ⅰ. Effect of Artificial Defoliation on Vine Regrowth and Fruit Development in 'Jecy Gold' Kiwifruit

Abstract

Leaves of kiwifruit have long petiole and large size, so that they are easily damaged by strong wind. This study was performed to evaluate the effect of leaf loss by typhoon damage on fruit quality and yield and new shoot growth with artificial defoliation. Five-year-old 'Jecy Gold' kiwifruit vine grown in plastic house were used in this study. Artificial defoliation was done on August 23 (100 days after anthesis) at the different defoliation levels, such as 0 (control), 50,75, and 100%. Vine regrowth by axillary bud burst, cane bark carbohydrate reserve, and fruit quality and yield were investigated. Severe defoliation at 75 and 100% level showed significantly higher axillary budburst than the control and the 50% defoliation. Especially, the 100% defoliation induced a few abnormal off-season flowering. Starch and sucrose contents were significantly declined during the first 2 weeks after defoliation at the 75% and 100% defoliation. However, other soluble carbohydrate reserves, including fructose, glucose, and myo-inositol were not affected significantly. Fruit drop was promoted and the mean fruit weight, firmness, and total soluble solid were lower by defoliation. Our results indicated the loss of leaves above 50% would induce a transient shortage of assimilate supply and reduce fruit quality and yield significantly.

***Additional key words*:** abnormal off-season flowering, axillary bud burst, carbohydrate reserve, fruit quality, fruit yield

Introduction

The kiwifruit is an important fruit crop cultivated in southern coastal areas including Jeju, in Korea. Since kiwifruit vines bear the wide and big leaves, they are very vulnerable to strong winds which frequently occur in the summer typhoon season in Jeju. The Jeju Island has been trespassed by typhoons every year and its frequency and severity depended on the particular year (Kwack et al., 2012, 2013). Strong wind not only affected on carbohydrate sources in the plant via the defoliating of partial tearing of leaves, but also induced fruit drop. However, fruit drop is not a severe as the leaf damages, because immature young fruits are small and not heavy in the summer typhoon season. The fruit yield and quality generally depend on the supplement of carbohydrates from leaves (Brundell, 1975; Cruz-Castillo et al., 2010). During the whole growing season, carbohydrate balance between the supply and consumption is a critical factor affecting on the fruit yield and quality in both current and following years. The defoliation caused by the strong winds may lead to the imbalance of the carbohydrate metabolism and reduce the fruit yield and quality. After severe defoliation, kiwifruit vines respond to produce more new shoots to recover the carbohydrate metabolism to supply the demand of carbohydrates arises from the developing fruit. Until the newly emerged leaves become fully functioning, there is a shortage of carbohydrates in the sink of the vines. Therefore, a severe defoliation could induce a temporary suspension of a carbohydrate supplement to fruit before securing the enough number of fully expanded leaves and the level of temporary suspension eventually affects the yield and quality of fruits.

There are two kinds of cultivated kiwifruit varieties, such as yellow flesh variety (*Actinidia chinensis*) and green flesh variety (*A. deliciosa*) and there are also variation in vine growth and development physiology between these two varieties. Cruz-Castillo et al. (2010) reported the partial defoliation could reduce the fruit starch and soluble sugar concentrations and the severe defoliation reduced fruit weight in ‘Hayward’ kiwifruit (*A. deliciosa*). Kwack et al. (2013) applied the defoliation on a young kiwifruit vine of ‘Goldenrush’ (*Actinidia chinensis*) and found out that the cane regrowth with axillary bud sprouting was affected by the level and time of defoliation. It is not well understood about the consequence of defoliation of kiwifruit vines, especially on the yellow flesh variety.

The objective of this study was to evaluate the effects of leaf loss on vine regrowth, fruit quality and yield in ‘Jecy Gold’ kiwifruit (*Actinidia chinensis*) by artificial defoliation.

Materials and Methods

Plant Material and Defoliation Treatments

The experiment was carried out at National Institute of Subtropical Agriculture (NISA), RDA in Jeju, Korea. The trail work was carried out on 5 years old 'Jecy Gold' kiwifruit (*A. chinesis*) vines, trained to the pergola system in plastic house. Four different defoliation treatments were applied, such as 0 (control), 50, 75, and 100% on August 23 (100 days after anthesis, DAA) by removing leaves including petioles at the petiole junction with canes. Leaves were removed at regular intervals. For example, in the 50% defoliation, leaves were removed at one leaf intervals and in the 75% defoliation three leaves intervals by removing three consecutive leaves. There were three replicates of each treatment arranged in a randomized complete block design.

Measurement of Vine Regrowth, Fruit Development, and Quality

Occurrence of abnormal off-season flowering was carefully monitored during the period of new shoot development. As new shoot stopped growing completely, percentage of axillary budburst and shoot length and diameter, node interval, number of leaves, and leaf area from new shoots were measured from five shoots. Ten fruits from each vine were harvested on November 9 and fruit quality indices including weight, length, diameter, firmness using a texture analyser (TA-XT 20042, Texture Technologies Co., USA) with a 3 mm diameter probe, total soluble solid (TSS) using a refractometer (JA0912, G-won Hitech Co., Ltd., Seoul, Korea) and dry matter content were determined. Percentage of fruit drop [(numbers of fruit drop/ total fruits) ×100] was recorded in the harvesting time commencing from September 1 to November 4.

Measurement of Carbohydrate Reserve

Bark tissues of canes were collected right before defoliation and 3, 14, 30, and 60 days after defoliation, or 100, 103, 117, 134, and 149 DAA, respectively, and were grounded after freeze drying at -80°C. For determination of soluble sugars (glucose, fructose, myo-inositol, and sucrose), 1 g powdered sample was mixed with 10 mL of 80% ethanol and was shaken at room temperature for 30 min and then centrifuged at 10,000 × g at 4°C. The supernatant was passed through 8 μm filter paper (Tokyo Roshi Kaisha, Tokyo, Japan) and extraction was repeated 2 times. The supernatant was taken to dryness, resuspended in water, and then filtered through C18 Sep-Pak cartridge (Waters, USA) and 0.2 μm syringe filter. Soluble sugars were determined by a high performance liquid chromatography (HPLC) with ReproSil carbohydrate column (5 μm, 250 × 4.6 nm, Dr. Maisch GmbH, Ammerbuch, Germany). The mobile phase was 78% (v/v) acetonitrile/water at a flow rate of 1.2 $mL \cdot min^{-1}$. Starch consisting of amylose and amylopectin was determined as described by Megel (1991).

Statistical Analysis

All data were analyzed by ANOVA using Statistix® 8 (Analytical Software, 2013) and the mean differentiation was done by LSD test, at the 5% level.

Results and Discussion

Vine Regrowth

The regrowth of kiwifruit vine could be recognized with the commencement of axillary bud burst in the first week after defoliation. The defoliation promoted axillary bud burst in lateral canes and the bud burst rate was significantly increased at the 50, 75, and 100% defoliation, from 1.4 to 21.1, 65.6, and 77.8%, respectively (Table 1). Meanwhile, shoot length was declined with the severity of defoliation but it was not significantly different among the treatments. Node interval was significantly different decreased at the 0 (control), 50, 75, and 100% of defoliation, from 40.3 to 31.3, 25.0, and 16.4% respectively. Number of leaves was similar in all treatments. However, leaf area was significantly different between the control and defoliation vines. There was no significant difference on DM between the control and defoliation treatments. Specially, a few of abnormal off-season flowering was observed only at the 100% defoliation (data not shown).

Kwack et al. (2013) showed the similar tendency in young and no fruiting vines of *A. deliciosa*, in which budburst rate was increased when the vines were subjected to severe defoliation. Based on the phonological stated of the kiwifruit vine, the commencement of budburst was determined as break of axillary buds enclosed by scales covered by brown trichomes (Salinero et al., 2009). Buwalda and Smith (1990) reported that the severe defoliation of kiwifruit vine resulted in the appearance of leaves characteristic of juvenile plant, because shoots have highest competitive strength among shoots, fruit, roots, and return bloom. The clear explanation on vine response of vine regrowth from severe defoliation was not provided in these previous studies. However, it might be presumed that some substance inhibiting axillary bud burst might exist in leaves and then vine regrowth was induced when the leaves were removed. Kwack et al. (2013) also suggested that axillary bud regrowth induced by severe defoliation was related to dormancy depth of the vine. Hunter and Visse (1990) described that removal of the leaves in grape vine might reduce the substances such as auxin which inhibits lateral bud growth. Abscisic acid produced in mature leaves might be translocated and accumulated in the buds of deciduous trees in early fall (Loveys et al., 1987; Pospisilova, 2003). These plant growth regulators were not determined in this study and then further study might be needed to interpret their roles. Piller and Meekings (1997) described that partial defoliation had a negative impact on kiwifruit vine growth by reducing the rate of shoot internode expansion and shoot elongation due to the limited of local carbon supplies.

Therefore, the results of this study suggested that reduction in vine regrowth, such as shoot length, node interval, and leaf area was related to intense competition for assimilate among the sink organs including fruit, shoot, and roots.

Table 1. Regrowth of 'Jecy Gold' kiwifruit vine as measured at fruit harvesting time after artificial defoliation of different levels.

Defoliation level (%)	Budburst (%)	Shoot length (cm)	Node interval (mm)	Number of leaves	Leaf area (cm^2)	DM[z] (%)
0 (control)	1.4±0.4[y] c[x]	48.9±9.7	40.3±3.4 a	12.4±1.7	108.4±2.8 a	29.3±2.0
50	21.1±7.1 b	34.3±2.4	31.1±3.4 a	11.0±0.7	89.1±4.3 b	26.9±2.2
75	65.6±9.3 a	23.6±2.3	25.0±1.9 b	10.1±0.9	89.9±5.1 b	26.8±1.8
100	77.8±4.7 a	15.0±6.0	16.4±3.4 b	8.5±1.5	76.6±4.5 b	26.2±0.8

[z]Dry matter content = DW/FW × 100.

[y]Mean±SE (n=3).

[x]Means with different letters differed significantly ($P \leq 0.05$) by DMRT.

Carbohydrate Reserve

Starch content was calculated by summing amylose and amylopectin contents. The result showed that starch appeared only as amylopectin type in kiwifruit cane bark (woody storage tissue). During September, starch content of cane bark was gradually decreased and recovered in October above the level of that in September with rapid increase in normal vines without any artificial defoliation. However, just severe defoliation with 75 and 100%, not 50%, decrease significantly starch content only at 3 days and 2 weeks after defoliation for short period and there was no significant differences in the other period (Fig. 4).

The contents of soluble sugars including glucose, fructose, sucrose, and myo-inositol in cane bark were measured and the highest sucrose content was found in the bark of kiwifruit cane (Fig. 5). The changes of soluble sugar contents were different from that starch content in a normal condition without any defoliation. While sucrose maintained a content level, fructose showed the tendency of slight decrease. Defoliation induced the different response from individual soluble sugar (Fig. 5). Distinct changes were observed only at the first 2 weeks of period, when axillary buds sprouted and new shoots grew rapidly in kiwifruit vines. There were significant decrease in sucrose contents, whereas on differences in the other soluble sugars.

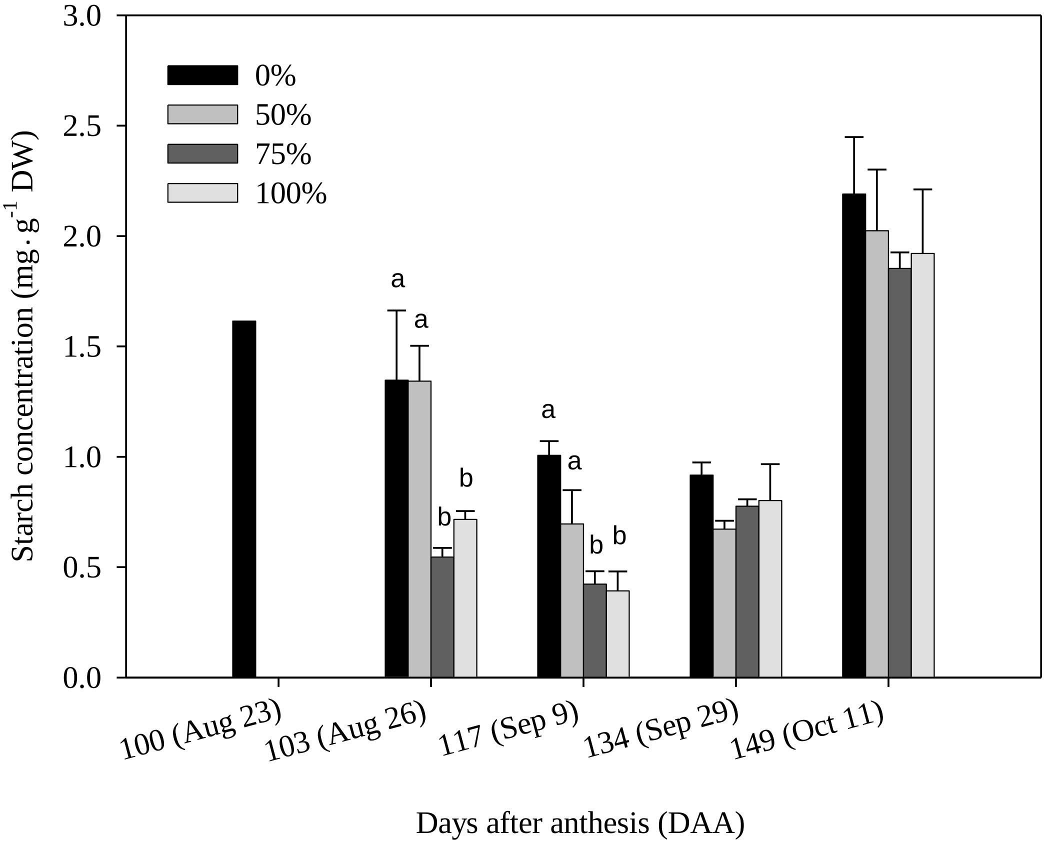

Fig. 4. Changes of starch content in cane bark of 'Jejcy Gold' kiwifruit after defoliated artificially at 0, 50, 75, and 100% on August 23. Each sampling date (DAA) column with the same letters was not significantly different at $P \leq 0.05$.

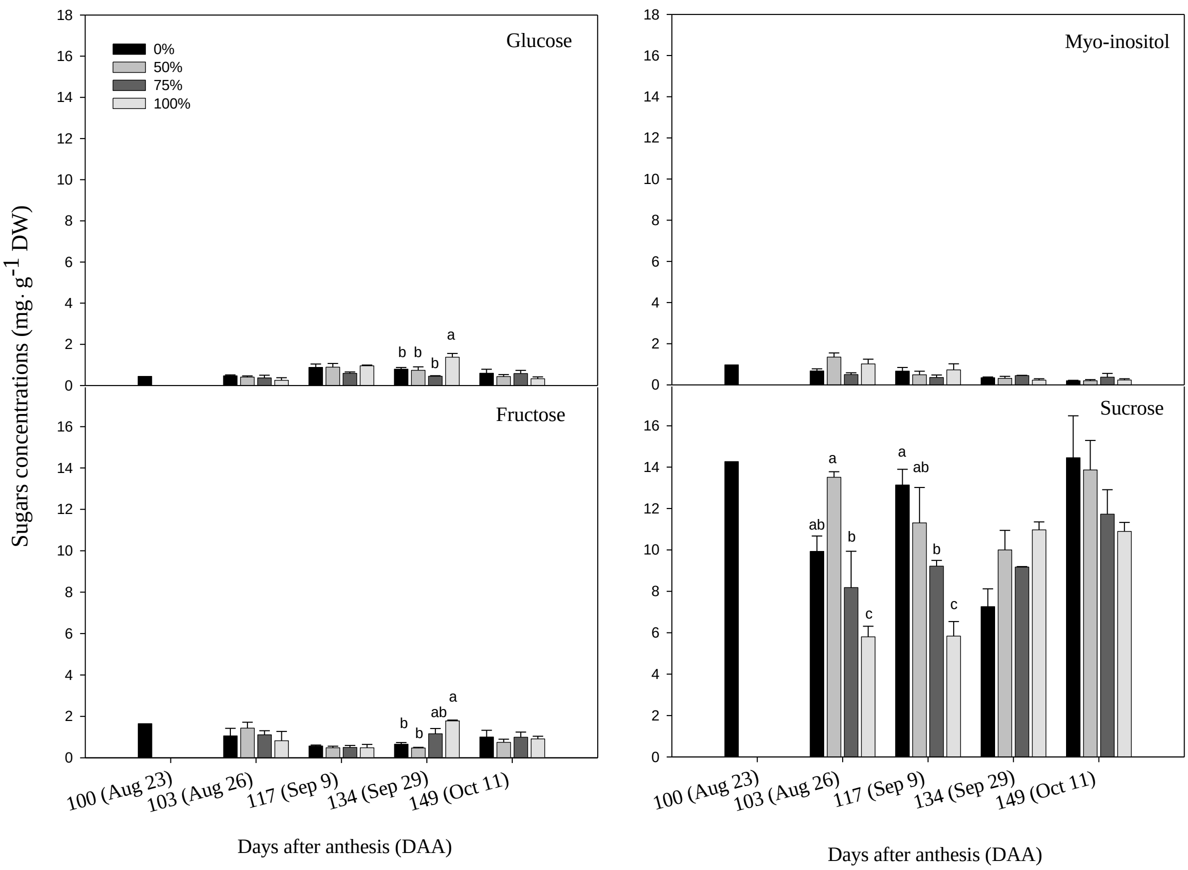

Fig. 5. Changes of soluble sugar (glucose, fructose, myo-inositol, and sucrose) content in the cane bark of 'Jecy Gold' kiwifruit defoliated artificially at 0, 50, 75, and 100% on August. Each sampling date (DAA) column with the same letter was not significantly different at $P \leq 0.05$.

Severe defoliation was thought to limit carbohydrate supply greatly with destruction of carbohydrate source and then there would be a rush of carbohydrate demand. Many axillary buds sprouted in one week after defoliation and new shoots and leaves has grown rapidly in next one week or two weeks (data not shown). Mostly leaves could not export their photosynthates to the other sinks such as bark, roots, and fruits before full expansion (Brundell, 1975). Therefore, the period of rapid regrowth for 2 to 4 weeks after defoliation could be allocated to great rush of carbohydrate demand, which will be satisfied with consumption of carbohydrate reserve. Starch and sucrose being major carbohydrates in cane bark, were significantly declined by severe defoliation for the first 2 weeks (Fig. 4 and 5). These results were in accordance with Kwack et al. (2013) reporting that the young leaves on the shoots newly emerged after defoliation might provide a new source for photosynthesis. Cruz-Castillo et al. (2010) and Smith et al. (1992) suggested that, when severe defoliation occurred, the concentration of starch and soluble sugars could be significantly reduced, especially at the fruit development stage grow in the trunk bark of 'Hayward' kiwifruit. Starch concentration in cane bark was highest at the harvesting time, i.e, immediately after harvesting of fruits. At that time, competition of assimilates was not great among the other organs because starch is accumulating in the bark due to loss of fruits, the biggest sink organ. Mehouachi et al. (1995) described that defoliation decreased sucrose content in woody tissues of citrus trees, because the fruit utilized photosynthates from other storage sink and carbon retranslocation from storage organs into fruits was the basic response of the woody species. Myo-inositol concentration was maximal in early fruit development to maintain cellular turgor, especially during rapid cell enlargement (Boldingh et al., 2000; Cui et al., 2013) The result showed that myo-inositol in cane bark did not respond greatly to defoliation, as similarly reported by Boldingh et al. (2000).

Fruit Growth and Quality

Fruit quality was affected by different artificial defoliation treatments (Table 2). Fruit abscission was significantly increased with 100% defoliation. Mean fruit weight was significantly decreased with the defoliation treatment. The highest fruit firmness values were observed at the 100% defoliation. Significant reduction in TSS was shown at both 75 and 100% defoliation treatment by 58.8 an 62.8%, respectively. Dry matter content was significantly decreased with the 75 and 100% defoliation treatments by 85.7 and 81.9%, respectively.

Kwack et al. (2013) and Buwalda and Smith (1990) reported that the defoliation of kiwifruit vine has significantly reduced fruit weight and soluble solid content. Mehouachi et al. (1995) also reported that defoliation in citrus, by commencing the defoliation during the period of anthesis, induced immature fruit drop due to the adequate lack of photosynthates which was associated with reduction of sucrose and starch. The amount of accumulated assimilates could be one of the factors of indices determining the fruit development and fruit quality, especially when the source activity or strength declined. The supply of photosynthates was drastically reduced by defoliation due to severe wind damage of pest attack, which directly affected fruit cell metabolic activities and cell enlargement. The carbohydrate reserve contents of cane bark were decreased during the first 2 weeks after severe defoliation and, thereafter, recovered quickly by full expansion of several leaves (Figs. 4 and 5). Furthermore, bark carbohydrate reserve declined continuously in normal vines without defoliation until a fruit harvesting time. Therefore, our results indicated that the period of fruit enlargement and maturation required a great supply of assimilates and still competed greatly for assimilates between fruits and other sink organs. Especially, the 50% defoliation showed several changes in the level of carbohydrate reserve including starch and soluble sugar, whereas significant decrease in fruit weight as show in Table 2. This results indicated that a decrease of assimilate supply from leaves to fruit might be related to a decrease of fruit yield and quality, because considerable assimilates provided from existed leaves must be metabolized to construct new lateral canes and leaves. Thus, the vines confronted with sudden shortage of carbohydrate supply would promote fruit drop by intense competition and stresses. This situation was sustained for more than 2 weeks from defoliation (Figs 4. And 5) and subsequently, fruit maturation would be delayed but fruit firmness could be retained (Table 2).

In conclusion, severe defoliation did affect axillary budburst and fruit yield and quality significantly in ‘Jecy Gold’ kiwifruit vines with fruit set. The physiological changes were associated with a transient shortage of carbohydrate supply, which was validated by determining the changes in starch and soluble sugars from cane bark for growing season.

Table 2. Effect of artificial defoliation treated on August 23 on fruit growth and quality of 'Jecy Gold' kiwifruit at harvesting time.

Defoliation level (%)	Fruit drop (%)	Mean fruit weight (g)	Fruit firmness (N)	TSS (°Brix)	DM^{z} (%)
0 (control)	0.3±0.3^{y} b^{x}	88.7±3.5 a	18.8±0.3 b	10.2±0.3 a	13.3±0.5 a
50	1.1±0.6 b	77.7±3.3 b	22.8±0.9 b	9.2±0.6 a	13.4±0.4 a
75	4.0±0.5 b	80.4±2.0 b	23.7±0.8 b	6.0±0.5 b	11.4±0.1 b
100	18.3±7.5 a	81.2±0.7 b	24.9±0.5 a	6.4±0.3 b	10.9±0.5 b

^{z}Dry matter content = DW/FW × 100.

^{y}Mean±SE (n=3).

^{x}Means with different letters differed significantly ($P \leq 0.05$) by DMRT.

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CHAPTER Ⅱ. Defoliation Time Induced the Different Response Related to Vine Regrowth, Off-Season Flowering, and Fruit Quality in 'Jecy Gold' Kiwifruit

Abstract

Abrupt leaves loss caused severely by typhoon disrupts the balance of normal physiological development and metabolism in kiwifruit vines. The aim of this study was to evaluate the effects of leaves loss time on off-season flowering, vine regrowth, and fruit quality in 'Jecy Gold' kiwifruit. 'Jecy Gold' kiwifruit vines were subjected to 100% defoliation by artificially on July 28 and August 29, 2014. In October, the occurrence of off-season flowering was observed on vines defoliated just on August 29. There was no significant difference in vine regrowth between both times of defoliation. However, defoliation on August 29 showed a significant reduction in total soluble solids of fruits at harvesting time. Further, there was no significant difference in starch and sugars content of cane bark between both times of defoliation. The results indicated that the floral evocation of 'Jecy Gold' kiwifruit might be occurred in August and the fruit maturity might be delayed by August 29 defoliation compare to the decrease of fruit growth by July 28 defoliation.

***Additional key words*:** carbohydrate reserve, flower evocation, fruit growth, fruit maturity, leaves loss.

Introduction

The responses to leaves loss encompass a large number of physiological and phenotypic changes in fruit crops. Moreover, it has been reported that the abrupt and severe leaves loss caused due to the typhoon damage might cause the great disruption of the physiology and metabolism in growth and development of several fruit crops (Bennett et al., 2005; Minchin et al., 2010; Zhou et al., 2000). The decrease of crop yield and return bloom as well as an abrupt release of axially buds supposed to be dormant and off-season flowering have been reported at the different severity of leaves loss in several fruit crops including kiwifruit (Cruz-Castillo et al., 2010; Kwack et al., 2013; Lyrene, 1992; Zhou et al., 2000). Other than the severity of defoliation, the timing of defoliation might be another main factor influencing the level of loss or damage in vegetative and reproductive growth and development. Kwack et al. (2012) reported that the artificial defoliation of 'Hayward' kiwifruit vines, a green flesh type, in August caused the high reduction of fruit yield such as fruit weight compared to that in September. Furthermore, higher disturbance of starch accumulation in roots was described from the 75% or greater severity of defoliation in August compared to those of July and September in non-fruit bearing young vines of 'Goldrush' kiwifruit (Kwack et al., 2014). Kwack et al. (2012, 2014) indicated that the detrimental phenomena by severe leaves loss might be caused by intense assimilate competition between fruits and growing shoots. However, it is not clear whether the response on assimilate competition will be very similar or not, yet regardless of different cultivars when severe leaves loss is imposed in different developmental stages and combined with an additional factor of flower bud differentiation in kiwifruit vines.

Flower bud differentiation consists of two distinct phenomena including floral evocation (flower bud initiation) and flower bud formation. Even though Snowball (1996) suggested that the floral evocation may not be occur in the previous summer until immediately before flower formation in the spring of the second growing season, it has been generally accepted that floral evocation of 'Hayward' and 'Bruno' cultivars, a green flesh type, occurs in the late summer of the first growing season (Davison, 1990; Fabbri et al., 1991; Snelgar et al., 2007). Moreover, the occurrence of off-season flowering was induced with the severe defoliation of *Actinidia chinenesis* cv. Jecy Gold in late summer by Srisook et al. (2015) and with the removal of the growing point of *A. eriantha* shoots in early summer by Walton (1995). These off-season flowering must have undergone floral evocation before flower development. Generally, green flesh kiwifruits (*A. deliciosa*) are hexaploids and have higher genetic variability than yellow flesh ones (*A. chinensis*) being diploids or tetraploids (Zhen et al., 2004). There have been reported a wide diversity of variation in vegetative morphology among polyploids of other crops (Oh et al., 2014) as well as variation in fruit features among polyploids of kiwifruits (Wu et al., 2012). Therefore, the time and pattern of floral evocation may be different between green flesh cultivars and yellow flesh ones. However, as of present, few studies have been reported on the time of floral evocation in yellow flesh cultivars.

The objective of this study was to evaluate that defoliation time defines floral evocation time through the occurrence of off-season flowering combined with the vine regrowth and that different levels of assimilate competition involved in floral evocation to determine a distinct pattern in change of fruit quality in 'Jecy Gold' kiwifruit.

Materials and Methods

Plant Material and Defoliation Treatment

This experiment was carried out at the National Institute of Subtropical Agriculture (NISA), RDA in Jeju, Korea. Six-years-old 'Jecy Gold' kiwifruit vines (*A. chinensis*) trained on pergola system in plastic green house were used in this experiment. The 100% defoliation including petiole was applied to the vines on July 28 and August 29, 2014, respectively during fruit development season. Two vines were randomly assigned to each treatment arranged in a randomized complete block design. All other cultural practices including winter pruning, flower and fruit thinning, soil management, pest and disease control had been generally managed according to the standard RDA's guideline.

Measurement of Off-Season Flowering, Vine Regrowth, and Fruit Quality

While the axillary buds produced a secondary shoots in the current growing season after the removal of all leaves, occurrence of off-season flowering was monitored and the number of flowers per vine and flower quality such as flower length, flower width, and number of petals and sepals were recorded in October 2014. Vine regrowth was measured for shoot length and diameter with 10 shoots per vine selected randomly in November 24, 2014 when shoots growth was completely stopped. Further, shoot fresh weight (FW), dry weight (DW), and dry matter content (DM) were measured with six shoots per vine selected randomly. Fruit quality was determined with fruits weight, length, width, firmness using a texture analyser (TA-XT 20042, Texture Technologies Co., USA) with a 3 mm diameter probe, total soluble solid (TSS), and acidity using a refractometer (JA0912, G-won Hitech Co., Ltd., Seoul, Korea), and dry matter content (DM) for randomly harvested 10 fruits per vine during the harvesting season (November 4, 2014).

Measurement of Non-Structural Carbohydrate Reserve

Carbohydrate reserve including soluble sugars and starch was measured after the defoliation until vine dormancy as described by Srisook et al. (2015). Bark tissues from canes of replicated vines were collected at 0, 3, 7, 15, and 30 days after defoliation (DAD). Samples were dried and grounded for measuring carbohydrate reserve. Soluble sugars (fructose, glucose, sucrose, and myo-inositol) were extracted with 80% ethanol and were determined by high performance liquid chromatography (HPLC) with ReproSil carbohydrate column with ReproSil carbohydrate column (5 μm, 250 × 4.6 nm, Dr. Maisch GmbH, Ammerbuch, Germany). The mobile phase was 78% (v/v) acetonitrile/water at a flow rate of 1.2 $mL \cdot min^{-1}$. Starch content was determined according to the protocols of Magel (1991).

Statistical Analysis

Statistical analysis was done using *Statistix*® 8 (Analytical Software, 2003) program and the means of vine regrowth were separated by *t*-test at $P \leq 0.05$. Fruit quality data was analyzed by ANOVA and the means differentiation was done by LSD test at $P \leq 0.05$.

Results and Discussion

Vine Regrowth and Occurrence of Off-Season Flowering

All 'Jecy Gold' kiwifruit vines defoliated in July 8 and August 29 showed the rapid vine regrowth through axillary bud initiation within one week after defoliation. The vine regrowth was measured in terms of growth rate and quality such as shoot length, node interval, shoot fresh weight, shoot dry weight, and dry matter content when shoots growth was completed and fruits were at maturity stage (November) and it was not significantly different between two different defoliation times (Table 3). Therefore, the results indicated that the regrowth of 'Jecy Gold' kiwifruit vines was not affected by July 28 defoliation and August 29 defoliation. This might happen due to the capability of shoots to utilize carbohydrate reserve at the condition of a limited carbohydrate supply. Minchin et al. (2010) elucidated that the greater fraction of assimilates was allocated into the vegetative sink than the fruit sink in 'Hayward' kiwifruit vines and this fact was further confirmed in same cultivar by Buwalda and Smith (1990). According to Piller and Meekings (1997), a greater share of carbohydrate reserve which supports the fruit growth might be utilized by shoots at the higher priority.

Off-season flowering was observed just in the August 29 defoliation about one month after defoliation, but not in the July 28 defoliation (Fig. 6). Flower width and flower length was 39.9 and 42.3 mm, respectively while the number of petals and sepal were 6.0 and 5.3, respectively (Table 4). However, the flower size was a little small compared to the flowers of undefoliated vines bloomed normally in spring (data were not shown) and the number of petal and sepal were very similar to those of the flower bloomed in spring. The results were in accord with the report with *A. chinensis* var. *chinenesis* by Polito and Grant (1984). Generally, two stages of flower development were recognized in kiwifruit vines. At the first stage, the floral evocation takes place in the previous growing season by converting vegetative meristems to reproductive meristems. The reproductive meristems develop into floral organs for flowering at the second stage from current growing season to return growing season (Hopping, 1990). Therefore, the occurrence of off-season flowering observed just in the August 29 defoliation, not in the July 28 defoliation, suggested that 'Jecy Gold' has floral evocation between late July and late August of summer season, which was accorded with that reported in 'Bruno' and 'Hayward' (Davison, 1990; Fabbri et al., 1991; Snelgar et al., 2007). However, the evocation time may be varied among the cultivars and shoot developmental stages (Snelgar and Manson, 1992; Walton et al., 1997). Also, in evaluating the floral evocation time using defoliation experiment, the response of floral evocation might be various because defoliation not only removes the source of the inductive signal but also the source of photosynthates (Snowball, 1996). Therefore, further studies using anatomical analysis and shading experiments are required to confirm the floral evocation time of 'Jecy Gold' in the late August even though the repeated occurrence of off-season flowering was observed by severe defoliation in both year of 2013 and 2014.

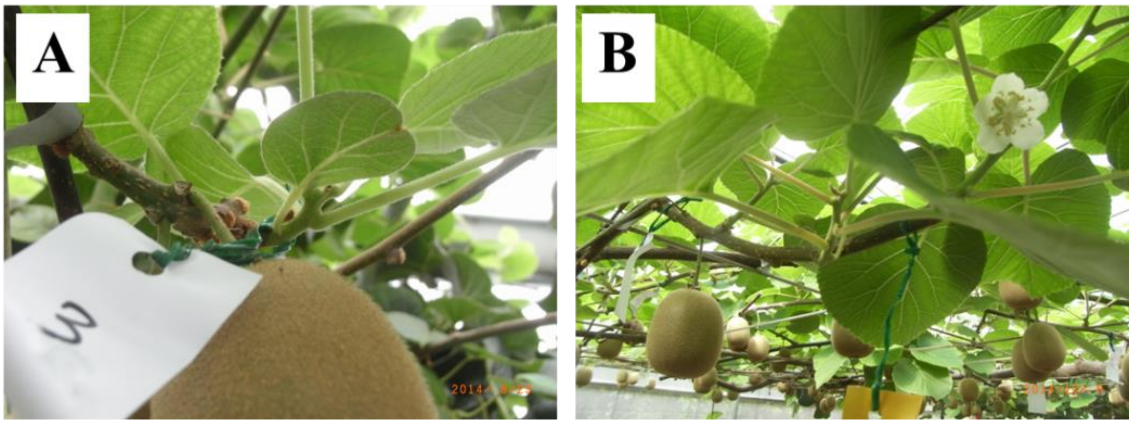

Fig. 6. Bud development without (A) and with off-season flowering (B) in 'Jecy Gold' kiwifruit vines after 100% defoliation treated on July 28 (A) and August 29 (B), respectively. The photos were taken on August 29 (A) and October 6 (B), respectively about one month after defoliation.

Table 3. Vine regrowth measured at the fruit maturity stage dated on November 24 in 'Jecy Gold' kiwifruit vines defoliated at two different times.

Defoliation time	Shoot length (mm)	Shoot diameter (mm)	Node interval (mm)	FW (g)	DW (g)	DM[z] (%)
Control	-	-	-	-	-	-
July 28	46.3±10.7[y]	6.6±0.4	9.3±1.8	0.7±0.0	0.2±0.0	28.5±1.2
August 29	53.4±17.0	6.5±0.3	11.1±1.4	0.8±0.1	0.2±0.0	25.0±1.1
Significance	NS[x]	NS	NS	NS	NS	NS

[z]Dry matter content = DW/FW × 100.

[y]Mean±SE (n=2).

[x]NS indicate non-significant at $P \leq 0.05$ by *t*-test.

Table 4. Description of off-season flowering in 'Jecy Gold' kiwifruit vines defoliated at two different times.

Defoliation time	Number of flowers per vine	Flower width (mm)	Flower length (mm)	Number of petals	Number of sepals
Control	0	-	-	-	-
July 28	0	-	-	-	-
August 29	1.5±0.5[z]	39.9±1.8	42.3±1.9	6.0±0.6	5.3±0.3

[z]Mean±SE (n=2)

Fruit Quality Change and Assimilate Competition

The different defoliation times affected the fruit growth and fruit quality distinctively at the harvesting time (Table 5). Although fruit growth such as fruit length, width, and weight was not affected significantly by defoliation time, the July 28 defoliation tended to decrease the fruit growth compared to the August 29 defoliation. However, fruit TSS was significantly affected by defoliation time and the August 29 defoliation tended to deteriorate the fruit maturity compared to the July 28 defoliation and control. There were no significant differences in fruit firmness, fruit acidity and DM between two different defoliation times and control.

Kwack et al. (2012) reported that the soluble solids content of fruits from defoliation during the mid August to the late September was lower than that from mid July defoliation in 'Hayward' kiwifruit vines. Vrsic et al. (2009) also reported that the fruit quality of 'Chardonnay' grape defoliated at the early stage was lower than that defoliated at the later stage of fruit growth. The cell division and cell enlargement might be greatly affected by the reduction of carbohydrate supply which subsequently might delay the fruit maturity (Minchin et al., 2010). Fruit growth patterns are quite similar between grapes and kiwifruits, both of which exhibit double-sigmoid curve and have a very rapid growth at the early stage of fruit development (Richardson et al., 2011). Kiwifruits attain approximately 65% of final fresh weight about 80 days after anthesis (DAA) equivalent to late July and approximately 80% of final fresh weight about 110 DAA equivalent to late August (Richardson et al., 2011). Therefore, July 28 defoliation at the rapid growth stage might affect the fruit growth much higher than the fruit maturity compared to August 29 defoliation. Contrary, August 29 defoliation at the late fruit expansion and seed coloration stage might affect the fruit maturity much higher than the fruit growth compared to July 28 defoliation and might delay the maturity due to intense sink competition.

Table 5. Fruit growth and fruit quality at harvesting time dated on November 4 in 'Jecy Gold' kiwifruit vines defoliated at two different times.

Defoliation time	Fruit length (mm)	Fruit width (mm)	Fruit weight (g)	Fruit firmness (N)	TSS (°Brix)	Acidity ($g \cdot L^{-1}$)	DM[z] (%)
Control	61.4±0.3[y]	51.3±0.6	94.5±0.8	23.5±0.6	9.3±0.4 a[x]	1.6±0.0	13.9±0.1
July 28	60.5±2.7	48.8±1.9	79.9±14.5	21.2±0.1	10.1±0.6 a	1.5±0.0	13.7±0.4
August 29	59.4±1.7	52.1±0.7	99.3±3.6	23.9±0.3	6.1±0.2 b	1.4±0.0	14.8±1.2

[z]Dry matter content = DW/FW × 100.

[y]Mean±SE (n=2).

[x]Means with different letters differed significantly ($P \leq 0.05$) by DMRT.

Non-structural carbohydrate contents of cane bark was measured to evaluate the assimilates competition during vine regrowth and fruit development. Starch content was not significantly different between July 28 and August 29 defoliation (Fig. 7). In both defoliation times, starch content tended to be decreased at 3 DAD and be increased from 30 DAD. Soluble sugars contents including sucrose, fructose, myo-inositol, and glucose were measured from cane bark and sucrose accounted as the greatest portion of soluble sugars in cane bark of 'Jecy Gold' kiwifruit (Fig. 8). Sucrose content was reduced at 3 DAD and was rapidly increased at 30 DAD. Further, the substantial reduction of sucrose was recorded in the July 28 defoliation than in the August 29 defoliation. The significant differences were not found in fructose, myo-inositol, and glucose contents between two different defoliation times.

According to our previous study, starch and sucrose contents between 0 and 100% defoliation were significantly decreased at 3 days and 14 days after August 29 defoliation and recovered at October 11 (Srisook et al., 2015). Bennett et al. (2005) reported that the early defoliation greatly declined the carbohydrate reserves contents in both root and trunk tissues of grapevines. Kwack et al. (2014) also reported that starch accumulation in roots was major portion compared to that in buds and shoots and was much higher inhibited in August defoliation than in July and September defoliation in non-fruit bearing young vines of 'Goldrush' kiwifruit. Further, it suggested that intense competition might occur in mid July and mid August, but mid July competition could be compensated by the increase of assimilates supply for a little bit longer period from early formed leaves. These previous studies were greatly accorded with the results of the present study. Moreover, the comparison of these results gave an explanation why a statistical significance was not existed in the changed amounts of cane bark carbohydrate reserve contents between two developmental stages despite an existence of tendency showing a different levels of assimilates competition. This may be due to the underestimation caused by the partial assessment of carbohydrates reserve just in cane bark, not in whole vine including roots, trunk, and buds in this study. Therefore, further study is required to evaluate the levels and times of assimilate competition precisely in kiwifruit vines depending on genotypes with different maturities and flesh colorations.

In conclusion, the time of floral evocation might be defined through occurrence of off-season flowering from kiwifruit vines defoliated at the different times and might be around late August in 'Jecy Gold' cultivar. Also, the fruit growth and fruit development might be differently affected with distinctive patterns depending on defoliation time, which might be related to the levels of assimilates competition.

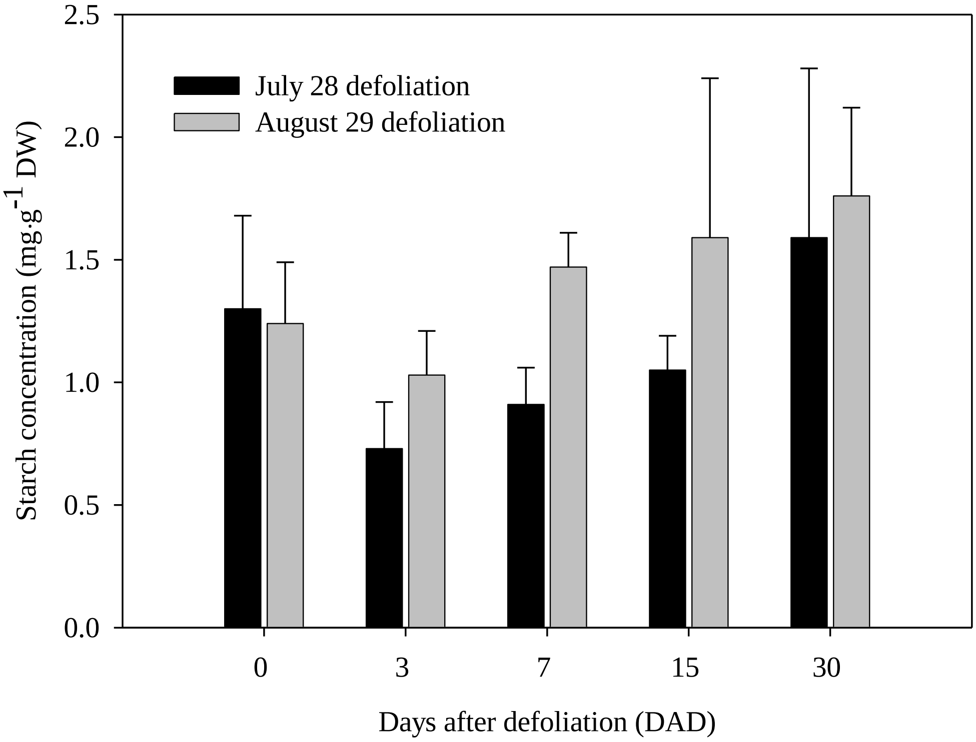

Fig. 7. Change of starch content during vine regrowth and fruit development in the cane bark of ‘Jecy Gold’ kiwifruit vines defoliated at two different defoliation times. Vertical bars indicate SE (n=2).

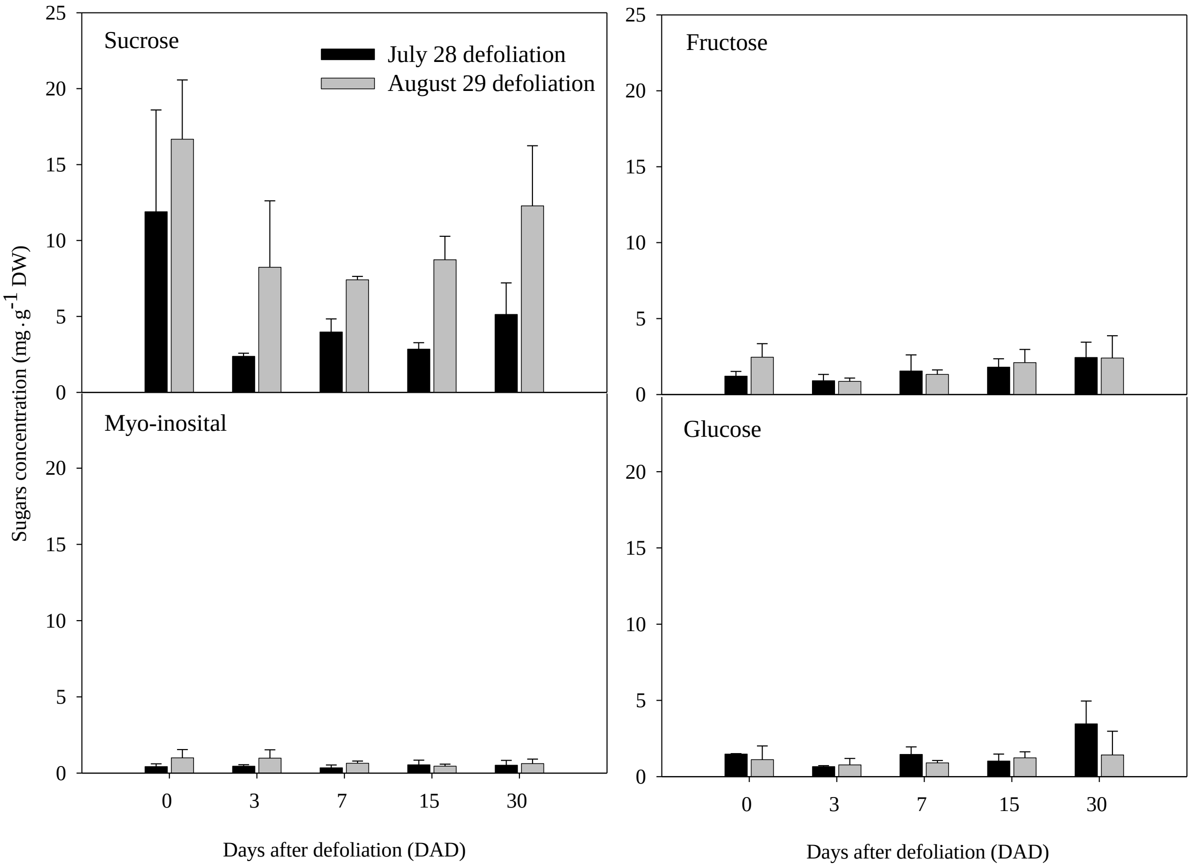

Fig. 8. Changes of soluble sugar contents during vine regrowth and fruit development in the cane bark of 'Jecy Gold' kiwifruit vines defoliated at two different defoliation times. Vertical bars indicate SE (n=2).

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CHAPTER Ⅲ. Effects of Defoliation Levels and Time on Return Bloom and Fruit Quality in the Following Two Years in 'Jecy Gold' Kiwifruit

Abstract

The study aimed to evaluate the damage persistence during subsequent years in kiwifruit vines defoliated by strong wind such as typhoons. Artificial defoliation was treated on five-year-old 'Jecy Gold' kiwifruit vines grown in a plastic house in year 2013 and 2014 by applying four levels of defoliation, i.e., 0, 50, 75, and 100% in August 23, 2013 and 100% defoliation in July 28 and August 29, 2014, respectively. Return bloom and fruit quality were investigated in the following two years, 2014 and 2015. A significant reduction in number of flowers per shoot in the following year, 2014 was recorded for the vines with 50% and 100% defoliations treated in 2013 compared to the control vines. The number of flowers per florescence was significantly reduced for defoliated vines. Nevertheless, the fruit quality parameters, i.e., fruit length, width, weight, firmness, TSS, acidity, and dry matter content were not significantly different for the defoliated vines compared to the control vines. The vines defoliated in 2013 at 75% and 100% levels showed a significant reduction of number of flower per inflorescence in 2015 compared to the 0% defoliation. However, the number of flowers per shoot and fruit quality were not significantly different. Also, the number of flowers per inflorescence in 2015 was significantly reduced by July 28, 2014 and August 29, 2014 defoliation compared to non-defoliated vines while the number of flowers per shoot, and fruit quality in 2015 were not significantly different between treatments and control vines. Accordance with the present findings, the flowering is considerably affected by the shortage of carbohydrate supply than the fruit quality of 'Jecy Gold' kiwifruit. In addition, the negative impacts of severe defoliation in flowering of 'Jecy Gold' kiwifruit might be persisted more than one season from the time of defoliation and consequently, the total yield might be reduced in the following seasons after defoliation.

***Additional key words*:** assimilate competition, floral evocation, flowering, fruit dry matter, fruit size.

Introduction

Kiwifruit vines are easily damaged by strong wind such as typhoon because of a feature having long petiole and large leaf blade. Leaf defoliation and tearing is such a typical wind damage and directly affects the sufficiency of photosynthates to retain normal plant growth and development through temporary destruction and reconstruction of photosynthetic factory depending on damage severity. Severe leaf loss causes the imbalance of carbohydrate supply between source and sink while inducing the competition for the assimilates supply among the sinks. High priority sinks such as shoots can utilize more carbohydrate supply than the lower priority sinks such as fruits, roots, and return bloom. The competition for assimilates supply was much severe at the peak growth phase of sinks.

Generally, the lack of carbohydrate supply has been negatively affected on the fruit quality in the current year and the flowering in following year. Tombesi et al. (1993) reported the reduction in fruit weight and soluble solid concentration in the current year while the reduction of percentage of bud burst in the following year at high level of defoliation in 'Hayward' kiwifruit vines. Furthermore, the reduction of flowering in the following year much greater than the final fruit yields in the current year when the vines subjected to severe defoliation (Buwalda and Smith, 1990; Minchin et al., 2010; Tombesi et al, 1993). According to, our previous study, the regrowth was observed in the first week after defoliation and the amount of carbohydrate supply was not significantly different at 34 days after defoliation (Srisook et al., 2015). Although, the defoliated vines can recover within one month after the removal of leaves, the surpass of negative impact on flowering in the following year is incompetent. The flowering process in kiwifruit initiates with the floral evocation during summer of the current year and completes with the development of floral organs in following year (Hopping, 1990). Shortage of carbohydrate supply during the floral evocation affected to the number of flowers in the following year (Snelga and Clearwater, 2007).

The different responses of artificially defoliated plants had been reported with the severity of leaf loss, plant growth conditions, and type of cultivar in kiwifruit vine (Buwalda and Smith, 1990) as well as papaya (Zhou et al., 2000) and peach (Lloyd and Daryl, 1990). There are key two economically important species in the genus *Actinidia*, i.e., *A. deliciosa* 'Hayward' is green-flesh kiwifruit and *A. chinensis* is yellow-flesh type. These two species are distinguished by different characteristics, ploidy levels, and vine growth (Cheng et al., 2004; Ferguson, 1990). Several studies have been reported the effects of defoliation on flowering of *A. deliciosa* ‘Hayward’, the green-flesh kiwifruit. Buwalda and Smith (1990) showed 29% reduction of flowering and complete cessation of flowering in following year by removing all shoots within fruiting zone and within the replacement cane zone, respectively. Moreover, Cruz-Castillo et al. (2010) observed the 25% and 53% reduction in return bloom as the number of flowers per winter bud in ‘Hayward’ kiwifruit vine at the 50% and 75% defoliations, respectively. However, few studies have been reported about flowering of the yellow-flesh kiwifruit, *A. chinensis*. Richardson et al. (2001) recorded the variation in flowering within vines of two *Actinidia chinensis* (Planch.) var. *chinensis* cultivars, ‘Hort16A’ and ‘37-3-18A’ as flowering capacities of 39 terminal flowers/m^2 of canopy and 106 terminal flowers/m^2 of canopy, respectively. Furthermore, Kwack et al. (2013) also observed the reduction in flower number per floral shoot in ‘Goldrush’ kiwifruit vines when the vines were defoliated more than 50% and the reduction was higher in September than in July and August defoliated vines. Moreover, the responses of vines to defoliation might be different among the cultivars and imposed time and the effects of negative impacts might be persisted over more than two seasons.

The objective of the present study was to evaluate the effects of levels and times of defoliation on flowering and fruit quality in *A. chinensis* ‘Jecy Gold’ kiwifruit in the following two years.

Materials and Methods

Plant Materials and Treatments

Defoliation trials were carried out from 2013 to 2015 at the National Institute of Subtropical Agriculture (NISA), RDA in Jeju, Republic of Korea. Six-years-old ‘Jecy Gold’ kiwifruit (*Actinidia chinensis*) vines trained to pergola system in a non-heated plastic house were used and subjected to the standard cultural practices. The treatments were comprised of different defoliation levels with 0, 50, 75, and 100% and different defoliation time. The leaves were removed at the petiole junction of shoots at the regular intervals with one after next and one after next two for 50 and 75% defoliation, respectively or totally for 100% on August 23, 2013 (100 days after anthesis, DAA). Three replications consisting of one vine per replication were randomly assigned. Also, the vines were completely defoliated on July 28, 2014 and August 29, 2014 for comparing the response to defoliation time. Two vines were randomly distributed into each replication.

Measurement of Return Bloom, Flowering, and Fruit Quality in Subsequent Years

In April 2014 and 2015, the number of flowers per shoot and number of flowers per florescences were determined on randomly selected ten shoots per vine. The fruits were harvested on November 24, 2014 and November 12, 2015, respectively. Every single vine was harvested individually and ten fruits were randomly selected from each vine. Fruit weight, length, firmness using a texture analyser (TA-XT 20042, Texture Technologies Co., USA) with a 3 mm diameter probe, total soluble solid (TSS), and acidity using a refractometer (JA0912, G-won Hitech Co., Ltd., Seoul, Korea), fresh weight, dry weight, and dry matter content (DM) were measured for fruit quality at harvest (Srisook et al., 2015).

Statistical Analysis

All data were evaluated by analysis of variance using ANOVA procedure of *Statustic*® 8 (Analytical Software, 2003); the mean differences were determined by LSD test, at the 5% level.

Results and Discussion

Influence of Defoliation Levels on Return Bloom and Fruit Quality in the Following Two Years

'Jecy Gold' kiwifruit vines were defoliated at 0%, 50%, 75%, and 100% in August 23, 2013. The 100% defoliation treatment was significantly reduced the number of flowers per shoot in year 2014. The reduction of the number of flowers per shoot in defoliated vines compared to undefoliated vines was 15.4%, 19.2%, and 50.0% with 50%, 75%, and 100% defoliation, respectively. The number of flowers per inflorescence was significantly reduced in all defoliation treatments compared with control in year 2014. The reduction of the number of flowers per inflorescence was 16.7%, 37.5%, and 58.3% with 50%, 75%, and 100% defoliation, respectively (Table 6). The significant reduction of the number of flowers per inflorescence also was observed in year 2015 for 75, and 100% defoliations compared to control. The reduction was 17.6%, and 25.0% with 75%, and 100% defoliation, respectively. There was no significant difference in the number of flowers per shoot in year 2015 (Table 6).

In our previous study, the significant reduction of starch and sucrose contents in bark tissue of 'Jecy Gold' kiwifruit were reported at 3 and 7 days after the defoliation in August 23, 2014 and the recovery of defoliated vines was observed at 34 days after defoliation (Srisook et al., 2015). Therefore, the shortage of carbohydrate supply caused the competition for assimilate supply among the sinks. According to Buwalda and Smith (1990), competitive strengths of the assimilate sinks ranking in descending order as shoot, fruits, roots, and return bloom of flowering. Due to the negligible assimilation in the return bloom sink the large reduction of flowering resulted in the following year after defoliation. In addition, lack of assimilates in shoots and trunk bark at the time of floral evocation contributed to the significant reduction in return bloom in kiwifruit vines (Cruz-Castillo et al., 2010). Further, Snelga et al. (1992) also reported the considerable reduction in return bloom by means of percentage of flower bearing shoots and the number of flowers per shoot due to the competition in carbohydrate supply between fruit and vegetative growth during flower evocation. In our contemporary study, a significant reduction of the number of flowers per inflorescence was recorded with 75% and 100% defoliation in both years, 2014 and 2015 and the reduction in 2015 was accounted as 50% for both 75% and 100% defoliation compared to 2014 (Table 6). These results supported the study of Snelgar and Manson (1993) described that flower differentiation was very sensitive to a lack of carbohydrate supply. Although, the reduction of flowering occurs even at the lowest defoliation level (Tombesi et al., 1993).

Table 6. Return bloom and flowering in the subsequent year of 'Jecy Gold' kiwifruit after different levels of defoliation applied during the growing season (August 23, 2013).

Defoliation level (%)	2014		2015	
	Number of flowers per shoot	Number of flowers per inflorescence	Number of flowers per shoot	Number of flowers per inflorescence
0 (control)	5.2±0.7[z] a[y]	2.4±0.1 a	5.6±0.4	2.9±0.1 a
50	4.4±0.3 a	2.1±0.1 b	5.3±0.2	2.6±0.1 ab
75	4.2±0.7 a	1.5±0.1 c	5.3±0.4	2.3±0.2 b
100	2.6±0.2 b	1.0±0.0 d	4.9±0.2	2.1±0.1 b

[z]Mean±SE (n=3).

[y]Means with different letters differed significantly ($P \leq 0.05$) by DMRT.

Fruits from the all experimental vines were harvested on 4 November, 2014 and 12 November, 2015. The fruit yields in one year after defoliation (2014) and two consecutive years after defoliation (2015) were not affected by defoliation. Further, the fruit growth and quality parameters, i.e., fruit length, width, and weight, fruit firmness, TSS, acidity, and DM were not significantly different with the defoliation treatments, i.e., 50, 75, and 100%, compared to the control (Table 7).

According to the recent findings, the considerable effects on kiwifruit growth and quality in the following year or two consecutive years were not found based on different defoliation levels. The fruit qualities such as, TSS, acidity, and skin coloration of grapevines cv. 'Pinot noir' were not significantly different in the following two years after two different types of defoliations commenced by removing of lateral leaves and removing all main leaves (Candolfi-Vasconcelos and Koblet, 1990). Moreover, Yuan et al. (2005) implemented the different levels of defoliation on 'Hamlin' orange trees during the harvesting season and not founded any negative impacts on fruit yield and fruit quality. The fruit quality of 'Hayward' kiwifruit by means of TSS, flesh firmness, and DM in the following year after defoliation was not affected by defoliation (Tombesi et al., 1993). The balance of carbohydrate supply between source and sinks in plants which are not subjected to the 100% defoliation can be compensated by the remaining leaves and newly immerging leaves after defoliation. This phenomenon was supported by Srisook et al. (2015) and reported that the significant reduction of starch and sucrose contents in the first two weeks after defoliation and they were recovered in one month after the defoliation. The recovery of starch and sucrose contents and the balanced mobilization from sucrose to sink organs might be resulted from the newly immerged leaves and remained leaves after defoliation. The optimum fruit growth and quality can be obtained with the unlimited availability of carbohydrates (Tombesi et al., 1993). However, according to the present data, the fruit growth and quality in the following year and two consecutive years in kiwifruit vines defoliated in the previous growing season had no effects on fruit growth and quality in either the following year or two consecutive years.

Table 7. Fruit growth and fruit quality of 'Jecy Gold' kiwifruit at harvest for two subsequent years (November 24, 2014 and November 12, 2015) at different defoliation levels treated in the previous growing season (August 23, 2013).

Defoliation level (%)	Fruit length (mm)	Fruit width (mm)	Fruit weight (g)	Fruit firmness (N)	TSS (°Brix)	Acidity ($g \cdot L^{-1}$)	DM[z] (g)
First following year (2014)							
0 (control)	60.5±1.0[y]	50.5±0.9	90.0±4.5	23.6±0.4	9.1±0.3	1.6±0.0	13.8±0.2
50	60.7±0.9	50.5±1.0	89.3±4.4	23.6±0.9	9.0±0.2	1.6±0.0	13.7±0.2
75	59.6±1.1	48.0±0.9	86.0±4.2	23.4±0.4	8.6±0.8	1.6±0.1	14.3±0.3
100	60.3±1.0	49.2±0.3	87.0±2.9	23.7±0.5	9.0±0.5	1.6±0.0	14.6±0.3
Second following year (2015)							
0 (control)	55.9±0.8	47.0±1.0	73.1±3.3	22.3±0.7	11.0±0.4	1.2±0.1	14.4±0.6
50	57.5±1.5	47.7±1.4	74.9±7.2	22.0±1.6	11.3±0.2	1.3±0.1	14.4±0.4
75	57.7±1.1	48.1±0.9	78.6±4.1	19.8±1.6	12.1±0.7	1.1±0.0	14.8±0.9
100	57.8±1.1	47.9±0.9	76.0±4.2	20.1±1.3	11.1±0.2	1.1±0.1	13.6±0.4

[z]Dry matter content = DW/FW × 100.

[y]Mean±SE (n=3).

Influence of Defoliation Time on Return Bloom and Fruit Quality in the Following Year

The 100% artificial defoliation in July 28 and August 29, 2014 affected to the return bloom. The number of flowers per inflorescence between the control and defoliated vines was significantly decreased by 29.15% and 37.28% in July 28 and August 29, respectively (Table 8). The number of flowers per shoot was not affected significantly by defoliation time, nevertheless, July 28 and August 29 defoliation tended to decrease the number of flowers per shoot compared to control vines (Table 8).

The 100% defoliation on July 28 and August 29 in 'Jecy Gold' kiwifruit vines caused reduction of the number of flowers per shoot and the number of flowers per inflorescence in the following year. Kwack et al. (2013) reported a similar tendency in young and non-bearing fruit of 'Goldrush' kiwifruit, and there was no flowering in the following season on 100% defoliation vines on August 15 while flowering in the following season was decreased compared to control on the defoliated vines on July 15, September 15, and October 14. Buwalda and Smith (1990) reported that the defoliation within the replacement zone in 'Hayward' kiwifruit vines reduced return bloom, especially in the early of growing season while defoliation within the fruiting zone reduced flowering in the following season by up to 29%. Furthermore, Candolfi-Vasconcelos and Koblet (1990) described that the defoliation commenced by removing the all main leaves of 'Pinot noir' grapevines in the early stage of berry development caused a large reduction of flowering in the following season. Therefore, the flowering in the following season of kiwifruit vines is accomplished as the consequence of the floral evocation in the current season. With the severe limitations of the carbohydrates at the time of floral evocation, the flowering in the following year has been reduced due to the competition among the strong sinks such as shoots and fruits (Tombesi et al., 1993; Cruz-Castiil et al., 2010). Moreover, Snelgar and Mansor (1992) also reported the reduction of the flowering percentage in the following year of kiwifruit vines which were defoliated at any time of the growing season compared to the non defoliated vines. However, the results of the current study showed the more intense competition for carbohydrate availability of the August 29 defoliation compared to the July 28 defoliation.

Table 8. Effects of defoliation time on return bloom (2015) in 'Jecy Gold' kiwifruit vines defoliated at two different times in the previous growing season (2014).

Defoliation time	Number of flowers per shoot	Number of flowers per inflorescence
Control	5.8±0.6[z]	3.0±0.1 a[y]
July 28	4.6±0.3	2.1±0.0 b
August 29	4.4±0.6	1.9±0.1 b

[z]Mean±SE (n=2).

[y]Means with different letters differed significantly ($P \leq 0.05$) by DMRT.

Defoliation on July 28 and August 29, 2014 had no effect on fruit growth and fruit quality in the first following year (2015) in ‘Jecy Gold’ kiwifruit. Fruit growth parameters such as, fruit length, width, and weight were not affected by July 28 and August 29 defoliation compared to the control (Table 9). Defoliation treatments did not affect on TSS, acidity, and DM in defoliated vines compared to non-defoliated vines (Table 9).

Fruit growth and fruit quality in subsequent years after treated with 100% defoliation were not affected by July 28 and August 29 defoliation treatments. Similarly, Howell et al. (1994) reported that the defoliation at the different stages of fruit growth had no significant effect on fruit yield and fruit quality in the following year in ‘Pinot noir’ grapevines. Tombesi et al. (1993) also did not report any effects on the fruit weight and fruit qualities, i.e., TSS, flesh firmness, and DM one year after the defoliation in ‘Hayward’ kiwifruit. Also, the interaction between source and sink is important to initiate the severity of negative impact on plant growth during the defoliation damage period (Mayer, 1998). Nevertheless, under the optimum carbohydrate supply fruits can reach to the maximum growth rate and it’s not affected by the defoliation treatments (Tombesi et al., 1993). Therefore, the fruit growth and quality were not affected by the previous season defoliation treatments since the abundance of carbohydrate supply from photosynthesis in the current season.

In conclusion, the defoliation levels and times caused the reduction of return bloom and flowering in the subsequent years in ‘Jecy Gold’ kiwifruit. Nevertheless, the fruit growth and quality in the following two years were not affected by either defoliation levels or times. However, the reduction in flowering might be decreased the fruit yield in the subsequent years.

Table 9. Fruit growth and fruit quality measured at harvest (November 12, 2015) in 'Jecy Gold' kiwifruit vines defoliated at two different times in the previous growing season (2014).

Defoliation time	Fruit length (mm)	Fruit width (mm)	Fruit weight (g)	Fruit firmness (N)	TSS (°Brix)	Acidity ($g \cdot L^{-1}$)	DM[z] (g)
Control	55.9±0.8[y]	47.0±1.0	73.1±3.3	22.3±0.7	11.0±0.4	1.2±0.1	14.4±0.6
July 28	56.6±0.7	46.6±0.2	75.9±1.3	22.7±0.1	10.3±0.1	1.3±0.1	13.6±0.2
August 29	57.7±1.0	47.4±0.5	76.0±3.4	23.1±1.2	10.3±0.2	1.3±0.0	13.1±0.1

[z]Dry matter content = DW/FW ×100.

[y]Mean±SE (n=2).

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ABSTRACT IN KOREAN

참다래는 1970 년대 후반에 한국에 도입되어 제주도를 포함한 남해안 지역에서 재배되고 있다. 제주도는 매년 태풍이지나가게 되는데, 특히 참다래의 잎은 크고 엽병이 길어 강풍의 피해를 입기 쉽다. 인위적엽은 강풍과 같은 악화된기 상조건이 참다래 수체 생육에미치는 영향을 평가하는데 적용되어 오고 있다. 본 연구는 3 년동안 (2013-2015 년) 적엽 수준과 시기가 '제시골드' 참다래의 수체 재생장, 과실 품질, 개화에미치는 영향을 평가하고자 비닐하우스내에 재식된 5 년생의 '제시골드' 참다래를 이용하여 수행하였다. 인위적엽은 신초와 접하고 있는 엽병 기부에서 엽병을 포함한 잎들을 손으로 제거하는 방식으로, 0 (control), 50, 75, 그리고 100% 의 각기 다른 수준에 서처리하였다. 잎은 나무 전체에서 일정한 간격으로 제거되었다. 더욱이 100% 적엽 처리는 2014 년에 7 월 28 일과 8 월 29 일 각기 다른 시기에 처리되었다. 액아 발아에 의한 수체 재생장, 가지 수피의 저장양분, 과실 품질, 수량 및 개화 정도가 조사되었다.

적엽 50, 75, 100% 처리는 적엽 1 주일 후 액아 발아를 유발시켰다. 적엽 75 와 100% 처리한 수체의 액아 발아는 대조구와 적엽 50% 처리보다 유의적으로 높게 나타났다. 더욱이 100% 적엽처리에서는 불시개화가 일부 발생했다. 인위적엽 후 2 주 동안 75 와 100% 적엽 처리에서 전분과 자당 함량은 유의하게 감소하였다. 적엽 100% 처리는 낙과와 과실 경도를 유의하게 증가시켰다. 그러나 과실 무게, 당도 및 건물율은 적엽 75 와 100% 처리에서 유의하게 감소하였다. 적엽 정도가 심한 경우에는 이듬해 개화가 크게 감소하였다. 2014 년의이듬해 개화는, 적엽 75 와 100% 처리에서 화총당 꽃수가 37.5 및 58.3% 각각 감소하였고 신초당 꽃수는 19.2 및 50.0% 각각 감소하는 것으로 나타났다. 특히, 화총당 꽃수는 이듬이듬해인 2015 년에도 적엽 75 와 100% 처리에서 각각 17.9 및 25.0% 감소하여, 그 경향이 지속되었다. 과실종경, 횡경, 경도, 당도, 산도, 그리고 건물율과 같은 과실 품질 요인에 있어서 2014 년과 2015 년 모두 유의적인 차이는 나타나지 않았다.

적엽 7 월 28 일 처리에서는 불시개화가 발생하지 않았으나 적엽 8 월 29 일 처리에서는 발생하였다. 신초의 재생장은 적엽 7 월 28 일과 8 월 29 일 처리

사이에 유의적인 차이를 나타내지 않았다. 가지 수피의 전분과 가용성 당 함량은 적엽 60 일 후를 제외하고는 유의적인 차이가 나타나지 않았으며, 자당의 함량은 적엽 8 월 29 일 처리에서 적엽 7 월 28 일 처리보다 높게 나타났다. 적엽 8 월 29 일처리에서 수확기의 과실 경도는 증가하였고 당도는 감소하였다. 또한 적엽 7 월 28 일과 8 월 29 일처리는 대조구와 비교하여 이듬해(2015 년) 과실 품질에는 차이가 없었다. 화총당 꽃수는 적엽 7 월 28 일과 8 월 29 일 처리시 각각 29.2% 와 37.3% 유의하게 감소하였으나, 신초당 꽃수는 대조구에 비해 적엽 7 월 28 일과 8 월 29 일 처리에서 유의적인 차이는 나타나지 않았다. 연구결과, 적엽 정도가 심하면 전분과 자당의 저장양분 부족으로 당년 생육기 과실품질은 저하될 수 있으나 이듬해까지 영향을 미치지는 않음을 보여주었다. 인위적엽은 적엽시기(7 월 28 일과 8 월 29 일)에 관계없이, 이듬해의 개화를 감소시켰다. 또한 8 월 하순 적엽에서의 불시개화 발생은 '제시 골드' 참다래의 화아분화로 설명될 수 있고, 화아분화는 7 월 29 일과 8 월 29 일 사이에 완료되는 것으로 보아졌다. 더욱이, 적엽 100% 의 8 월 29 일 처리는 적엽 7 월 28 일 처리에 비해 과실 품질, 특히 과실 경도, 및 당도에 영향을 크게 미쳤는 것으로 나타났다.

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