Effect of S-Girdling on Fruit Growth and Fruit Quality of Wax Apple

Minh Tuan, Nguyen, and Chung –Ruey, Yen

***Abstract*—**The study was performed to evaluate the effect of S-girdling, fruit thinning plus bagging with 2,4-D application, fruit thinning plus bagging on growth and quality of wax apple fruit. Girdling was applied three week before flowering. The 2,4-D was sprayed at the small bud and petal fall stage. The effect of all treatments on fruit growth was measured weekly. The physical and biochemical quality characteristics of the fruits were recorded. The results showed that no significant effect on number of bud among treatments. S-girdling, 2,4-D application produced the lowest bud drop, fruit drop compared to untreated control. Moreover, S-girdling enhanced faster fruit growth producing the best final fruit length and diameter than the control treatment. It was also observed that S-girdling greatly increased fruit set, fruit weight as well as total soluble solid, reduced fruit crack, and titratable acidity. In conclusion, S-girdling had a distinctive and significant effect on most of the fruit quality characteristics assessed. Application 2,4-D was also recommended as the industry norm to increase fruit set, and fruit quality in wax apple.

***Keywords*—**Wax apple, S-girdling, 2,4-D, fruit bagging, fruit thinning.

I. Introduction

THE wax apple is a tropical fruit tree with its origin in the Malay Archipelago [37]. The fruit tree, although almost completely unknown outside southeastern Asia, is an economically important fruit crop in Taiwan [42]. Fruit vary greatly in size, shape and skin color. The fruit size can be about 3.4-6 cm long and 4-5 cm wide. Fruit mass ranges from 28 g to 100 g to the jumbo size of more than 200 g per fruit. Fruit shape ranges from round to bell-shape, oval or elongated and the skin color diverges from white to pale green to dark green, pink to red to deep red. The fruit of wax apple are sweet, flesh white, spongy, dry to juicy, low acid and very bland in flavor [26].

The serious problem with many fruit tree species is an alternate bearing, causing considerable economic losses to growers [29], [43]. The extent of the problem depends on tree species, cultivars, and climatic conditions [11]. Many horticultural techniques have been used to reduce the severity of alternate bearing. The main ones are thinning to remove excess fruit in ‘on’ years, and girdling at time of flower bud differentiation to increase the amount of developing flowers and later fruit set in ‘off ’ years.

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In agriculture the application of girdling techniques has been employed as a practice to affect the size of fruit and also used to improve crop productivity [9]. Girdling, removal of a ring of bark and phloem around the outer circumference, is a practice used worldwide in agriculture, horticulture, and forestry, with various purposes [34].

Fruit set and growth requires large amounts of carbohydrates, which are provided by the photosynthesis of the current season’s leaves and/or by the reserves accumulated during the winter. According to [30] girdling interrupts the transport of photosynthates to the roots and has a variety of physiological and biochemical effects on plants such as accumulation of carbohydrates above the girdle and a decline of carbohydrates below the girdle which increases fruit set and yield. It has also been reported that in the area above the girdling point, the leaf N content, C/N ratio and carbohydrate content were increased. An accumulation of amino acids above the girdle has been reported in Salix fragilis twigs [36]. Moreover, girdling removal of a wide strip of bark without injuring the xylem, is widely used in citrus species mainly to increase fruit set and size as well as fruit quality [34]. Some reports [21], [6] specify the response of olive trees to girdling as increased fruit set. Furthermore, reference [5] reported a marked increase in the number of inflorescences on winter-girdled scaffolds of Manzanillo and Novo olive trees during the ‘off’ year, in Israel.

Reference [49] suggested that girdling can change the fruit quality (increased soluble solids content and reduced acid concentration) by blocking the translocation of sucrose from leaves to the root zone through phloem bundles. The ringing of trees can bring about an increase in the size and sugar content of fruits and cause them to mature a few days to a week earlier. Moreover, girdling, as a form of partial ringing, of four-year-old peach trees reduced shoot growth but promoted fruit quality development [3], [23].

Other agricultural practices which may increase yield and improve fruit quality are also the application of plant growth regulators. It was reported that 2,4-D increased total sugar content and enhanced the activities of antioxidant enzymes [8]. The application of 2,4-D, GA3, and NAA significantly reduced acidity percentage and increased vitamin C content of citrus fruits [48].

Moreover, bagging, a physical protection technique commonly applied to many fruits, can not only protect fruit from diseases and pests, but also change the microenvironment of fruit development, which exerts multiple effects on the growth and quality of fruits [45], [31]. Furthermore, fruit thinning is also important technique in apple growing for improving fruit quality [32]. Since thinning can be performed mechanically or chemically, thinning intensity may vary not only on the method used but also on the physiological condition of the trees and cultural practices employed. For the fresh market, fruit size, appearance, flavour, firmness are of main interest. Therefore, the growers will have to focus their orchard practices to satisfy these market demands in order to produce high quality fruit consistently at maximum yields.

Taiwan climate is suitable for the wax apple production. Fruit can be harvest all year-round. There is a great scope to develop wax apple industry in Taiwan and other tropical countries. Although achieved, the production of wax apple in Taiwan there are still challenge with these problems such as lack of techniques, severe fruit drop, low quality impair wax apple production, resulting in lower market prices. Girdling considered an important practice responsible for improving fruit setting, yield as well as quality of fruits. Therefore, the aim of present study was to evaluate the effects of S-girdling on fruit development and quality attributes in wax apple under field conditions.

II. Materials and Methods

A. Plant Materials

The experiment was carried out in Tropical fruit orchard located at Department of Plant Industry, National Pingtung University of Science and Technology from March to June 2012. Sixteen trees were selected for the study. Sixty four the uniform branches (four branches per tree) of about the same length and diameter from sixteen trees were selected for the experiment. The experiment consists of four treatments including the control was design in Randomized Complete Block Design (RCBD) with four replicated and a singer uniform branch was taken as an experiment unit.

B. Treatment

Girdling was performed using a girdling knife which simultaneously cuts and removes the bark strips. The width of the girdle was between 1.5 mm to 2 mm depending on the branch size. The cut reached the cambium and was left bare without injury to the inner layer. The girdling was carried out three weeks before flowering. A total of 10 mg/L 2,4-D (2,4-dichlorophenoxyacetic) was applied at small bud and petal fall on windless mornings with a truck mounted motorized sprayed until dripoff.

C. Data Collection

For the number of bud and bud drop (%), the total number of buds was determined when the bud size was 0.8-1.0 mm. Bud dropping percentage was calculated according to the following formula:

$$\text{Bud drop (\%)} = \frac{\text{Total No.of buds at initial stage - Buds before bloom}}{\text{Total No. of buds at initial stage}} \times 100$$

For the determination of fruit setting percentage from tagged branches on the experimental tree, the percentage of fruit setting was calculated using the following formula:

$$\text{Fruit set (\%)} = \frac{\text{Total No. of fruitlets}}{\text{Total No. of flowers}} \times 100$$

Fruit dropping percentage was calculated at 35 days after anthesis using the following formula:

$$\text{Fruit drop (\%)} = \frac{\text{Total No.of fruitlets} - \text{No.of fruits in 35 days after anthesis}}{\text{Total No. of fruitlets}} \times 100$$

Number of inflorescences per shoot was determiner by choosing randomly 5 shoot on each tagged branches and the number of inflorescences were counted. For the flower count, 5 inflorescences on each of the tagged branches were randomly selected and the numbers of flowers on each inflorescence were counted. Later, fruit growth (length and wide) were measured weekly with vernier calipers. At harvesting, final fruit length, fruit diameter, flesh thickness were determined with the help of Vernier caliper. Average fruit weight was determined by weighing. Fruit crack per cluster and number of seeds were measured.

Total soluble solid (TSS) were measured by using a hand refractometer (ATAGO Co. LTD., Tokyo, Japan) juice was squeezed from the fresh-cut wax apple and the result was expressed as ^{o}Brix. Titratable acidity (TA) was determined using the method described by [7]. The results were expressed as percentage of citric acid. The pH of the wax apple juice was recorded using a pH meter (Hanna pH 211, Italy).

D. Statistical Analysis

The data obtained from the study were analyzed using SAS 9.1 statistical software. The least significant difference was calculated following a significance F-test (at $P \leq 0.05$)

III. Results and Discussion

A. Total Number of Buds and Bud Drop

The results summarize in Table I showed that S-girdling treated were found to have the highest number of buds (45.0 buds/branch), follow by the other treatments, whereas the lowest bud number (35.1 buds/branch) recorded in untreated control, although the difference was not statistically significant ($p \leq 0.05$), which is in accordance with the findings of [41]. Moreover, there were significant differences among treatments concerning buds drop (Table I). In control treatment bud drop recorded the highest of 47.0%, while the lowest bud drop value was found in S-girdling treatment with 28.3%. On the other hand, fruit thinning plus bagging in combination with 2,4-D application also reduced bud dropping compared with the control treatment. In contrast, fruit thinning plus bagging treated had no beneficial effect on bud dropping compared with the untreated control. The same has been reported by [40] who found branch girdling, which interrupts the phloem pathway and hence disrupts the transport of carbohydrates in and out of the branch, has been utilized experimentally for control bud drop as well as increase the fruit set in apple.

TABLE I
EFFECTS OF S-GIRDLING ON NUMBER OF BUDS, BUD DROPPING, NUMBER OF FLOWER, NUMBER OF INFLORESCENCE, FRUIT SETTING AND FRUIT DROPPING OF WAX APPLE[1]

Treatment	Number of bud	Bud drop (%)	Number of flower/ inflorescence	Number of inflorescence/ shoot	Fruit set (%)	Fruit drop (%)
Control	35.1[a]	47.0[a]	4.06[b]	3.00[b]	26.7[b]	59.8[a]
Fruit thinning+bagging	42.0[a]	40.6[a]	5.00[ab]	3.75[a]	42.9[a]	41.2[b]
Fruit thinning+bagging+2,4D	40.4[a]	29.5[b]	5.81[a]	4.14[a]	45.6[a]	38.3[b]
S-gridling +fruit thinning +bagging	45.0[a]	28.3[b]	5.91[a]	4.08[a]	48.3[a]	36.0[b]

1. Mean in each column followed by the same letters are not significantly different at P≤ 0.05 according to Duncan's multiple range test.

B. Number of Flowers per Inflorescences and Number of Inflorescences per Shoot

From the results of Table I, it was found that S-girdling resulted in significant number of flowers per inflorescences enhancement compared to control treatment. However, no significant difference was observed in fruit thinning plus bagging treatment. Thus, the relationship of fruit thinning plus bagging treatment to the total number of flowers per inflorescence is variable and not yet clearly established.

For the number of inflorescence per shoot, it was observed that number of inflorescence per shoot differs between treatments in this study. The higher number of inflorescences per shoot was seen at the combining fruit thinning plus bagging with application 2,4-D, followed by S-girdling treatment, whereas the untreated control produced the lowest value of 3.00 numbers of inflorescences per shoot (Table I).

According to [43] girdling of fruit trees is commonly used as a tool to achieve better bloom, fruit set, and fruit size. Moreover, different results regarding the effect of girdling on the total number and type of flowers have been reported [5], [16]. Therefore, when we evaluated the number of flowers, a difference in response was observed in all treatment in this study. Thus, in the present study applied S-girdling and 2,4-D increased number of flowers per inflorescences, and number of inflorescences per shoot (Table I). These results are in agreement with [3] who stated that flowering in apple trees was significantly increased by girdling.

C. Fruit Set and Fruit Drop

Data in Table I showed that the control treatment had the lowest amount of fruits set with a value of 26.7 %. However, in S-girdling treatment fruit set increased in comparison to control treatment, and reached a maximum 48.3%. On the other hand, combining fruit thinning plus bagging with 2,4-D application also increased fruit set compared with the untreated control. Reference [17] demonstrated that fruit-set seems to be quantitatively correlated with carbohydrate availability. The enhancement of carbohydrate availability has been associated with an improvement of fruit set and yield of citrus trees [18], [19]. Therefore, from the data in present study it can be suggest that S-girdling reduced fruit drop, but resulted in greater fruit set (Table I). Similar results were reported by [6], showing specifies the response of olive trees to girdling as increased fruit set.

As can be seen from Table I, the result showed that the control treatment was found to have the highest fruit drop (59.8%), whereas the S-girdling treatment produced the lowest fruit drop only 36.0%, followed by combining fruit thinning plus bagging with 2,4-D application, and fruit thinning plus bagging treatment. Similar finding have been reported in orange; 2,4-D has been shown to increase the total number of fruits, the fruit weight per plant by reducing pre-harvest fruit drop [10]. Moreover, it is known that girdling produces many growth alterations including a decline in fruit abscission [49]. The increased carbohydrate supply caused by girdling correlated with the transient reduction in fruitlet abscission that was observed. Similar findings were reported previously in 'Ponkan' mandarin by [33]. Furthermore, reference [27] reported that girdling resulted in low fruit abscission rates, through the increase of carbon availability for the fruitlets above the girdle of citrus. Therefore, the results presented in this study showed that S-girdling greatly increased fruit set compared with the untreated control. Moreover, S-girdling the most effective for control fruit drop, delaying abscission of young fruits and increasing the final fruit set. This result is in agreement with results obtained in other fruit species [35].

D. Fruit Growth Length and Diameter

All treatments promoted fruit growth as reflected by faster increase in fruit length and diameter compared to untreated control. At the 7th week of observation, S-girdling treatment showed the highest fruit length development (5.82 cm), followed by fruit thinning plus bagging with 2,4-D application, fruit thinning plus bagging with value of 5.67 cm, 5.55 cm, respectively, whereas the control treatment had the lowest fruit growth rate which recorded 5.0 cm (Fig. 1). For the fruit diameter, similarly trend was investigated during fruit growth rate. The Fig. 2 showed that fruit diameter growth rate was greatly enhanced by applied S-girdling treatment (5.3 cm), whereas the lowest fruit growth rate was found in untreated control, only 4.7 cm at the 7th with of observation. On the other hand, fruit growth rate of fruit thinning plus bagging in combination with 2,4-D application was also significantly higher compared to untreated control.

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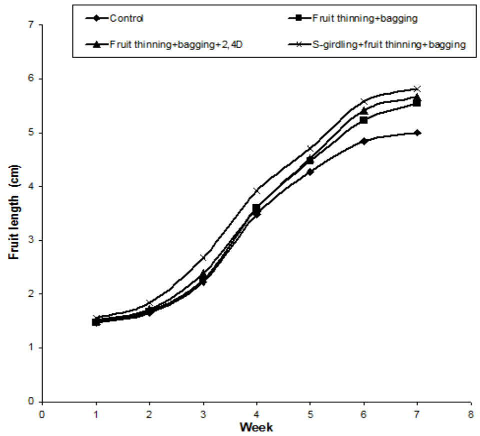

Fig. 1 Effect of S-girdling on fruit growth (length/week)

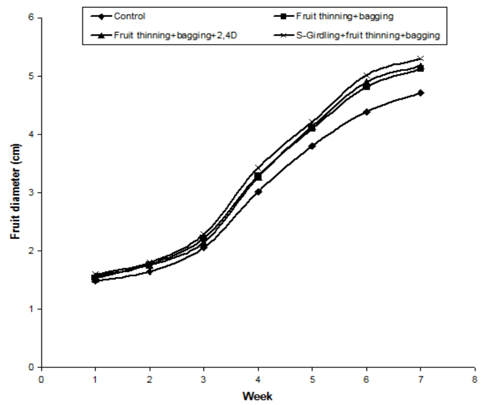

Fig. 2 Effect of S-girdling on fruit growth (diameter/week)

Reference [34] reported that girdling alone or with potassium sprays increase the fruit size and fruit weight in Balady mandarin orange. The increase in fruit size demonstrated here in response to girdling application at the three weeks before flowering may indicate their ability to stimulate carbohydrate translocation to the fruit in combination with their effect on increasing cell wall elasticity. From this result, it can be seen that fruit growth (length and diameter) rate was significant between the treatment and control. S-girdling treatment showed the highest fruit growth rate from the 1st week till the 7th week, followed by fruit thinning plus bagging with 2,4-D application compared to untreated control (Fig. 1 and 2). This is in accordance with the finding reported by [20] who indicated that girdling increased in photosynthetas above the girdle available for fruit growth.

E. Effect of S-girdling on Quality Parameters of Fruit

Fruit weight

A number of workers have reported useful data on the application of various forms of girdling in fruit production. Reference [13] used overlapping, half-circumference-band girdles in which 25 mm wide strips of bark and phloem were removed from opposing sides of the stem. Reference [47] working on Douglas fir compared partial-overlapping-band girdles to similar girdles applied with a pruning saw. They found both methods increased cone yield. According to [28] scoring one type of girdling significantly increased the fruit weight in persimmon. This is in accordance with the finding of [24]. As can be seen the Table II, S-girdling significantly increased fruit weight compared with the control treatment. In the case of this study, the highest fruit weight was found in S-girdling treatment with 76.4 g, followed by combining fruit thinning plus bagging with 2,4-D application, whereas the control treatment showed the lowest value of 56.4 g. This implies that S-girdling might be effective in improving fruit weight. It seems that either scoring or girdling will suffice for the goal of increasing fruit set and yield and to induce early production [2]. Therefore, our result showed that fruit weight was greatly increased by S-girdling treatment than the untreated control. This is in agreement with the equal effectiveness of scoring and girdling in increasing fruit size in loquat [2], peach and nectarine [1].

TABLE II
EFFECTS OF S-GIRDLING ON FRUIT CHARACTER OF WAX APPLE[1]

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Flesh thickness (mm)	Number of seed/ fruit	Fruit crack/ cluster	TTS (°Brix)	TA (%)	pH
Control	56.4[b]	51.1[c]	48.1[b]	13.0[b]	0.35[a]	0.51[a]	7.67[c]	0.77[a]	3.69[c]
Fruit thinning+bagging	75.9[a]	56.3[b]	53.2[a]	15.7[a]	0.10[b]	0.28[b]	9.08[b]	0.60[b]	3.80[b]
Fruit thinning+bagging+2,4D	74.2[a]	57.2[b]	53.3[a]	16.1[a]	0.08[b]	0.26[b]	8.82[b]	0.51[b]	4.00[a]
S-Girdling+ fruit thinning+bagging	76.4[a]	59.1[a]	54.0[a]	16.5[a]	0.05[b]	0.23[b]	10.1[a]	0.45[b]	4.03[a]

1. Mean in each column followed by the same letters are not significantly different at $P \leq 0.05$ according to Duncan's multiple range test

F. Fruit Length, Fruit Diameter and Flesh Thickness

The results of Table II showed that there was significantly fruit length for all treatment in this study. The lowest fruit length (51.1 mm) was found in the control treatment, while the highest fruit length (59.1 mm) was observed in S-girdling treatment. Moreover, fruit thinning plus bagging in combination with 2,4-D application also increased fruit length compared with control treatment. For the fruit diameter, there was greatly enhanced in all the treatments than the untreated control (Table II). In term, the highest fruit diameter of 54.0

mm was obtained in S-girdling treatment, whereas the control treatment showed the lowest fruit diameter of 48.1 mm.

Moreover, the data presented in study showed that the control treatment had the lowest of flesh thickness (13.0 mm), whereas the highest flesh thickness (16.5 mm) were recorded with S-girdling treatment, followed by fruit thinning plus bagging combination with 2,4-D application, fruit thinning plus bagging treatment in this study (Table II). Scoring and girdling were equally effective in decreasing vegetative growth in apple [4] and increasing fruit size. Therefore, our results indicated that S-girdling, fruit thinning plus bagging combination with 2,4-D application were greatly increase fruit size compared to untreated control. Moreover, the flesh thickness was improved by S-girdling, fruit thinning plus bagging combination with 2, 4-D application than the control treatment. Reference [22] working on ‘Matsumotowase Fuyu’ persimmon’ reported similar finding.

G. Number of Seed per Fruit, Fruit Cracking

From the results showed in Table II, it was observed that seed number higher in fruits from untreated control compared to all other treatments. In term, the control treatment has the highest seeds number with 0.35 numbers of seeds per fruit, whereas the lowest seed number recorded 0.05 numbers of seed per fruit in S-girdling treatment. This is in accordance with the findings reported by [15]. Fruit cracking is caused by a number of reasons. Drought, hot temperature, heavy rain and high humidity have been reported to induce fruit cracking in litchi and longan [25]. As showed in the Table II, fruit cracking was statistically significant ($P \leq 0.05$) between control and other treatments in this study. S-girdling, and fruit thinning plus bagging in combination with 2,4-D application treatments significantly lessened fruit cracking as compared with the control. The results suggest that S-girdling, fruit thinning plus bagging with 2,4-D application were effective in prevention of fruit cracking. Similar finding had been reported by [12].

H. Total Soluble Solid

Reference [50] indicated that stem girdling is known to improve fruit quality. Girdling severes phloem vascular vessels thereby preventing translocation of photosynthates from the source to sinks located below the girdle until the wound heals. Thus, girdling has an indirect effect of reducing sink size and increasing the amount of photosynthates available to fruits and other active meristems above the girdled region [39]. Reference [46] reported that girdling enhanced fruit color, total soluble solids and total sugar content in Marisol’ Clementine’s. Fruits from the girdle branch yielded the higher amount total sugars which may be due to carbohydrate availability and starch content high in upper part of girdle. From the results presented in study, the total soluble solid in all treatment were higher significant than the control treatment, in term the highest total soluble solid value of 10.1 (^{o}Brix) was observed in S-girdling treatment. The minimum total soluble solid in untreated control was 7.67 (^{o}Brix) (Table II). This is in agreement with [14] who found that girdling of ‘Pione’ grapevine led to a significant increase in TSS, coloring and anthocyanin content.

I. Titratable Acidity (TA) and pH

For the TA acid, the lowest amount of TA (0.45%) was recorded in S-girdling treatment, followed by fruit thinning plus bagging combination with 2,4-D application, fruit thinning plus bagging treatment, while the highest TA (0.77%) was recorded in the control treatment (Table II). Reference [38] reported that partial ringing and partial ringing plus trunk heating had led to a reduction in shoot length while improving fruit quality. Therefore, our results showed that S-girdling caused a decrease in TA as compared to the control treatment (Table II). On the other hand, fruit thinning plus bagging combination with 2,4-D application also caused a reduced in TA. The reduction in titratable acidity observed with the applicationof 2,4-D, can probably be attributed to the conversion of the organic acids to sugar during fruit ripening. Similar results were reported by [44] who started that the acidity of tomato fruits was reduced when the plant was sprayed with GA3 and 2,4-D.

Finally, the differences in pH were statically significant between treatments and control. The results showed that the highest amount of pH (4.03) was achieved in S-girdling, whereas the lowest amount of pH (3.69) was recorded in the control treatment, which is in accordance with the finding of [34]. Moreover, synthetic auxin increases absolute juice content in citrus fruits, through simultaneous increases in fruit size and juice content from pulp [48]. Similarly, significant change in pH at combining fruit thinning plus bagging with 2,4-D application compared to untreated control (Table II). This data for fruit juice pH were in agreement with the finding of [44].

IV. Conclusion

In conclusion, S-girdling improved the number of flowers, reduced bud drop as well as fruit drop and increased fruit set. The results also suggested that S-girdling enhanced faster fruit growth and improved significantly the quality characteristics of the fruits, increase the total soluble solid as a result of increased carbohydrate concentration and reduce acidity. Hence, S-girdling could be a valuable tool in improving wax apple fruit quality, based on both physical and biochemical quality characteristics. On the other hand, fruit thinning plus bagging with 2,4D application could be also strategies to regulate the growth and development of wax apple.

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