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Effects of the Phloemic Stress on the Growth, Development and Quality of Wax Apple (*Syzygium samarangense*) cv. Jambu madu

(Kesan Tekanan Floem Terhadap Pertumbuhan, Perkembangan dan Kualiti Epal Lilin (*Syzygium samarangense*) cv. Jambu Air Madu)

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ABSTRACT

A study was carried out to investigate the effects of different girdling techniques on the growth, development and quality of red wax apple fruits (Syzygium samarangense). *Selected horticultural parameters were monitored at one week interval during the growth period from December 2008 to October 2010, using I, C, V shaped, 50%, and 100% girdling. Girdling was applied 2 weeks before flowering. The results showed that the C-shaped girdling technique produced the best results with regard to the fruit setting and chlorophyll content in comparison to the control and the other girdling techniques employed. Furthermore, C-shaped girdling enhanced faster fruit growth producing the best final fruit length and diameter. In addition to significantly increased yield, juice percentage, leaf dry matter, biomass and* TSS *content of fruits. It was also observed that 50% girdling decreased fruit dropping. V-shaped girdling also increased the number of bud and reduced bud dropping compared to control. I-shaped girdle fruits produced the highest amount of* K^+ *content in fruit juice compared to other treatments. The color development of the fruit peel in 100% girdling was also the highest among the treatments. From this study, it can be concluded that C-shaped girdling applied two weeks before flowering produced better fruit growth, yield and quality of red wax apple fruits under field conditions.*

Keywords: Fruit quality; girdling; Syzygium samarangense

ABSTRAK

Satu kajian telah dijalankan untuk menentukan kesan teknik girdling yang berbeza ke atas pertumbuhan, pembangunan dan kualiti air buah epal merah (Syzygium samarangense). *Parameter hortikultur yang terpilih telah dipantau pada selang seminggu dalam tempoh pertumbuhan dari Disember 2008 hingga Oktober 2010, dengan menggunakan teknik girdling berbentuk I, C, V, 50%, dan 100% girdling.* Girdling *telah diaplikasikan 2 minggu sebelum berbunga. Keputusan menunjukkan bahawa teknik girdling berbentuk C menghasilkan keputusan yang terbaik mengenai tetapan buah-buahan dan kandungan klorofil berbanding kawalan dan teknik-teknik girdling yang lain. Tambahan pula, girdling berbentuk C didapati meningkatkan pertumbuhan buah-buahan dengan lebih cepat dalam menghasilkan panjang dan diameter akhir buah yang terbaik, sebagai tambahan kepada peningkatan hasil yang ketara dalam peratusan jus, berat kering daun, biojisim dan kandungan* TSS *buah. Girdling 50% juga dapat dilihat menurunkan keguguran buah. Girdling berbentuk V juga meningkatkan bilangan putik dan mengurangkan keguguran berbanding kawalan. Girdling berbentuk I menghasilkan jumlah kandungan* K^+ *tertinggi dalam jus buah berbanding perlakuan lain. Perkembangan warna bagi pengupasan buah dalam girdling 100% juga adalah yang tertinggi di antara perlakuan. Daripada kajian ini, dapat disimpulkan bahawa girdling berbentuk C yang diaplikasikan dua minggu sebelum berbunga menghasilkan pertumbuhan hasil dan kualiti buah epal merah yang lebih baik di lapangan.*

Kata kunci: Girdling*; kualiti buah;* Sizigium samarangense

Introduction

The wax apple or *jambu* fruit tree, known locally as *jambu air*, belongs to the genus *Syzygium* in the family Myrtaceae. It is widely cultivated and grown throughout Malaysia and in neighboring countries such Thailand, Indonesia and Taiwan on a small scale where the climate is suitable for its production all year round. Currently in Malaysia, it is cultivated mainly as smallholdings ranging from 1 to 5 ha with its hectarage estimated at about 2000 ha (Zen-Hong. et al. 2006). The fruits are generally pear shaped, often juicy, with a subtle sweet taste, an aromatic flavor and are eaten raw or cooked as a sauce. It has become increasingly popular in this region and has the potential to bring great benefit to local farmers and the country's economy. However relatively little study has been reported on the development of this fruit with a scarcity of information available in the literature.

In agriculture the application of plant growth substances has been employed as a practice to affect the size of a fruit. However this strategy has become increasingly viewed as inappropriate due to its possible effects on the environment and human health. Another route to achieving the same end would be employing the girdling technique, an old practice used to improve crop productivity. The removal of a small strip of bark around a branch or trunk will obstruct basipetal phloem transport and make available more photosynthetic metabolites to the growing regions above the strip (Casanova et al. 2009). Although removing the strip of bark wounds the tree, it heals within several weeks. It has been well documented that 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 (Arakawa et al. 1997; Hossain et al. 2006; Tukey 1978).

It has been 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. However, Hossain et al. (2006) reported that girdling, as a form of partial ringing, of four-year-old peach trees reduced shoot growth but promoted fruit quality development.

Girdling is still widely used worldwide in the cultivation of crops such as citrus, grape, peach and other fruit trees, mainly to increase flowering, fruit set and fruit size (Hossain et al. 2007; Tuzcu et al. 1994). It has also been reported that the cytokinin and gibberellin content in shoots are also modified by girdling (Barut & Eris 1994). They also reported that in the area above the girdling point, the leaf N content, C/N ratio and carbohydrate content were increased. Hossain et al. (2007) reported a new modified girdling technique as a form of partial ringing and observed that the peach plants can survive 98% girdling with improved fruit size, although the peach plants with 100% girdling did not survive.

The precise biochemical changes resulting from girdling have been studied only in limited cases and a detailed interpretation of the physiological effects of girdling is still lacking (Beruter & Feusi 1997). The aim of the present study was to examine the effects of various forms of girdling on fruit development and quality in the red water apple fruit (*Syzygium samarangense*) over two seasons.

Materials and Methods

EXPERIMENTAL SITE

The experiments were performed in orchards located at the Malaysian Agricultural Research and Development Institute (MARDI), Klang (2^0 30N, 112^0 30E) and at a commercial farm in Banting ($1^0$28 N, 111^0 20E), Malaysia, both at an elevation of approximately 45 m above sea level. The area under study has a hot and humid tropical climate. The soil in both orchards is peat, with a mean pH of approximately 4.6. The experiments were conducted between 2008 and 2010. The first season (December 2008–April 2009) of experiment was performed at MARDI, Jalan Kebun, Klang, and the second season (May 2009– October 2010) experiment was conducted at a farm in Banting. The trees were irrigated every seven days with fertilizers and insecticides applied according to the recommendations of the State Agricultural Department.

PLANT MATERIAL

Thirty six trees were selected for the study. The experiment consisted of six treatments including the control, in six replicates and five uniform branches were taken as a sample per experimental tree. The experiments were arranged in a randomized complete block design (RCBD) with six replicates.

GIRDLING

Different girdling techniques namely, I-shaped, 50% stress, 100% stress, V-shaped and C-shaped girdling were applied two weeks before flowering. Girdling was performed using a girdling knife which simultaneously cuts and removes the bark strips. The width of the girdle was between 2 and 5 mm depending on the branch size. In all the cases, the cut reached the cambium and was left bare without injury to the inner layer.

Partial ringing (I, C and V) was done by removing a partial ring 4 cm long and leaving a connecting strip 2 mm of I, C and V shape on the main stem. In the case of complete bark girdling, the bark was removed in ring fashion around the stem, without any phloem connection left. All the girdling was carried out 2weeks before flowering. Measurement of physiological parameters studied

NUMBER OF BUDS 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:

$$\text{Bud drop (\%)} = \frac{\text{Total number of Flowers}}{\text{Total number of buds}} \times 100.$$

FRUIT SET (%)

For the determination of fruit set from the tagged branches on the experimental tree, the number of flowers and total number of fruitlets were counted before and after anthesis. Fruit setting percentage was calculated using the following formula:

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

FRUIT DROP (%)

Fruit dropping percentage was determined using the following formula:

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

DETERMINATION OF CHLOROPHYLL CONTENT, FRUIT GROWTH, YIELD AND PEEL COLOR

The chlorophyll content in the leaves was determined using a SPAD-502 meter (Minolta Japan). Fruit growth (length and wide) and final fruit length and width were measured weekly with vernier calipers. Final fruit length and width was also determined with the help of Vernier caliper. Yield per treatment was recorded by weighing and counting the total number of fruits per treatment at the time of harvesting. The surface color of each tagged fruit was determined at three different points of the fruit using a standard color chart (Minolta, Japan) and expressed as percentage of color cover

EXTRACTION OF FRUIT JUICE

The fruit juice of each harvested fruit was extracted with a Philips juice extractor (model HR 1854) and juice volume was measured separately for each treatment with a measuring cylinder.

DETERMINATION OF POTASSIUM CONTENT AND TOTAL SOLUBLE SOLDS (TSS)

The TSS was evaluated at 25°C with a hand refractometer (Atago 8469, Atago Co. LTD., Japan) and expressed as °Brix. The K^+ content of the juice was determined by using a cardy Potassium meter (Model-2400, USA).

DETERMINATION OF TOTAL SUGAR

One gram of fruit pulp was homogenized in 4 mL of 0.5 M of sodium hydroxide and ground in a motar and pestle and then centrifuged at 3 500 rpm for 20 min at 4°C. The pellet was discarded and the supernatant neutralized with 0.5 M acetic acid. The resulting solution was made up to 40 mL and stored at 4°C until use. These extracts were then used for the determination of total soluble sugars according to the phenol-sulphuric method by Dubois (1956).One milliliter of the fruit juice was placed in a test tube and 1 mL of phenol (5% w/v) was added followed by 5 mL of concentrated sulphuric acid. Then the mixture was shaken and incubated in a water bath at 25-30°C. The absorbance was then determined in a spectrophotometer at 490 nm. The sugar concentration was obtained by referring to a standard glucose graph. The assay for this standard glucose graph was obtained by adding phenol and sulphuric acid to a standard glucose solution with concentrations ranging between 0-100 µg ml^{-1}. Total soluble sugars was expressed in g/100 g fruit fresh weight

STATISTICAL ANALYSIS

The two season's data were pooled and statistical analysis was performed using MSAT-C software. The one way ANOVA was applied to evaluate the significant difference of the parameter studied in different treatments. Duncan's new multiple range test (DMRT) was used to compare treatments when ANOVA showed significant differences among means at 5% level of significance.

RESULTS AND DISCUSSION

TOTAL NUMBER OF BUDS

It is well documented in the literature, from an agronomic point of view, that practices such as girdling can improve carbohydrate availability to fruits and as a consequent lead to an increase in fruit-set and yield (Goren et al. 2004; Rivas et al. 2004). In this study, different girdling techniques were employed to see their effects on fruit development. As shown in Table 1, there was no significant difference ($p \leq 0.05$), in terms of the number of buds/ branch V-shape phloemic stresses branches produced the highest number of buds amounting to about 38 buds per branch, followed by C-shape stress and the other treatments. Arakawa et al. (1997) reported that girdling of apple trees significantly increased flowering the following spring.

TABLE 1. Effects of different types of gindling on physiedogical charcater of wax jambu fruits*

Treatment (stress)	Number of buds	Bud drop (%)	Fruit set (%)	Fruits drop (%)	Yield kg/ branch)	Average fruit weight (g)
Control	35 ± 4.9a	48 ± 2.02a	32 ± 4.40c	55 ± 6.0a	0.31 ± 0.1d	38 ± 1.3c
I-S	35 ± 4.0a	36 ± 3.48b	43 ± 3.00b	40 ± 5.8a	0.51 ± 0.2bc	49 ± 1.8ab
50%	35 ± 2.3a	30 ± 2.02b	45 ± 6.62b	35 ± 7.9a	0.41 ± 0.1c	49 ± 1.74ab
100%	35 ± 4.0a	30 ± 1.45b	40 ± 5.29b	40 ± 2.9a	0.45 ± 0.1c	49 ±1.95ab
C-S	36 ± 3.5a	16 ± 1.88dc	62 ± 7.26a	36 ± 3.1a	0.76 ± 0.1a	51 ± 1.55a
V-S	38 ± 4.0a	10 ± 1.54c	56 ± 458ab	36 ± 5.9a	0.56 ± 0.1b	45 ± 2.20b

*Different alphabets within the same column indicate significant difference ($p = \leq 0.05$) ($n = 6$). (S= shape)

BUD DROP (%)

As shown in Table 1, V-shape girdling exhibited the lowest bud abscission number, averaging about 10% followed by C-shape girdling, 50% stress, 100% stress and I-shape girdling, respectively, in order of least bud dropped. Control branches recorded around 48% bud dropped. Almost five times more buds dropped in untreated branches compared to the V-shape girdled branch, which was statistically significant. Similar findings were reported previously in 'Ponkan' mandarins by Mataa et al. (1998). 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 of apple (Priestly 1976). The increase in carbohydrate supply caused by girdling has been shown to correlate well with a transient reduction in fruitlet abscission. Among other different factors, poor tree nutrition is a crucial factor which can cause bud and fruit drop (Stepenson et al. 1986).

FRUIT SET (%)

Girdling can improve photosynthesized availability and increase fruit-set and yield in citrus fruit (Goren et al. 2004; Rivas et al. 2004). The data in Table 1 shows that fruit setting was almost doubled in C-shape girdled branches compared to control branches. All the girdling treatments posted significantly higher ($p \leq 0.05$) fruit set values compared to the control which recorded about 32 % fruits set per branch.

FRUIT DROP (%)

Table 1 shows control branches showed the highest number of fruit dropped, whilst the least percentage of fruit drop was observed in the 50% stress treated branches followed by C and V-shape girdlings and 100% stress treatments. However, the percentage difference between the control and the other treatments were relatively small, between 0 and 15 percent and statistically non-significant ($p \geq 0.05$).

FRUIT GROWTH (LENGTH AND DIAMETER)

As can be seen in Figures 1 and 2, all the girdling treatments exhibited a higher growth rate of the fruits from the first week till the 7th week, with regard to fruit length and diameter, compared to the control. At the 5th week of observation, fruit length was 6.93 cm and 6.83 cm in C and V-shape girdlings, respectively whereas it was 5.23 cm in control. This growth trend was observed throughout the fruit developmental period until the harvesting period. Similar results were reported by Carreño et al. (1998).

In the case of fruit diameter, a similar trend was observed during the fruit development (Figure 2). At the 5th and 7th week of observation, fruit growth (diameter) was found to be significant between the treatments and control. The fruit diameter was 4.23 cm in C-shape stress whereas it was 3.26 in the control treatment. The control treatment showed the lowest growth rate compared to all the other treatments. Di Vaio et al. (2001) reported that the faster fruit growth rate observed could be the result of the accumulation of carbohydrates above the girdle. They reported that girdling has a positive effect on berry size in grapes. One of the possible causes for the fruit enlargement is the increase in sucrose levels, a few days after girdling which would enhance its availability for cell division and growth of fruitlets (Iglesias et al. 2006).

PEEL COLOR (%)

It has been shown that the application of sugars, especially sucrose, improves the color of skin disks of wax apple (Liaw et al. 1999). Recently it was reported that trunk girdling stimulated fruit color development and fruit softening after harvest of Japanese persimmon (Kazutoshi et al. 2009). The results in Figure 3 shows that fruit color was greatly enhanced by the various girdling techniques used in this study, with the C-shape and 100% girdling treated fruits exhibiting the greatest percentage color cover from day 14 till 28. Furthermore it was observed that on 14 days after anthesis, the red color of the fruits had already started to show in the treated branches compared to the control fruits,

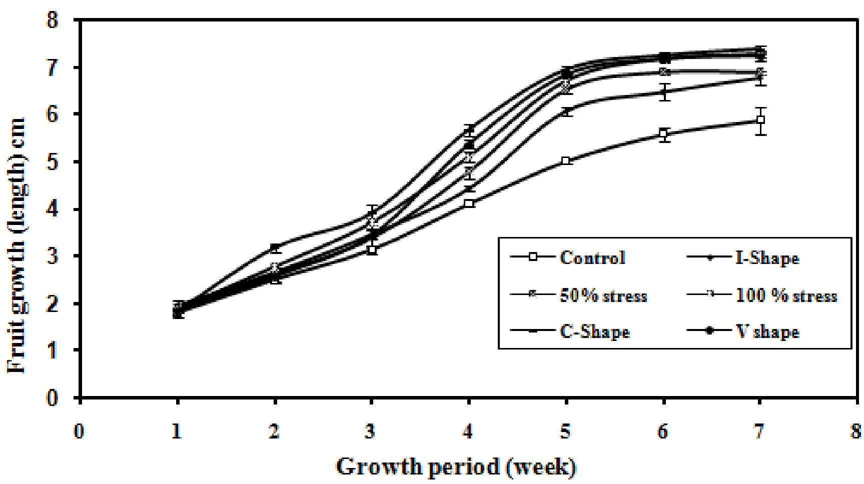

FIGURE 1. Fruit growth (length) as affected by diferent girdling techniques.

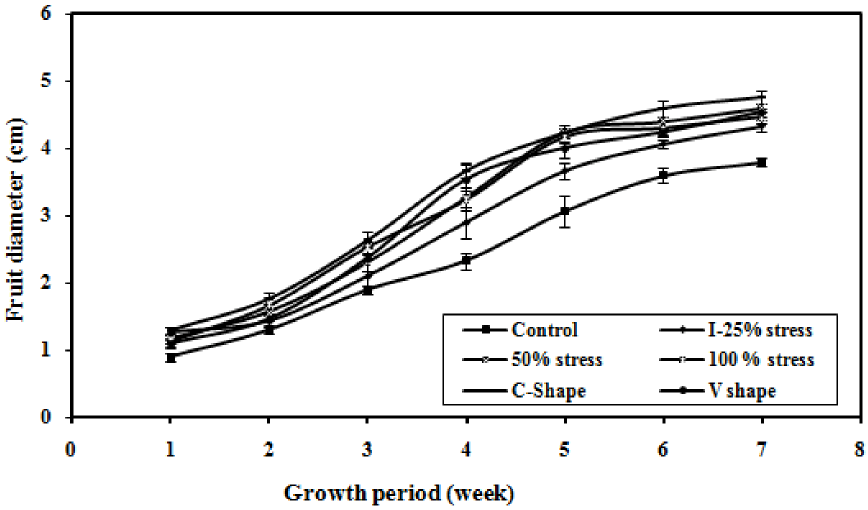

FIGURE 2. Fruit growth (diameter/week) as affected by different girdling techniques

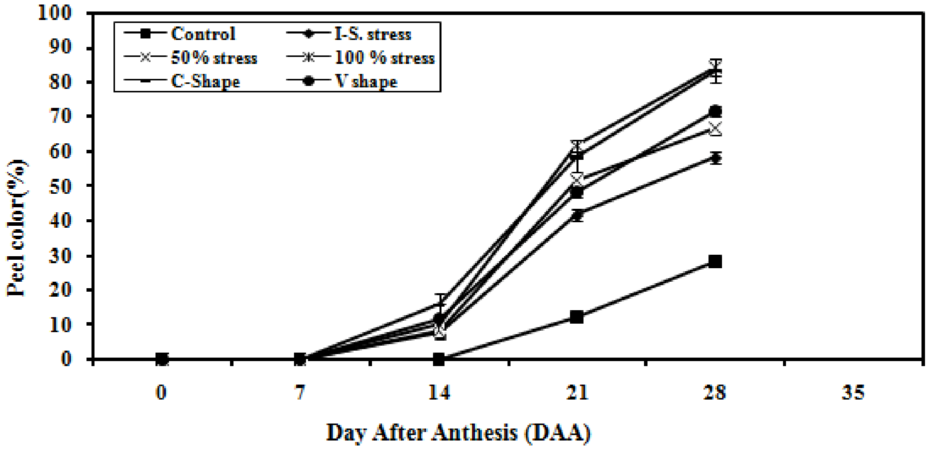

FIGURE 3. The effect of different type of girdling on peel color (%) of wax apple fruits after anthesis

which only started colouring one week later. From the graph it can be seen that a significant difference ($P \leq 0.05$) was observed in peel color development among different treatments and control. Matsui et al. (1979) reported similar results in grapes. They reported that anthocyanin and sugar accumulation increased proportionately with increasing leaves per cluster of girdled shoots.

YIELD (KG/TREATMENT)

It is well documented that girdling is considered to be an important horticultural practice responsible for improving fruit set, yield as well as the physical and chemical properties of various fruits through the accumulation of carbohydrates and natural plant hormones above the girdling rings. It has been reported that girdling had a positive effect on berry size (Carreño et al. 1998). As shown in Table 1, all the girdled branches in this study yielded higher fruit weight than the untreated control. The yield, on a fruit weight basis, was almost 50% higher in the treated branches compared to the control. Lahav et al. (1986) reported that a general increase in yield of the girdled branch was observed in the first season, after girdling in avocado trees. Allan et al. (1993) reported that girdling resulted in a greater number of fruits, larger and of desirable marketable size (>90 g) than the control, in the low chill peach cultivar, Florida prince. After the first season the girdled branches regenerated new phloem to fill the gap left by the girdle as a healing process. After a few months, regenerated phloem will make a connection between upper and lower part of girdling ring.

LEAF CHLOROPHYLL CONTENT

Girdling has been shown to alter the partitioning of photosynthates, mineral nutrients and plant growth regulators in trees (Mataa et al. 1998). It would be interesting to see how this in turn affects, if at all, the leaf chlorophyll content.

In this study the chlorophyll content was determined using a Minolta SPAD meter. As shown in Figure 4 the chlorophyll readings in leaves from all the treated branches were higher than the control branch, up to 43% higher, in the C-shape treated branches. The greener leaves observed could be linked to possible increase in sugars resulting from the girdling and stress treatments, although this has to be investigated further. Furthermore the partitioning of photosynthates, mineral nutrients and plant growth regulators as a result of such treatments could also have had an effect.

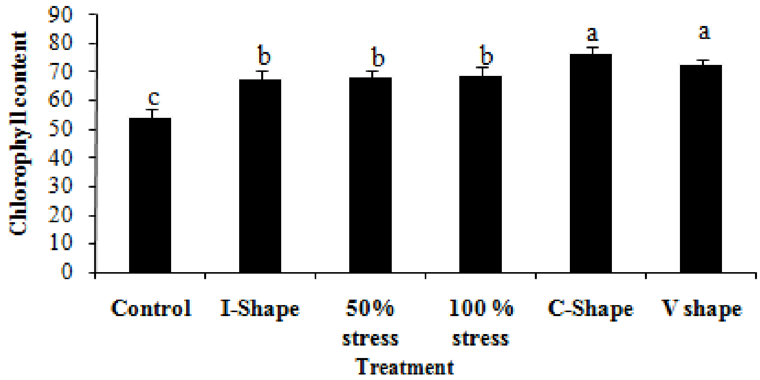

FIGURE 4. Content of mean chlorophy ll (SPAD) of leaves as affected by different types of girdling techniques (n=12)

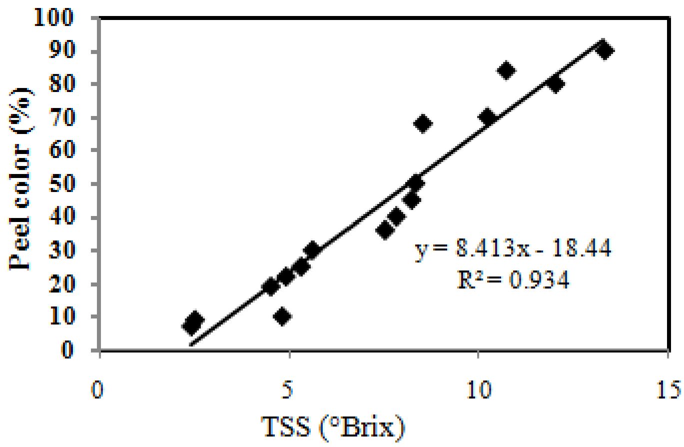

FIGURE 5. Correlation between peel color (%) and TSS (°Brix) of waxjambu fruit as affected by C-shaped phloemic stress

TABLE 2. Effects of different types of girdling on juice content, dry matter, K^+, TSS (°Brix) and total sugar content in wax jambu fruits.*

Treatment (stress)	Juice (m1/100g)	DM fruit (g/100g)	DM leaf (g)	K+ content mg/kg	TSS (°Brix)	Total Sugar (mg/10g)
Control	88 ± 3.5a	9.2 ± 0.1c	1.12 ± 0.1c	15.3 ± 0.1c	5.6 ± 0.3d	3.63 ± 0.6c
I-S	87 ± 4.3a	17.5 ± 0.1a	1.88 ± 0.1a	48.7 ± 9.3a	10.7 ± 1.3c	6.18 ± 0.4a
50%	84 ± 3.2a	14.5 ± 0.2b	1.68 ± 0.2ab	46.7 ± 5.8ab	11.4 ± 0.4bc	4.75 ± 0.4b
100%	78 ± 4.4a	14.9 ± 0.3b	1.52 ± 0.2b	37.3 ± 7.5b	12.1 ± 0.4b	4.64 ± 0.5b
C-S	89 ± 4.5a	18.0 ± 0.7a	1.93 ± 0.1a	38.0 ± 10.4b	13.3 ± 0.5a	6.80 ± 0.3a
V-S	87 ± 3.1a	17.4 ± 0.2a	1.59 ± 0.1ab	41.3 ± 5.8ab	13.0 ± 0.6bc	6.57 ± 0.0a

*Different alphabets within the same column indicate significant difference (p=≤ 0.05) (n = 6). (S= Shape)

CORRELATION BETWEEN PEEL COLOR AND TSS

As can be seen in Figure 5, it was observed that fruit peel color correlated with its TSS content. In the case of C-shape girdled fruits the TSS content of fruit juice increased positively with the peel color development.

FRUIT JUICE AND DRY MATTER CONTENT

There was no significant difference for juice content between the different treatments. Table 2 shows that mean juice content (mL/100 g) was 89 mL in C-shape girdling followed by the control, I-shape and V-shape and 50% stress treatments, with a juice content of 88, 87 and 82 mL, respectively. The results indicated that fruit dry matter (DM) content increased with the different girdling practices. From Table 2 can be seen that the highest DM content of fruit/100 g was observed in C-shape stress (18.00g) followed by I-shape, V-shape and 50% stress, with a DM content of 17.50, 17.36 and 14.50 g, respectively, whereas the control was 9.21 g. However the results for the four stress treatments were not statistically significant although they were significantly different ($p \leq 0.05$) from the control. The leaf DM content analyzed on the 5th week of fruit development also showed significant differences ($P \leq 0.05$) between the treatments and control. It was observed that the highest leaf DM content was recorded in C-shape stress treatment (1.93 g) followed by I-shape, 50% and V-shape treatments with a value of 1.88, 1.68 and 1.59 g, respectively. Control leaves had the lowest value of 1.12 g. Hossain et al. (2006) found similar results in peach trees. They reported that carbohydrate transport from leaves to roots through phloem was reduced with girdling. This will in turn suppress food movement to the lower parts of the plant or tree and increase growth in the upper regions of the plant.

POTASSIUM AND TSS CONTENT OF FRUIT

In the case of K^+ content, the different girdling techniques produced significant variation ($P \leq 0.05$) between themselves and the control. Results showed that the K^+ content of fruit juice was higher (48.67 g) in I-shape stressed branches followed by 50% stress, V-shape and C-shape girdle fruits with a value of 46.67, 41.33 and 38.00 g, respectively with the control recording the lowest value of 15.33 g. The TSS content of fruit juice was found to be statistically significant ($P \leq 0.05$) between the treatments and control. From the results, it was observed that the highest TSS was recorded in C-shape stress fruits (13.33 °Brix), followed by V-shape, 100 %, and 50 % stress with a TSS of 13.00, 12.13 and 11.36 (°Brix), respectively (Table 2) while, the lowest TSS (5.63 °Brix) was recorded in untreated fruits. These results are in agreement with the findings of Iwahori et al. (1976). They reported that fruit quality enhancement in ponkan mandarin oranges, with regard to fruit color and soluble solids, in phloem ringed plants compared to the control.

TOTAL SUGAR CONTENT

The total sugar content of fruit juice was found to be statistically significant between the different ($P \leq 0.05$) treatments and control treatment. From the results, it was observed that the highest (6.8 mg/100 g) total sugar was recorded in C-shape stress fruits followed by V-shape, I-shaped, 50%, and 100% stress with a total sugar of 6.57, 6.18 ,4.75 and 4.64 mg/100 g, respectively (Table 2) while, the lowest total sugar (3.63 mg/100 g) was recorded in untreated control fruits. These results are in agreement with the findings of Kazutoshi et al. (2009). They reported that sugar content increased in Japanese persimmon, in phloem ringed plants compared to the control.

CONCLUSION

It can be concluded that different types of girdling (phloemic stress), particularly C-shape girdling can improve the growth and development as well as the nutritional status of wax jambu. C-shape girdling improved fruit set, reduced fruit dropping, enhanced faster fruit growth and increased the yield, dry matter, chlorophyll content, TSS and the total sugar content of fruit. V-shape girdling gave similarly promising results with regard to bud and fruit dropping which is a serious problem in wax jambu production. Girdling also enhanced the K^+ content, peel color development and dry matter content as well as improved the yield and quality of the fruits. Thus, it can be concluded that C and V-shape phloemic stress applied two weeks before flowering can enhance the growth and development of wax jambu fruits to meet commercial demands.

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