J. Trop. Agric. and Fd. Sc. 29(1)(2001): 7–15

Growth, precocity and productivity of starfruit (*Averrhoa carambola* L.) in response to root restrictive membranes

(Kesan membran pembatasan akar terhadap tumbesaran, kematangan dan daya pengeluaran belimbing besi (*Averrhoa carambola* L.)

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Key words: growth, precocity, productivity, root restrictive membrane, starfruit

Abstrak

Tumbesaran serta peningkatan hasil pokok buah-buahan saka dapat dikawal melalui banyak kaedah. Pembatasan akar menggunakan membran geotekstil telah dikaji terhadap belimbing besi bagi mengawal tumbesaran tampang dan meningkatkan hasil. Sebanyak 60 pokok belimbing (B10 dan B17) yang berumur satu tahun telah diujikaji dengan empat perlakuan pembatasan akar menggunakan reka bentuk blok lengkap terawak yang diulangsama sebanyak enam kali. Ketinggian pokok dan garis pusat batang tanaman yang dibataskan akarnya berkurangan sebanyak 10–12% berbanding dengan kawalan. Tumbesaran pucuk seperti jumlah keluasan daun, bilangan daun dan bilangan pucuk juga berkurangan. Pembungaan pula lebih cepat manakala purata berat buah, bilangan buah dan hasil yang boleh dipasarkan tidak terjejas. Tambahan pula, hasil tanaman daripada kaedah pembatasan akar adalah lebih tinggi daripada hasil tanaman yang ditanam secara konvensional pada tahun kedua pengeluaran. Pembatasan akar juga dapat mengurangkan tumbesaran tampang dan mempercepat pengeluaran hasil. Kaedah ini boleh digunakan secara praktik untuk mengawal saiz pokok serta dapat menjimatkan penggunaan tenaga buruh dalam perusahaan penanaman belimbing.

Abstract

Tree vigour control and yield improvement of perennial fruit trees could be achieved through many cultural practices. A study was conducted on starfruit trees using geotextile membrane to examine the effects of root restriction in controlling vegetative growth and improving precocity. Sixty one-year-old starfruit trees (B10 and B17) were subjected to four treatments of root restrictive membranes arranged in a randomized complete block design with six replications. Plant height and stem diameter of root restrictive-membraned plants were reduced by 10–12% compared to the control. Vegetative shoot vigour also decreased as indicated in the reduction of total leaf area, leaf number and shoot number. Although flowering was enhanced, average fruit weight, fruit number and marketable yield were unaffected. Moreover, the yield of restricted plants was more compared to the yield obtained through conventional planting in the second year of production. This study shows that root restrictive membrane is an effective mean to reduce vegetative growth and promote precocity. It offers a practical approach to control tree size and labour saving in commercial planting of starfruits.

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Introduction

Modern orchard production depends on efficient means of tree growth control. Besides using dwarfing rootstock, root pruning and chemical growth retardants to control tree size, there is an increasing recognition of the importance of root growth restriction. The classic example of root restriction in which plants are dwarfed by growing them in shallow containers with small soil volume is bonsai trees (Tukey 1964; Erez 1982; Brace 1904). Physical restriction of the tree roots has proven beneficial results, such as reduced tree size and increased precocity (Ferree 1981; Schupp and Ferree 1988; Erez et al. 1992). Plant size control through root restriction is effective in large and fast growing fruit trees (Ferree et al. 1992). Otherwise, trees with large canopies are difficult to prune, spray and hand harvest the fruits, and even have poor light distribution (Lakso et al. 1989).

It is known that confining the root system of tree crops controls their shoot growth. Cockroft and Wallbrink (1966) pointed out that peach tree vigour is related to the volume of soil readily accessible to the root system. Reducing container volumes in apple and peach dramatically reduced plant size, leaf area and shoot length (Erez et al. 1992). Tree height, trunk diameter and mean number of lateral shoots per tree were reduced in peach trees grown in fabric-lined trenches (Williamson and Coston 1990).

Starfruit (*Averrhoa carambola* L.) has been identified as one of the important fruit types to be promoted commercially. Due to high demand, starfruit has become popular in the local market and among consumers abroad (Izham and Abd Razak 1992). Although the future prospects are bright, the cultivated area is still small. In 1990, starfruit cultivation was 1 533 ha while, in 1996 it was 1 423 ha with production of 17.2 and 37.2 thousand tonnes of fresh fruits, respectively (Department of Agriculture 1996). There are not many limitations to growing this fruit extensively due to its wide soil and climatic adaptability. However, there are other constraints that hinder their cultivation (Izham and Abd Razak 1992). The major problems are high production cost in pruning and fruit wrapping because of large tree size. Due to its vigorous and indeterminate vegetative growth, plant height increase is tremendously fast. High rainfall and plentiful sunshine promote further shoot growth. Besides the high production costs, the prospects for future fruit cultivation are hampered by labour and land shortages.

Innovative techniques need to be investigated to develop productive fruit trees of manageable size. One of the possible avenues is by controlling vegetative vigour through effective and safe methods that can restrict tree size and canopy development as well as increase production efficiency (Quinlan and Tobutt 1990; Robinson et al. 1991). Hence, a study was carried out to observe the effects of different sizes and shapes of root restrictive membrane in response to growth, precocity and productivity of starfruit. This information may help in understanding the performances of tropical fruit tree subjected to root restriction. This may lead to rapid increase in starfruit cultivation in the country.

Materials and methods

Planting materials

Sixty one-year-old starfruit plants (B10 and B17 variety) were used in this study. The experimental plants were subjected to four root restrictive membrane treatments i.e. V-shape (187-litre), rectangular shape (182-litre), V-shape (91-litre), rectangular shape (91-litre) and a control (no membrane). The plants were planted at planting distance of 2 m x 4 m. The study was initiated at MARDI, Serdang on 24 April 1997. The soil type is of the Serdang Series. Fertilizer and water were given as scheduled according to Rahman et al. (1992).

Restrictive root membrane and site preparation

Prior to field planting, two trenches were dug in the experimental plots by an excavator in early February 1997. Each trench measured 45 cm wide, 45 cm deep and 60 m long. Individual sections of porous membrane were cut accordingly to predetermined volumes. These membranes were then folded into envelopes with one end opened and placed horizontally in the excavated trenches. The open-end of each membrane was curved upwards from the trench bottom and protruded about 10 cm above the soil surface. Geotextile membrane (*Terram 3000*) made of 100% polypropylene with 100 µm pore size was used in this experiment. Reinforcement of porous membrane in the ready-made trenches was accomplished by securing predetermined plywood templates of known volumes. The trenches were then backfilled with soil to the original level *(Figure 1)*. Each planting hole was given 10 kg of organic matter and 200 g of rock phosphate (CIRP) as starter fertilizer.

Measurement of parameters

Vegetative shoot measurements such as plant height, stem diameter, total shoot length and shoot number were recorded at two-month intervals for 14 months. Plant height was measured with a self-made extended ruler. Stem diameter was measured using a micrometer at the union between rootstock and scion (about 15 cm from the ground).

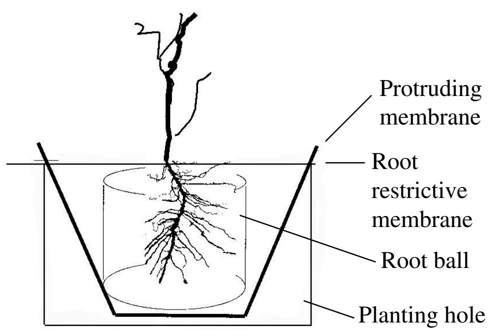

Figure 1. A schematic diagram of root restrictive membrane laid in a planting hole

Total shoot length was obtained by summing up all primary subtending shoots measured. Shoot number was obtained by counting all the new flushes emerging from every shoot. Total leaf area per plant was estimated from leaf area model, TLA = ALA*LN*0.7 where TLA is the total leaf area, ALA is the average leaf area obtained from a 50 leaf-sample using a planimeter, LN is the total leaf number, 0.7 is the conversion factor. The total leaf number was obtained by manually counting all the leaves of the experimental plant.

Inflorescence number per tree at 50% full bloom was accounted for all branches, starting from the bottom to the topmost shoot at 6 and 12 months. Fruit thinning was done manually and only one fruitlet (more than 5 mm) on each inflorescence was retained and fruiting data were recorded at 14th month. Fruits were wrapped and harvested at index 2.

Experimental design and statistical analysis

The experiment was arranged in a completely randomized block design. Each experimental plot comprised a single plant, and was replicated six times. Data were analysed using the SAS package (SAS Institute 1985) and the Least Significant Difference (LSD) was carried out to determine level of significance among treatment means. Flowering and fruiting parameters were transformed to log (x+1) to stabilize the variance before ANOVA was carried out. The original means of transformed data were used when the ranking order of means in the original scale and the transformed scale were not different (Gomez and Gomez 1976). For significant treatment effects, contrast analysis was carried out to test specific hypotheses namely; i) Restricted vs Non-Restricted (Control) ii) 'V' Shape vs Rectangular shape iii) V shape : Large volume vs small volume (>180-litre vs >90-litre) and iv) Rectangular Shape : Large volume vs small volume (>180-litre vs >90-litre). Constrast analysis using orthogonal coefficients to partition means sum of squares among treatment comparisons were used. The method of orthogonal polynomial comparisons were chosen over multiple comparison because of greater sensitivity (Nelson and Rawlings 1983).

Results

Growth

Plant height, stem diameter and total shoot length are growth indicators to measure vegetative plant performances. Other parameters used are total leaf area, leaf number and shoot number. The restrictive membrane treatments had significant influences on plant height and stem diameter. All restricted plants had lower overall means of plant height and stem diameter than the control by 9.4% and 12%, respectively. However, total shoot length showed no response *(Table 1)*. Significant differences in plant height were also detected in the treatment comparisons between V and rectangular-shape membrane *(Table 2)*. The mean plant height of rectangular-shape membranes was much lower (3%) than that of V-shape. For varietal growth performances, B17 was more superior than B10 in plant height, stem diameter and total shoot length by 7, 15 and 63%, respectively.

Total leaf area was significantly influenced by the root restrictive membrane treatments. The 91-litre of V-shape membrane had the least total leaf area of 2.9 m^2 per plant. All restricted plants had 67% lower total leaf area than the control (no membrane) *(Table 3)*. For treatment comparisons, significant differences were observed between restricted and non-restricted treatments and between large and small volumes of V-shape membranes *(Table 4)*. All restricted plants had an overall mean total leaf area of 4.2 m^2 per plant compared to 7.0 m^2 per plant in non-restricted plants while small volume of V-shape membrane had significantly smaller (41%) total leaf area than bigger volume. For leaf number, the overall mean leaf number in all

Table 1. Vegetative plant performance of starfruit (B10 and B17) grown in root restrictive membrane after 14 months

Treatment	Plant height (cm/plant)			Stem diameter (mm/plant)			Total shoot length (cm/plant)		
	B10	B17	Mean	B10	B17	Mean	B10	B17	Mean
V-Shape (187-litre)	213.0	234.7	223.8b	42.1	50.0	46.0b	744.7	887.0	815.8a
Rectangular (182-litre)	197.5	221.0	209.3bc	38.4	48.0	43.2b	760.8	828.5	794.7a
V-Shape (91-litre)	208.5	222.0	215.8abc	42.4	48.1	45.3b	783.8	845.3	814.6a
Rectangular (91-litre)	202.0	205.0	203.5c	41.8	46.8	44.3b	749.8	806.7	778.3a
Control (no membrane)	226.3	239.2	232.8a	47.1	53.3	50.2a	763.5	896.3	829.9a
Mean	209.5a	224.6b	217.1	42.3a	49.2b	45.8	760.5a	852.8b	807.0

Mean values in the same row or columns with the same letters are not significantly different at $p < 0.05$

Table 2. Treatment comparisons in plant height, stem diameter and total shoot length

Treatment comparison	Plant height	Stem diameter	Total shoot length
Restricted vs Non-restricted	*	**	ns
V-shape vs Rectangular shape	*	ns	ns
V-shape : (187-litre vs 91-litre)	ns	ns	ns
Rectangular shape: (182-litre vs 91-litre)	ns	ns	ns

*Significance level at $p < 0.05$
**Significance level at $p < 0.01$
ns = not significant

restricted plants was 204 leaves/tree compared to 302 leaves/tree in non-restricted plants i.e. a difference of 48%. For treatment comparisons, the V-shape of small volume had 44% lesser leaf number than the large volume. However, no significant difference was detected between different membrane shapes irrespective of volumes.

Similarly, root restrictive membrane treatments had partial effects on shoot number. The overall mean shoot number in all membraned plants was 130 compared to 163 in the control (*Table 3*). Treatment comparisons showed that all restricted plants had significantly lesser shoot number than non-restricted plants (*Table 3*). But, no significant response was observed between membrane volumes or shapes. For varietal performance, B17 had 63% higher shoot number, 30% higher total leaf area and 25% higher leaf number respectively, compared to B10.

Precocity

Root restrictive treatments significantly influenced precocity which was indicated by the highest number of inflorescences at 6 months *(Table 5)*. Treatment comparisons also showed that there were significant differences between different volumes of the V-shape membranes *(Table 6)*. The small volume of 91-litre in V-shape membranes had significantly higher inflorescence number with 50.8 inflorescences/tree compared to large volume of 187-litre with only 13.3 inflorescences/tree. All restricted plants had overall mean of 615 inflorescences per tree compared to 745 in non-restricted plants at 12 months, a difference of 21% but showed no significance. Highly significant differences were observed due to varietal effects on number of inflorescences at both 6 and 12 months. B17 had 30% and 51% higher inflorescence number than B10 at 6 and 12 months, respectively.

Yield

No significant root restriction effects was observed on average fruit weight of starfruits (*Table 7*). It showed that the membrane treatments did not influence individual fruit growth. However, regardless of treatments most fruits were heavier than 150 g per fruit, which is an important fruit size selection for marketing. Similar results of non-significant effects of membrane treatments were observed for harvestable fruit number and marketable yield. Overall results showed that B10 had higher average fruit weight, harvestable fruit number and marketable yield than B17. All these results indicated that yield was unaffected by root restriction.

Discussion

Restricting starfruit root system using root restrictive membranes resulted in a reduction of plant height and stem diameter by 9.4% and 12%, respectively after 14 months of planting. Similar results were shown in peach trees that reduced both tree height and diameter by 35% after three years of growth in fabric-lined trenches (Williamson and Coston 1990).

Table 3. Total leaf area, leaf number and shoot number of starfruit (B10 and B17) grown in root restrictive membrane after 14 months

Treatment	Total leaf area (m^2/plant)			Leaf number (no./plant)			Shoot number (no./plant)		
	B10	B17	Mean	B10	B17	Mean	B10	B17	Mean
V-Shape (187-litre)	4.4	5.4	4.9b	226	243	234b	102.3	166.9	134.6ab
Rectangular (182-litre)	3.4	6.5	4.9b	160	278	218bc	102.5	161.1	131.8ab
V-Shape (91-litre)	2.3	3.6	2.9c	129	195	162c	103.0	143.8	123.4b
Rectangular (91-litre)	4.6	3.7	4.2bc	216	186	201bc	105.0	144.4	124.7b
Control (no membrane)	6.0	8.0	7.0a	247	357	302a	102.2	224.6	163.4a
Mean	4.1a	5.4b	4.8	196a	252b	224	103.0a	168.1b	135.6

Mean values in the same rows or columns with the same letters are not significantly different at $p < 0.05$

Vegetative shoot vigour which decreased by membrane treatment irrespective of shape or volume, was possibly due to early inhibition of the root system. This means that plants have less water and nutrient uptake resulting in a smaller plant canopy spread and less flushing of new shoots. Several researchers who carried out studies in peach supported this finding where they found that root restriction caused reduction in mean number of lateral shoots per tree and shoot length (Erez et al. 1992; Boland et al. 1994; Rieger and Marra 1994). The reduction in vegetative shoots was also suggested to be due to hormonal regulation (Richards and Rowe 1977), but others proposed that it was due to water stress (Ismail and Mohd Noor 1996).

In addition, total leaf area and number were affected by the membrane treatments; particularly in the small size membrane (91-litre) of V-shape. The reduction of these parameters would consequently lead to smaller plant size. Hence, the advantage of reduction in plant size is not only for easy maintenance, but also ease in hand wrapping and harvesting, and less pruning frequency.

Root restriction enhanced flowering of starfruit in this study. Similar results were also observed in peach (Williamson and Coston 1990; Boland et al. 1994) and starfruit (Ismail and Mohd Noor 1996). Although early flowering was observed in root restriction, there was an indication of inconsistency of flowering in the following season. It was believed that enhancement of flowering was triggered by stress, and high reserves utilized during the first flowering was uncompensated during subsequent season and this phenomenon similarly occurred in durian (*Durio zibethinus*) (Zainal Abidin, M., MARDI, Serdang, pers. comm. 1998). Others proposed that it might be possibly due to an alteration in the supply of growth substances from the roots to shoots (Williamson and Coston 1990).

Average fruit weight and fruit number were unaffected by root restrictive

Table 4. Treatment comparisons in total leaf area, leaf number and shoot number

Treatment comparisons	Total leaf area	Leaf number	Shoot number
Restricted vs Non-restricted	**	**	**
V-shape vs Rectangular shape	ns	ns	ns
V-shape : (187-litre vs 91-litre)	*	ns	ns
Rectangular shape: (182-litre vs 91-litre)	ns	ns	ns

*Significance level at $p < 0.05$
**Significance level at $p < 0.01$
ns = not significant

Table 5. Number of inflorescences at 6 and 12 months in starfruit (B10 and B17) grown in root restrictive membrane

Treatment	6 months (no./tree)			12 months (no./tree)		
	B10	B17	Mean	B10	B17	Mean
V-Shape (187-litre)	11.3	15.1	13.3c	605.7	770.7	687.7a
Rectangular (182-litre)	18.7	41.8	30.3abc	497.0	735.3	616.2a
V-Shape (91-litre)	56.1	45.5	50.8a	476.7	750.8	613.8a
Rectangular (91-litre)	34.1	45.5	39.8ab	424.0	659.3	541.7a
Control (no membrane)	19.0	31.3	25.2bc	545.8	945.0	745.4a
Mean	27.8a	35.9b	31.9	509.6a	772.2b	640.9

Mean values in the same rows or columns with the same letters are not significantly different at $p < 0.05$

Table 6. Treatment comparisons in number of inflorescences per tree at 6 and 12 months

Treatment comparisons	6 months	12 months
Restricted vs Non-restricted	ns	ns
V-shape vs Rectangular shape	ns	ns
V-shape : (187-litre vs 91-litre)	*	ns
Rectangular shape: (182-litre vs 91-litre)	ns	ns

*Significance level at $p < 0.05$
**Significance level at $p < 0.01$
ns = not significant

membranes as these parameters are important in yield components. Similar results were also observed in peach that fruit weight and diameter were not affected (Mandre et al. 1995). As root-restricted plants are smaller in size, at least four times more root-membraned plants could be grown per unit area (1 250 plants/ha) compared to conventional planting. Thus, closer planting distance might attribute to high yield production. The estimated marketable yield of starfruit (B10 and B17) in this study was estimated to be 19.6 t/ha. This means that the present yield obtained was 18% higher compared to conventional planting yield of 16.6 t/ha (Rahman et al. 1992). This eventually will benefit commercial growers in gaining more yield and early returns. Recent studies by Fumuro et al. (1997) also found that root restriction in Japanese persimmon resulted in high precocity and yield after three years of planting.

No nutrient deficiency symptoms in shoot growth were observed in the root restrictive membranes in this study. Probably nutrients in the confined root system were still adequate (data not shown). However,

Table 7. Average fruit weight, harvestable fruit and marketable yield of starfruit (B10 and B17) grown in root restrictive membrane

Treatment	Average fruit weight (g/fruit)			Harvestable fruit (no./tree)			Marketable yield (g/plant)		
	B10	B17	Mean	B10	B17	Mean	B10	B17	Mean
V-Shape (187-litre)	180.0	130.3	155.2a	35.0	15.2	25.1a	6323	2060	4192a
Rectangular (182-litre)	155.5	153.6	154.5a	30.7	14.9	22.8a	5743	1539	3641a
V-Shape (91-litre)	173.5	179.6	179.6a	35.0	15.2	25.1a	4996	3412	4204a
Rectangular (91-litre)	180.7	168.6	174.6a	28.0	15.0	21.5a	5653	1707	3680a
Control (no membrane)	183.7	134.4	159.1a	44.4	15.2	29.8a	7981	1790	4886a
Mean	175.3b	150.9a	164.0	35.0b	15.1a	25.0	6139b	2101a	4120

Mean values in the same rows or columns with the same letters are not significantly different at $p < 0.05$

Williamson and Coston (1990) suggested that P concentrations were low in peach trees after two years. It was believed that starfruit root system was not adversely suppressed as to show detrimental effects on its leaves.

The mechanism by which root restrictive membrane control the growth and precocity has not been fully elucidated. Clearly, additional research is needed to study physiological response such as water and nutrient uptake on growth regulation of starfruit.

Conclusion

The present study shows that restricting the root system in starfruit using root restrictive membranes irrespective of volume or shape is able to effectively reduce plant size and increase precocity. The advantage of using these membranes is that more plants could be planted per unit area since no dwarfing rootstock is currently available. Besides, growers would expect an early returns as well as labour saving in the commercial planting of starfruits. The high yield obtained could offset additional cost incurred by these membranes.

Acknowledgement

The author thanked Mr Mohd. Nasir Abdullah, Ms Zaharah Talib and Dr Izham Ahmad for their field assistance, statistical analysis and technical comments, respectively. Special thanks are also due to Prof. Wong Kai Choo and Ass. Prof. Wan Mohamad bin Wan Othman of Universiti Putra Malaysia and Universiti Malaysia Sabah, respectively for their continuous and kind encouragements. He also thanked the Ministry of Science, Technology and Environment and MARDI for research grant through IRPA Project No. 01-01-03-0371.

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Accepted for publication on 16 May 2001