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Selective pruning and crop removal increase early-season fruit production of carambola (*Averrhoa carambola* L.)

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Abstract

Carambola (*Averrhoa carambola* L.) trees grow and bear fruit year-round in their native, tropical environment. Fruits of this species are borne mainly on the canopy periphery, and the delicate skin is easily damaged during windy conditions (wind-scar). Pruning, as well as fruit drop caused by strong winds, stimulates re-bloom of carambola trees. In subtropical southern Florida, cool temperatures and dry winds during the winter inhibit tree growth and shorten the production season to July–February. Crop value is greatest during the early part of the season. We evaluated manual, selective pruning and crop removal as techniques for increasing production of early-season fruit in 'Arkin' carambola. Pruning 3–4-year old branches to their main axes in early March (late winter in the Northern Hemisphere) resulted in flowering during mid-April (mid-spring) and a crop by the end of June (early summer), whereas harvest of intact, non-pruned trees began 4–5 weeks later. Pruned branches produced 15 kg (November pruning) to 24 kg of fruit (July pruning). Selectively pruned branches deep within the tree canopy did not appear to be moved by wind as much as branches along the canopy periphery. Thus, fruit from pruned branches were nearly 100% free of wind-scar and had excellent appearance. In comparison, more than 58% of fruit harvested from the canopy periphery had wind-scar, with only ca. 20% free from such damage. Crop removal in November or December (mid–late-autumn) increased early bloom and the amount of early fruit produced in the summer. De-fruited trees produced an average of 48 kg per tree of early fruit, harvested July 7, whereas non-de-fruited trees produced an average of only 5 kg per tree.

Keywords: Star fruit; Canopy manipulation; Flowering; Phenology; Fruit quality

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1. Introduction

Carambola (*Averrhoa carambola* L., Oxalidaceae), a fruit tree originally from tropical Asia (15°S–23°N latitude), is now grown in many tropical and subtropical regions of the world between latitudes 0°N and 30°S. The main carambola producing areas are in Taiwan, Malaysia, Indonesia, Hawaii, Florida, and India (Galán-Saúco, 1993). In their natural, tropical habitat, carambola trees bloom and produce fruit nearly year-round owing to the near absence of environmental stress and continuous, growth-promoting warm temperatures (Watson et al., 1988; Galán-Saúco, 1993; George and Nissen, 1994). In subtropical southern Florida, however, winter months are characterized by cool night temperatures below 15°C, and frequent strong winds, which inhibit growth of the main cultivar, 'Arkin'. Winter conditions in Florida reduce growth and the annual production season of 'Arkin' trees to a 7-month period lasting from mid-July to mid-February (Campbell et al., 1985; Núñez-Elisea and Crane, 1999). Very little to no carambola fruit is produced in southern Florida from late February to early July. As with other seasonal crops, the value of carambola fruit increases substantially during times of scarce production. Therefore, carambola production between March and July would increase crop value.

Judicious manipulation of growth and production cycles in fruit trees, including carambola, requires an understanding of the trees' developmental and phenological features. The normal flowering period of 'Arkin' trees extends from March to early November. Flowers occur on panicles that arise mainly from axillary buds on 1–2-year old wood and current season's leafy shoots. However, panicles can also emerge from lateral buds on older, leafless wood, including scaffold branches and the trunk. Flower production on old branches occurs after trees are mechanically pruned for tree size control (Crane et al., 1991). In addition, buds of carambola readily form new panicles if the original panicle fails to set fruit or is destroyed (Núñez-Elisea and Crane, 1998). This feature does not appear to be age-related, as it is observed in young (1–2-year old) axillary buds on leafy shoots, as well as in older, lateral buds on leafless wood. The long flowering period and the ability of different wood types to initiate panicles indicate that environmental, physiological, or cultural factors conducive to overall tree growth trigger floral initiation in carambola. Since pruning stimulates new growth, selective branch pruning may be useful in forcing flowering episodes for timing carambola fruit production. Preliminary pruning trials revealed that upon cutting back and thinning out lower canopy branches of 'Arkin' trees at various times of the year, panicles were produced not only from dormant lateral buds on cut-back wood, but also around the branch collars (stumps) of thinned-out lateral branches that had been removed (Núñez-Elisea and Crane, 1999).

Carambola production peaks in August–September and December–January in southern Florida. Most of the crop (about 70–80%) is produced on the canopy periphery on long, thin branches that are moved by strong winds, resulting in fruit damage. A large volume of fruit (often more than 30%) is unsightly due to damage caused by wind-scar, and is discarded at the packinghouse. Thus, increasing production of fruit free of wind damage can potentially increase carambola crop value.

Complete fruit removal caused by the winds of hurricane Andrew in August of 1992 suggested that timely fruit removal may help modify the cropping cycle of carambola. Winds in excess of 200 km/h completely defoliated carambola trees and caused total fruit loss (Crane et al., 1994). Abundant re-foliation took place within the following 2 months, during September–October. Flowering and fruiting during 1993 occurred earlier than usual, and fruit harvest began in late June, about 1 month ahead of the normal start of the harvest season. It is possible, therefore, that controlled fruit removal in the autumn–winter could help produce early 'Arkin' carambola crops the following summer. Our study was conducted to test the efficacy of selective branch pruning and manual crop removal as techniques for extending the production season of 'Arkin' carambola under the subtropical conditions of southern Florida.

2. Materials and methods

2.1. Plant material

The study was conducted during 1994–1995 in a commercial grove located in Homestead, FL, using 9-year-old 'Arkin' trees grafted onto seedling rootstock. Trees were planted at 4.0 m×6.3 m, measured 3.5–4.0 m in height, and were managed according to local recommended cultural practices (Crane, 1994). The phenology of 'Arkin' carambola trees in southern Florida in relation to seasonal temperature variations was recently documented (Núñez-Elisea and Crane, 1999).

2.2. Selective pruning

Trees were selectively pruned at approximately 2-month intervals starting March 7, 1994, and ending January 12, 1995 (see pruning dates in Table 1). Each pruning treatment was applied to 5–7 trees, using between 12 and 18 branches per treatment. A total of 34 trees and 87 branches were used for the study. Two to three branches were selectively pruned per tree. Branches were 3–4-year old and located in the inner, lower canopy. Selective pruning consisted of cutting back branches to about 50% of their original length, removing all lateral wood on each main axis and retaining only the main 2–3 axes (Núñez-Elisea and Crane, 1999). All leaves were removed from branches at the time of pruning. Branches selected for pruning were 75–105 cm from the ground, 1.5–2.1 m long, with 1–3 main

Table 1
Effect of selective pruning date on production of new growth for ‘Arkin’ carambola in Homestead, FL, 1994–1995

Pruning date	% of flowering branches	Days to flowering	New growth (% of total buds[a] per branch)	
			Vegetative shoots[b]	Panicles[b]
March 7	100 a	33 ab	3.5 b	12.6 c
May 12	100 a	31 ab	2.6 b	15.3 bc
July 17	93 a	29 b	5.1 a	21.6 a
September 7	100 a	24 b	6.0 a	18.9 a
November 9	100 a	36 a	3.2 b	14.2 c
January 12	94 a	38 a	1.9 c	13.5 c

[a] Includes vegetative shoots and panicles formed at branch collars from removed lateral branches.

[b] Means with different letter within columns are significantly different according to Duncan's multiple range test, $P \leq 0.05$.

axes, and their basal diameter ranged from 4 to 7 cm. Experimental branches represented about 25% of the total canopy volume. Each pruned branch had between 36 and 104 dormant, lateral buds. Flowering of selectively pruned branches was recorded on lateral buds (which typically represent more than 90% of the flowering sites) and branch collars left after thinning out lateral branches (Núñez-Elisea and Crane, 1999).

2.3. Crop removal

The entire crop was removed from trees on November 19, December 3, or December 12, 1994. Fruits from treated trees (n=8–12) were manually shaken off. Most of the fruits removed were 50% or more of their final size. Such fruits detached easily from the tree upon vigorous shaking of the major limbs. Small fruit could not be detached easily by shaking branches and were stripped off by hand. Between 23 and 61 kg of fruits were removed from each de-fruited tree. Control trees were left intact. Flowering was assessed by monitoring the percentage of shoots (n=10 per tree) producing panicles.

3. Results

3.1. Effects of selective pruning on flowering and fruiting

Pruning 3–4-year old branches to their main axes stimulated production of new vegetative shoots and panicles on nearly all pruned branches, regardless of time

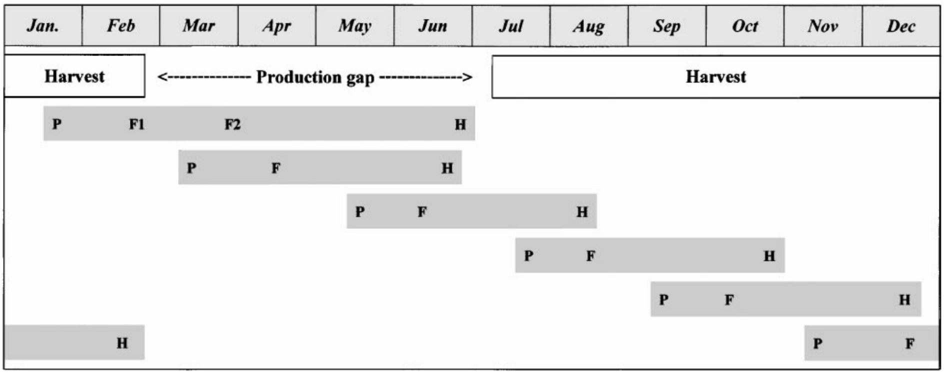

Fig. 1. Effect of date of selective pruning on time to flowering and harvest in 'Arkin' carambola. Each horizontal bar shows the pruning date (P), start of flowering (F), and harvest (H) for branches of each pruning date. For branches pruned in January, the first bloom (F1) did not set fruit owing to cool temperatures; fruit set occurred on flowers produced on a second bloom (F2). Pruning in January or March resulted in early-season fruit by the end of June.

of year (Table 1, Fig. 1). Production of new vegetative shoots and panicles was greater when branches were pruned during warm weather in July and September. Branches pruned during July and September produced significantly higher amounts of panicles than branches pruned during the cooler months of November–March (about 20% vs. 14%, respectively). Flowering was also stimulated for branches pruned in January, which produced panicles in February (Table 1, Fig. 1).

The time from pruning to flowering varied with seasonal temperature (Table 1, Fig. 1). Flowering was quickest during the warm months of July and September (29 and 24 days after pruning, respectively), and was significantly delayed during the cool months of November and January (36 and 38 days after pruning, respectively).

3.2. *Effect of selective pruning on harvest date and fruit yield*

Pruning between March and November produced a crop 13–14 weeks after pruning (Table 2). Pruning in January caused bloom about 40 days afterwards (Table 1), but flowers produced during cool weather in February failed to set fruit. Selective pruning in January or March resulted in fruit production in late June (Table 2). Each pruned branch produced ca. 20 kg of early fruit, and 2–3 branches were pruned per tree in this study.

Yield of intact, non-pruned canopy portions was not recorded in this study because our objective was to test the feasibility of increasing early fruit production by selective pruning. However, periodic orchard inspections indicated that fruit production on intact canopy portions of experimental trees was not influenced by selective pruning of the lower canopy. While pruning in March or

Table 2
Effect of selective pruning on time to harvest and fruit yield in 'Arkin' carambola in Homestead, FL, 1994–1995

Pruning date	Harvest date[a]	Weeks from pruning to harvest	Fruit yield	
			g per bud[b,c]	kg per branch[b]
March 7	June 25	14	223 b	18.1 b
May 12	August 18	13	259 b	18.7 b
July 17	October 29	13	381 a	23.6 a
September 7	December 22	14	255 b	21.3 a
November 9	February 26	14	325 a	19.2 ab
January 12	June 30[d]	22	185 c	14.5 c

[a] Harvest of non-pruned trees began July 30, 1995.
[b] Means with different letter within columns are significantly different according to Duncan's multiple range test, $P \leq 0.05$.
[c] Includes fruit from panicles formed at branch collars from removed lateral branches.
[d] No fruit set occurred on these branches until March 15.

January allowed producing an early crop in the last week of June, no fruit was harvested from the intact canopy portion of experimental trees during late June and negligible production was obtained in early July. Intact canopy portions of experimental trees and trees outside of the study began to be harvested by the end of July.

3.3. Effect of selective pruning on fruit quality

Nearly all fruit harvested from pruned branches were free of wind damage and had excellent appearance (Figs. 2 and 3). In comparison, more than 58% of fruit

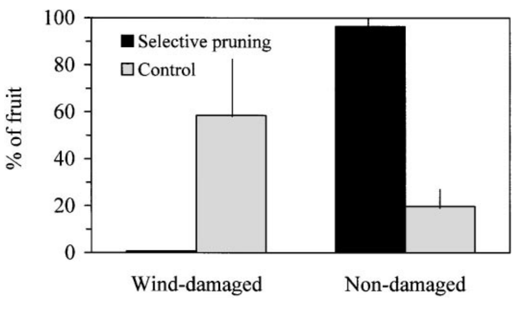

Fig. 2. Comparison of the amount of wind-damaged 'Arkin' carambola fruit produced in selectively pruned branches vs. fruit harvested from the canopy periphery (control). For pruned branches, data are the pooled average of all pruning dates. A total of 12 pruned and 12 non-pruned trees (controls) were used for sampling; 50 fruits were collected from each tree. S.D. bars are shown.

Fig. 3. Fruit production on selectively pruned branches of 'Arkin' carambola. Pruning stimulated synchronous flowering and fruit development. Pruning during March–November resulted in fruit production 13–14 weeks after pruning. Pruning during cool weather in January resulted in fruit production 22 weeks after pruning due to delayed fruit set. Fruit produced on pruned branches was nearly 100% free from wind-scar.

harvested from the canopy periphery displayed wind-scar, with only about 20% free from such damage.

3.4. Effect of winter crop removal on early-season flowering and fruit production

On March 26, flowering of de-fruited trees was more than 2-fold, and by April 12 almost 3-fold, that of intact, fruit bearing trees (Table 3). By April 29, ca. 60%

Table 3
Effect of time of crop removal on the intensity and earliness of flowering in 'Arkin' carambola in Homestead, FL, 1994

Crop removal date[a]	% of flowering shoots[b]		
	March 26	April 12	April 29
Control	12.7 b	20.1 b	65.0 c
November 19	40.2 a	63.3 a	77.2 b
December 3	35.7 a	58.4 a	90.1 a
December 12	37.4 a	62.6 a	82.4 b

[a] Fruits were removed manually from treated trees; control trees were left intact. Flowering rates were monitored on 10 one-year-old shoots per tree, selected from the canopy periphery.

[b] Means with different letter within columns are significantly different according to Duncan's multiple range test, $P \leq 0.05$.

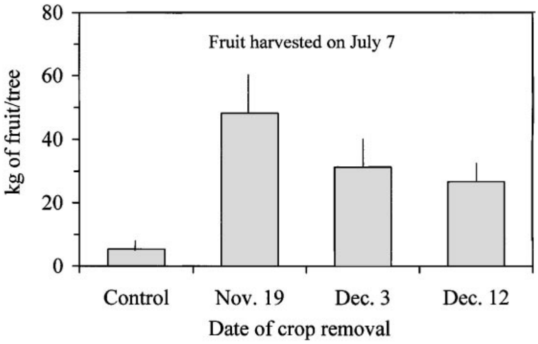

Fig. 4. Effect of removing the winter crop of 'Arkin' carambola trees during November and December on production of early fruit the following summer. Non-pruned trees were left intact. All fruits on treated trees were removed manually. Bars represent amount of fruits harvested per tree (±S.D.) on July 7, 1995, which was the earliest harvest of the season.

of shoots from control trees had flowers, compared to 80–90% in de-fruited trees. Fruit harvest began on July 7 (Fig. 4). Trees that were de-fruited on November 19 produced an average of 48 kg of early fruit per tree on July 7, whereas control trees produced an average of only 5 kg per tree of early fruit on this date.

De-fruiting on December 3 or 12 also increased production of early fruit (31 and 27 kg per tree, respectively) compared to intact control trees. In addition to showing early flowering and fruiting, trees that were de-fruited in November or December retained more foliage than the heavily fruiting, control trees. Further, the foliage of de-fruited trees was less chlorotic during the winter than that of controls.

4. Discussion

Selective pruning and crop removal were effective methods for increasing production of early fruit in 'Arkin' carambola in this study. Pruning stimulated flowering of pruned branches regardless of time of year, and the response was greatest when pruning was done during warm weather in July and September compared to the cooler months of November–March (Table 1, Fig. 1). Flowering was also stimulated for branches pruned in January, which produced panicles in February, when trees normally do not bloom due to cool weather (night temperatures are often below 15°C). This result shows that the growth-inhibitory effect of cool night temperatures was overridden by pruning. The fact that flowering was produced during both warm and cool weather may indicate that temperature does not influence floral induction (bud programming for inflorescence development) of carambola (Salakpetch et al., 1990; Núñez-Elisea and Crane, 1999), but it does influence the time of inflorescence initiation

(Table 1). The effect of temperature on flowering of 'Arkin' carambola differs from that observed in other tropical and subtropical fruit trees such as litchi (Menzel, 1983), mango (Whiley et al., 1989; Núñez-Elisea et al., 1996), and longan (Watson, 1984), where temperatures below 15°C promote floral induction, while slightly higher temperatures appear to stimulate inflorescense initiation. Further, in comparison to carambola, pruning of litchi, mango, and longan trees during the summer in Florida results in vegetative growth, but no flowering.

Trees of 'Arkin' carambola in southern Florida normally bloom from March to early November (Núñez-Elisea and Crane, 1999). Little to no flowering occurs between mid-November and February, presumably due to the onset of cool night temperatures (J.H. Crane, personal communication), which repress overall tree growth. However, flowering is probably also restrained during the winter owing to poor canopy condition, as trees defoliate when exposed to cold, dry winds, and the retained foliage shows symptoms of nutritional stress (Marler et al., 1994).

Selective pruning caused flowering of pruned branches under a wide range of environmental conditions, including low temperatures. We have previously demonstrated that carambola buds attain the ability to initiate flowering upon reaching an age of about 10 weeks (Núñez-Elisea and Crane, 1999). The predominantly floral response observed after pruning 3–4-year old wood in this study shows that dormant carambola buds, once programmed for floral initiation, retain the potential to form panicles for several years. Further, pruning triggered the growth of dormant buds, stimulating inflorescence initiation under cool, growth-inhibitory temperatures, and at a time when tree canopies appeared in poor condition.

Pruning between March and November produced a crop 13–14 weeks after pruning (Table 2). Pruning in January caused bloom about 40 days afterwards (Table 1), but flowers produced during cool weather in February failed to set fruit. Possible causes for the failure of these flowers to set fruit during cool weather include flower and pollen dehydration, lack of pollination due to decreased insect activity, lack of fertilization, or lack of pollen tube growth in pollinated flowers. Branches pruned in January, however, produced new panicles that eventually set fruit when warm weather resumed, and produced a crop 22 weeks after pruning. More research is needed to overcome the problem of lack of fruit set during cool weather to obtain fruit between February and June.

Harvest of 'Arkin' carambola in southern Florida normally begins in mid–late-July and extends to February (Núñez-Elisea and Crane, 1999). Selective pruning in January or March resulted in fruit production in late June, when fruit is at least five times more valuable than that harvested during the peak periods of August–September and December–January (Table 2). Each pruned branch produced ca. 20 kg of early fruit (Fig. 4), and two to three branches were pruned per tree in this study. Thus, pruned trees produced an average of 40–60 kg of high-priced, early fruit (Fig. 4).

Branches selected for pruning in this study were structurally strong, and fruit originated from panicles that emerged directly from the main axes (Fig. 3). Fruit had no freedom of movement during strong winds. Consequently, nearly 100% of fruit harvested from pruned branches were free of wind damage and had excellent appearance (Figs. 2 and 3). In contrast, about 60% of fruit harvested from the canopy periphery had wind-scar, and only about 20% were free from damage. The results demonstrate that selective pruning of 2–3 lower canopy branches allowed producing between 40 and 60 kg of early, high-quality fruit per tree using only about 25% of the total canopy. We speculate that higher yields of early fruit could be obtained by pruning more branches per tree, since 10-year-old 'Arkin' trees can easily produce more than 150 kg of fruit per year (Campbell et al., 1985). However, further work is needed to confirm this assertion.

Removal of the winter crop (the fruit that would have been harvested in December–February) increased flowering intensity of de-fruited trees (Table 3). About 60% of shoots from control trees had flowers on April 29, compared to 80–90% in de-fruited trees. On this date, however, shoots from control trees had mainly panicles at anthesis, whereas shoots from de-fruited trees already had fruitlets measuring up to 15 mm in length. Thus, removing all fruits during November or December significantly increased the amount of early bloom produced in the spring.

Crop removal in November or December increased early bloom and consequently the amount of early fruit produced in the summer. Trees that were de-fruited on November 19 produced an average of 48 kg of early fruit per tree on July 7, almost 10-fold the amount of early fruit produced by control trees, which carried the winter crop. De-fruiting in December increased production of early fruit about 6-fold compared to intact control trees. Branches pruned in November produced more early fruit (July 7) than branches pruned in December due to the earlier forced flowering and fruit maturation.

Trees de-fruited in November or December retained more foliage during the winter than the heavily fruiting, control trees. In addition, the foliage of de-fruited trees was less chlorotic during the winter than that of intact, control trees. It is likely that canopies of de-fruited trees had greater carbohydrate reserves than those of intact controls. If so, reserves of de-fruited trees were probably readily available for new vegetative growth and flowering as soon as permissive temperatures set in, resulting in earlier growth. In comparison, control trees probably required mobilization of reserves from the roots to the canopy, resulting in delayed new growth.

This study demonstrated that early fruit production of 'Arkin' carambola was increased by selective pruning of lower canopy branches in early March or removal of the winter crop during November or December. Fruit produced on pruned branches was almost free of wind-scar. Because of the high value of early fruit (5- to 8-fold compared to fruit produced during production peaks), these techniques can potentially increase carambola economic returns in southern Florida. Although pruning stimulates flowering year-round, further research is needed to achieve fruit set in flowers produced during the cool winter months, which would result in year-round carambola production under the subtropical conditions of southern Florida.

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