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PHENOLOGY, SHOOT DEVELOPMENT, AND FLORAL INITIATION OF CARAMBOLA (*AVERRHOA CARAMBOLA* L. CV. ARKIN) IN A SUBTROPICAL ENVIRONMENT

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Abstract. **Carambola (*Averrhoa carambola* L. cv. Arkin) in subtropical south Florida is affected by harsh winter conditions (cold temperatures, strong, dry winds, and increased solar radiation) which repress tree growth. Tree canopies deteriorate and defoliate during February-March as a result of environmental and nutritional stress. Vegetative growth and flowering occur from mid-March to October-November. Fruit is produced from July to early February, with peaks in August-September and December-January. Buds ca. 10 wk of age or older are capable of differentiating panicles, whereas younger buds produce mainly vegetative growth. Adventitious vegetative or reproductive buds regenerate readily from previously active buds, dormant lateral buds, or the base of branch stumps. Thus, flowering can be forced at any time of the year by pruning or artificial defoliation. Carambola canopies are very amenable to cultural manipulations for controlling the times of flowering and fruiting.**

Carambola (*Averrhoa carambola* L.) originated in the humid tropics of Southeast Asia, where trees grow, bloom, and produce fruit nearly year-round (Galán-Saúco, 1993). Carambola has been grown commercially in south Florida for about 25 years, and nearly 500 acres are currently planted. The main commercial cultivar, Arkin, originated in Florida and represents more than 90% of the Florida industry. 'Arkin' produces high annual fruit yields (often >150 kg/tree in 10-yr-old trees) and tolerates post-harvest storage and handling (Campbell, 1989). Winter conditions in south Florida are unfavorable for tree growth (Campbell et al., 1985) and alters the typical growth patterns of carambola. This report describes phenology, shoot development, and floral initiation in 'Arkin' carambola trees grown in south Florida. Observations were documented between 1993 and 1995 from growers' commercial plantings in Homestead, Florida.

Phenology. The phenological stages of 'Arkin' carambola trees in south Florida are shown in Fig. 1. Compared to its native, humid tropical environment in Southeast Asia, carambola in subtropical south Florida exhibits a period of defoliation and general lack of growth as a result of adverse weather conditions during winter (particularly February and March). Tree canopies deteriorate during this period due to low temperatures and strong winds, and apparently also due to intensified solar radiation (Marler et al., 1994), as the reduced cloud cover during the winter results in increased irradiation, which causes chlorophyll photo-oxidation and subsequent leaf chlorosis.

Tree condition, along with adverse weather, contributes to carambola canopy deterioration during the winter. Leaf production declines considerably after mid-October, yet trees continue to carry a heavy fruit load, which is harvested in December-January. Tree reserves likely decline sharply under these conditions (Fig. 1). During late fall (November), as the winter approaches, canopies consist to a large extent of aging leaves, now several months old. During the winter leaves appear drought and nutritionally stressed. The oldest leaves turn chlorotic and drop during February-March as a result of exposure to cold, dry winds, and continuous intense sunlight. Foliage remaining on the tree at this time is typically located on the tips of shoots, and corresponds to the most recent growth flush produced in September-October.

Trees remain visually dormant and partially defoliated during cool weather and begin to re-foliate as soon as temperatures rise in March. Re-foliation takes place from mid-March to mid-May, with new leaves being formed at the tips of previous season's shoots (shoot elongation), and also as new lateral vegetative shoots emerging from defoliated portions of previous season's shoots and older wood. Vegetative growth continues until mid- to late October in the presence of warm, rainy weather.

Consistent with previous reports (Campbell et al., 1985) we found two main reproductive growth phases per year. A first bloom peak occurred in May and resulted in a harvest peak during August-October. A second bloom peak occurred in September and caused a second harvest peak in December-

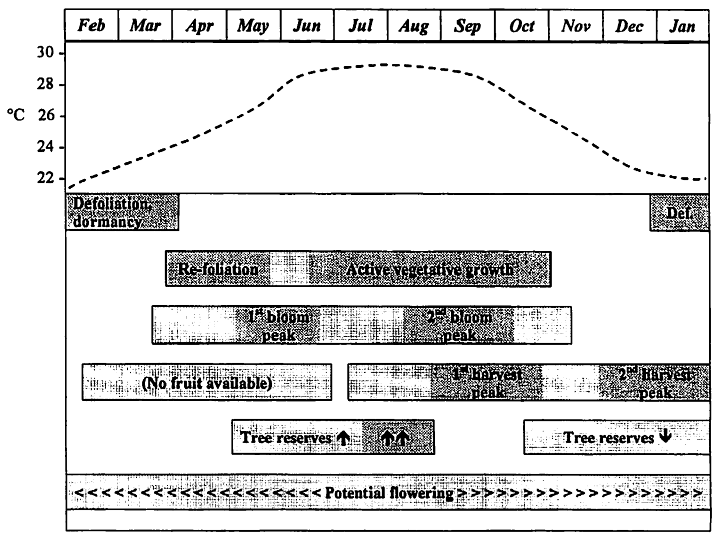

Figure 1. Mean monthly temperature and phenological stages of 'Arkin' carambola in south Florida. Darkened areas within each bar represent periods of intensified vegetative or floral activity, and of greater fruit availability. The duration of each stage is (2 wk depending on cultural management and annual weather patterns. Flowering occurs from mid-March to early November, but the potential flowering period covers the entire year.

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January. Sporadic flowering episodes took place between April and early November. Since there was almost no bloom after mid-November, virtually no fruit was available from March to June.

Studies are lacking on the carbohydrate levels of carambola trees during the different phenological stages. We assume that tree carbohydrate reserves reach their peak between June and August, when canopies contain an abundance of young leaves (< six months old), and prior to the first fruit production peak (Fig. 1).

Shoot development. Vegetative growth took place throughout the spring and summer months in the presence of warm temperatures and rain. As in most tropical and subtropical fruit trees, carambola shoots alternate episodes of growth with periods of dormancy. Periodic activity at the shoot apex results in an extension of the shoot axis, with each segment of new extension growth (growth flush) containing between eight and 12 leaves. The number of leaves produced increased with shoot vigor and during warm, rainy weather. Such conditions also increased the frequency of flushing for individual shoots and throughout the tree canopy. For example, shoots formed in the early spring extended four-five times during warm weather before cool, fall temperatures set in, while shoots formed in the late summer normally flushed only once or twice before ceasing extension growth in the fall.

An undesirable feature of carambola is the tendency of fruiting shoots (particularly the smallest and thinnest ones) to die soon after their fruit is harvested. Twig death probably results from a severe depletion of reserves after nourishing the attached fruit. It is not uncommon to find shoots about 50 cm long carrying 1.5 kg of fruit. Upon dying, shoots desiccate and remain attached to the canopy for several months. Carambola fruit skin is very delicate and is easily blemished when rubbed against the dry twigs. The damage, known as "wind scar", is particularly severe on the outermost fruit during windy weather, and in groves lacking adequate wind protection.

Bud developmental programming and floral initiation. We clipped vegetative shoots to force growth of axillary buds along vegetative shoots, which would indicate the type of growth (vegetative or floral) buds are programmed to express according to their position on a vegetative shoot (Fig. 2). This information allowed determining the period of potential flowering, which often extends beyond the period of actual flowering, depending on the plant species and location. During the summer (August), shoots consisting of three or more flushes were clipped (the shoot apex and 4-6 terminal leaves were removed) and all leaves along the remaining shoot were removed to force bud growth. The terminal flush of these selected shoots was 6 wk old, with fully expanded leaves, and the sub-terminal flush was at least 12 wk old. Growth produced by the 6-wk-old axillary buds of the terminal flush consisted of new vegetative shoots in all cases, whereas growth produced by the 12-wk-old or older axillary buds from previous flushes consisted of panicles in more than 90% of cases. The results imply that the axillary buds on a 6-wk-old or younger flush of extension growth were initially programmed for vegetative development and gradually attained the capacity to form panicles.

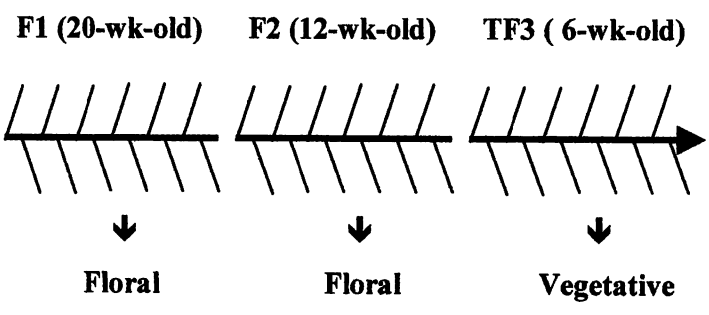

Figure 2. Schematic diagram of a carambola vegetative shoot showing the type of growth produced by axillary buds within each flush (F). Slanted lines represent individual leaves, each with an axillary bud; the dark line represents shoot main axis; the triangle represents the dormant shoot apex on the terminal flush (TF). The shoot shown above consists of 3 flushes, with each flush containing 12 axillary buds. The buds within each flush were forced to grow by clipping/defoliating the shoot. Six-wk-old buds (TF3) produced axillary vegetative shoots, whereas 12- to 20-wk-old buds (F2 and F1, respectively) produced panicles.

In a subsequent trial, shoots with terminal flushes of different ages (6, 10, or 14 wk old) were clipped during the months of May, July, and November (Table 1), to force growth of buds of varying ages at different times of the year. Six-wk-old buds always produced new vegetative shoots regardless of time of year, whereas 10- to 14-wk-old buds produced mainly (93% to 100%) panicles. Therefore, buds need to be about 10 weeks old to be able to form panicles, and mature buds that remain dormant for several weeks or months retain the ability to form panicles throughout the year.

Our finding that forced, mature buds produced panicles during contrasting weather conditions supports the notion that floral initiation of carambola is under internal control (Salakpetch et al., 1990a, 1990b) and does not result from exposure of trees to an environmental cue. Our results further indicate that carambola buds attain the ability to initiate panicles via endogenous changes associated with aging. In other tropical and sub-tropical fruit trees such as mango or lychee (litchi), floral initiation requires not only that buds reach a mature condition, but also the exposure of trees to a period of several weeks of cool temperatures (usually below 15°C) or water stress.

The flowering responses of clipped shoots indicate that although the normal flowering period of 'Arkin' carambola in south Florida is from mid-March to early November, there is a potential for flowering during the entire year (Fig. 1). Tree carbohydrate status has been suggested as a regulatory mechanism for floral initiation in carambola (George and Nissen, 1994). Although flowering normally does not occur during periods of cool weather (night temperatures (15°C; see Fig. 1), we found that forcing growth during cool weather (November) resulted in panicle formation (Table 1). Carbohydrate levels were presumably at their lowest level at this time of year. Therefore, it would appear that growth-promoting environmental conditions (warm temperatures, water availability) or cultural factors (pruning, defoliation, N-fertilizer application) impact the timing of floral initiation more directly than tree carbohydrate status. Since carambola trees contain an ample supply of mature buds capable of producing panicles (dormant buds > 10-wk-old are located throughout the canopy), bloom will occur at any time, provided such buds are stimulated to grow and conditions permit their growth.

Flowering and fruiting sites. Carambola trees flower profusely. Most panicles are formed along (1) long (often more than 1 m in length), thin shoots or "whips" on the canopy periphery, (2) small, weak shoots or "feathers" measuring less than 15 cm in length, and (3) dormant buds on bare portions of older branches. However, old dormant buds on scaffold

Table 1. Effect of age of terminal flush and time of year on growth produced by axillary buds of 'Arkin' carambola. Each value represents the mean percentage of axillary buds producing new vegetative shoots or panicles.

	Effect of flush age on growth produced by axillary buds (mean ± sd)					
	6 wk[z]		10 wk[z]		14 wk[z]	
Month of clipping[y]	Vegetative	Flora	Vegetative	Floral	Vegetative	Flora
May	100.0	0.0	2.5 ± 0.8	97.5 ± 2.2	0.0	100.0
July	100.0	0.0	3.7 ± 1.2	96.3 ± 2.6	4.2 ± 1.6	95.8 ± 4.3
November	100.0	0.0	6.8 ± 2.2	93.2 ± 3.1	0.0	100.0

[z]New vegetative or floral growth was recorded 35 days after clipping.
[y]Terminal flushes (n ≥ 24 per treatment) were pruned by clipping the shoot apex.

Figure 3. Adventitious bud formation in branch stumps of 'Arkin' carambola. Tissue surrounding the base of the stump readily regenerated inflorescences within 3 weeks of pruning. The response can be observed at any time of the year, including winter, when trees do not normally bloom.

branches and on the main trunk are also capable of forming panicles. Early season blooms (mid-March to May) typically occur on whip- and feather-type shoots. Subsequent blooms (June-October) occur on whip-shoots and on older wood on the inner canopy.

Most carambola fruit (we estimate >75% of the tree's annual production) is borne on the canopy's periphery, where it is subject to wind damage as already discussed. The smaller amount of fruit produced along older branches suffered little wind damage and was often considered to be sweeter than fruit produced on thin wood, although further work is needed to clarify the effect of branch size on fruit total soluble solids (°Brix) and sugar content.

Bud regeneration. A striking feature of carambola is the ability of buds, especially lateral buds on branches more than 3 years of age, and also of stumps of pruned branches, to regenerate adventitious buds (Fig. 3). Multiple panicles, vegetative shoots, or both vegetative shoots and panicles can arise from the same bud or stump tissue over a period of several months or years. This unique regenerative feature, the capacity of nearly all wood on the canopy to initiate panicles, and the tree's ability to initiate flowers under a wide range of environmental conditions, appear to be the key factors in the prolific bearing behavior of this tropical fruit tree in the tropics and subtropics.

Conclusions. The carambola canopy appears exceptionally well adapted to respond to a variety of manipulations (such as pruning, defoliation, fruit removal, or N-fertilization) to control the time of flowering and fruiting according to market demands. Pruning for tree size control altered the pattern of flowering in young 'Arkin' trees (Crane et al., 1991). Growing carambola under protected cultivation was suggested for the Canary Islands (Galán-Saúco et al., 1989), and has been attempted by commercial growers with promising results (RNE personal observation, Tenerife, Canary Islands, 1995). Winter canopy condition in south Florida may be improved by timely pruning and crop removal during the fall to stimulate new growth and relieve nutritional stress, and help increase valuable early fruit production in June-July. Watson et al. (1988) realized the opportunities for crop regulation of carambola in Australia, and suggested the removal of flowers and fruit to produce off-season flowering. The potential for crop regulation of carambola in subtropical south Florida is evident and work is currently under way to control flowering and fruiting times by canopy manipulation.

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