

THE INFLUENCE OF WITHIN TREE POSITION ON 'ARKIN' CARAMBOLA (*AVERRHOA CARAMBOLA* L.) FRUIT QUALITY AND NUMBER

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Abstract. In Florida, carambola has two harvest periods, July through September (summer crop) and November through February (winter crop). Knowledge of the location within the canopy of the highest quality fruit may improve the efficacy of spot picking. The effect of position within the canopy on fruit yield and quality was determined for five, ten-year-old 'Arkin' carambola trees at the Tropical Research and Education Center. The canopy of each tree was divided into three horizontal layers (i.e., lower, middle, and upper) and four quadrants (i.e., north, south, east, and west). Mature fruit were harvested from 4 August to 26 September 2003 (summer crop) and 2 December 2003 to 20 January 2004 (winter crop). Fruit number, fruit weight and length, and total soluble solids ($^{\circ}$ Brix) were determined at each harvest date. Tree yields were estimated from the average weight per fruit and the total number of fruit per tree. In summer, the highest fruit $^{\circ}$ Brix was generally observed in the south quadrant and in the middle and upper canopy layers. There was no significant difference in fruit $^{\circ}$ Brix among layers in winter. Overall, fruit from the summer harvest weighed less than fruit from the winter harvest. Fruit length varied with canopy location in summer but not winter. The number of fruit was generally highest in the middle layer followed by the upper and lower layers, respectively.

'Arkin' is the major commercial carambola (*Averrhoa carambola* L.) cultivar in Florida and accounts for approximately 98% of the estimated 202 acres currently in production. Commercial carambola plantings are usually established adjacent to natural windbreaks such as pinelands, planted windbreaks of bamboo, Australian pine, or another fruit crop (e.g., avocado, mango), or within man-made windbreaks. Carambola has two primary harvest seasons in Florida, June through September (summer crop) and November through February (winter crop). Within the extended harvest period, identifying the specific time of year to pick and where to find fruit of the highest quality at those times may allow commercial and home growers to reduce harvest times and thereby reduce commercial harvesting costs.

In citrus, differences in citrus fruit quality are related to the position of the fruit on the tree (Reitz and Sites, 1948). For example, in 'Valencia' orange and 'Orlando' tangelo fruit, soluble solid content among fruit is variable within the tree, but is generally higher in the top versus the lower portions of the canopy (Davies, 2004; Morales et al., 2000). Similarly, Hatten

et al. (1956) reported 'Lula' avocado fruit oil content was higher in the top compared to the lower half of 7 to 10 year old trees. In apple trees, fruit quality and yield also vary with position in the canopy which is related to light transmission throughout the canopy (Jackson, 1971). For 'Granny Smith' apple, fresh fruit weight and soluble solid concentration increased with increasing height in the canopy (Tustin, 1988.) With this in mind, an investigation into the effect of canopy position on carambola fruit quality and number was initiated.

Materials and Methods

Five 10-year-old 'Arkin' carambola trees grafted on 'Golden Star' seedling rootstock located at the Tropical Research and Education Center in Homestead, Fla., were used to investigate the effect of fruit canopy position on fruit quality and number. The orchard is located within a man-made wind-screen designed to reduce wind speeds within the orchard by at least 50%. Trees were spaced 15 ft. by 20 ft., oriented in north-south rows, and irrigated and fertilized using standard local practices. On 6 July 2003, trunk diameter of the experimental trees ranged from 14 to 18 cm, tree heights ranged from 3.3 to 3.6 m, and canopy volume (calculated as a parabola) ranged from 19.6 to 30.6 m³ on 6 July.

The canopy area of each tree was divided into 4 quadrants: north, east, south, and west quadrants (Fig. 1). Mean tree height (3.5 m) was divided into 3 layers as follows: up to 1.2 m (lower); 1.2 m-2.4 m (middle); and above 2.4 m (upper) (Fig. 2). Fruit were harvested from 4 Aug. through 26 Sept. 2003 (summer harvest) and from 2 Dec. through 20 Jan. 2004 (winter harvest). The date at which horticulturally mature fruit first appeared in each canopy layer and quadrant was recorded. Fruit were considered horticulturally mature when they were yellow along the mid-rib. The date, quadrant, and layer from which mature fruit were sampled for quality analysis were recorded prior to removal from the tree and fruit sam-

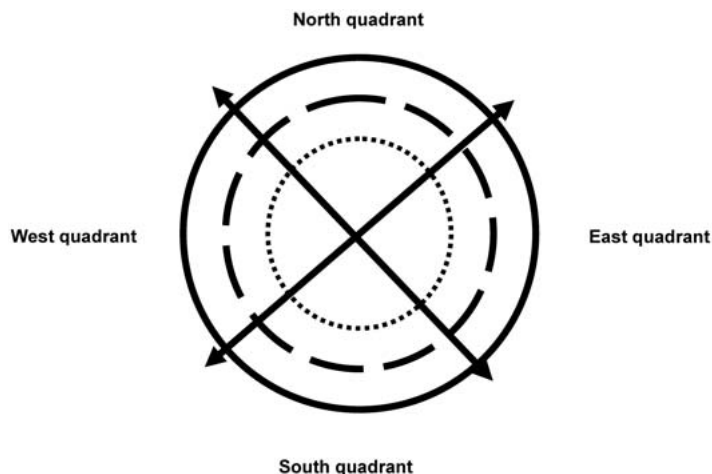


Fig. 1. Depiction of carambola tree canopy from above showing the division of the canopy into north, south, east, and west facing quadrants.

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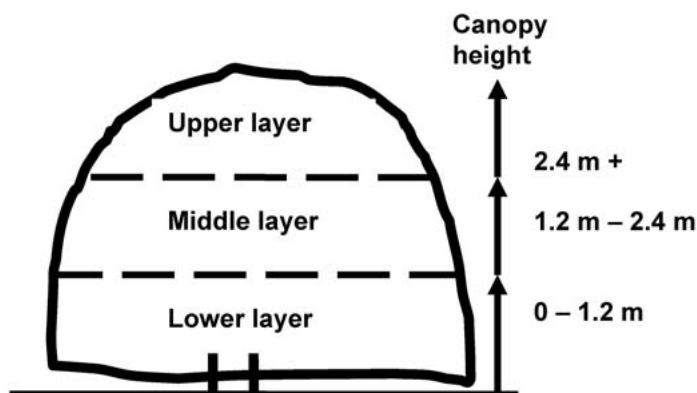


Fig. 2. Depiction of carambola tree canopy divided into 3 layers above the soil surface: upper (2.4 m +), middle (1.2 m to 2.4 m) and lower (0 m to 1.2 m).

ples (subject to availability) were gathered from similar layers and quadrants (e.g., upper layer of the north quadrant) at each harvest (Table 1). Fruit were sampled from appearance of the first mature fruit through the peak in fruit production for each tree. Fruit weight, length and total soluble solids ($^{\circ}$ Brix) were measured at each harvest. Fruit weight was measured in grams using a balance (Denver Instruments Company, Model Tr-6101), length was recorded in centimeters, and $^{\circ}$ Brix was determined with a Fisher handheld Brix refractometer (Fisher Scientific, Pittsburgh, Pa.). The total number of fruit in each quadrant and layer were counted for each tree.

Statistical analysis. Data were subjected to analysis of variance. Treatment means within layers and quadrants were compared using Waller-Duncan K-ratio t-test ($P < 0.1\%$ level) (SAS, 2004).

Results

Summer Harvest

Number of fruit. The mean number of fruit per tree was 619.8 and ranged from 266 to 784. The mean number of fruit per quadrant and canopy layer was 51.6 and ranged from 13 to 90 (Table 2). There was no significant difference in the mean number of fruit produced among quadrants within the lower, middle, and upper canopy layers (Table 2). However, there tended to be more fruit in the middle and upper layers of the tree canopy compared to the lower layer in the north, south, and west canopy quadrants (Table 2). In general, significantly more fruit was produced in the middle and upper canopy layers compared to the lower canopy layer in the N, S, and W canopy quadrants. In contrast, there was no significant difference in the mean number of fruit produced among canopy layers in the east quadrant.

Table 1. The date at which horticulturally mature fruit were sampled for fruit quality analysis from each tree canopy.

Summer harvest	Date	Winter harvest	Date
1	Aug. 4, 2003	1	Dec. 2, 2003
2	Aug. 6, 2003	2	Dec. 8, 2003
3	Aug. 12, 2003	3	Dec. 18, 2003
4	Aug. 13, 2003	4	Dec. 30, 2003
5	Sept. 2, 2003	5	Jan. 2, 2004
6	Sept. 3, 2003	6	Jan. 20, 2004
7	Sept. 8, 2003	7	—
8	Sept. 26, 2003	8	—

Table 2. Mean number of fruit of 'Arkin' carambola from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the summer.²

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 26.2 _b	^a 28.8 _a	^a 30.2 _b	^a 13.0 _b	24.6
Middle	^a 87.2 _a	^a 55.6 _a	^a 75.4 _a	^a 90.4 _a	77.2
Upper	^a 53.2 _{ab}	^a 32.4 _a	^a 67.8 _{ab}	^a 59.6 _a	53.3
Overall mean	55.5	38.9	57.8	54.3	51.6

²Superscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test ($P < 0.05$).

Fruit maturity. On 4 Aug., several of the trees had horticulturally mature fruit in the middle canopy layer in all quadrants and in the upper canopy layer in the west and south quadrants. Within one week from this time, fruit became mature in the upper east canopy quadrant. Approximately one month from the first harvest date (4 Sept.) most of the trees had reached peak fruit production in the middle and upper canopy layers in all quadrants. However, only a small number of mature fruit was observed in the south quadrant of the lower canopy.

$^{\circ}$ Brix. The mean $^{\circ}$ Brix per quadrant and canopy layer ranged from 7.3 $^{\circ}$ Brix to 9.5 $^{\circ}$ Brix (Table 3). The $^{\circ}$ Brix varied significantly among canopy quadrants and layers (Table 3). The highest $^{\circ}$ Brix was generally observed in the south quadrant and in the middle and upper canopy layers. However, within the lower canopy layer the $^{\circ}$ Brix was significantly greater in the south quadrant (9.0 $^{\circ}$ Brix) compared to the north (7.4 $^{\circ}$ Brix), east (7.7 $^{\circ}$ Brix) or west (7.3 $^{\circ}$ Brix) quadrants (Table 3). In contrast, there was no significant difference among quadrants in $^{\circ}$ Brix in the upper tree canopy.

Weight. Mean fruit weight per quadrant and canopy layer varied from 100.0 g to 151.2 g during the summer (Table 4). There was no significant difference in fruit weight among quadrants in the lower, middle, and upper canopy layers (Table 4). However, within the east and west quadrants, fruit weight was greatest in the middle layer (east, 145.9 g; west, 151.2 g) compared to the upper (east, 109.4 g; west, 124.3 g) and lower canopy layers (east, 131.3 g; west, 112.3 g).

Length. Mean fruit length per quadrant and canopy layer ranged from 9.8 cm to 11.9 cm (Table 5). Fruit length varied significantly by canopy quadrant and layer (Table 5). In the lower canopy layer, there was no significant difference in fruit length among the east, south, and west quadrants, but the

Table 3. Mean $^{\circ}$ Brix of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the summer.²

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^b 7.4 _b	^b 7.7 _c	^a 9.0 _a	^b 7.3 _b	7.9
Middle	^{ab} 8.9 _a	^b 8.7 _b	^a 9.3 _a	^{ab} 8.8 _a	8.9
Upper	^a 9.0 _a	^a 9.5 _a	^a 8.9 _a	^a 9.1 _a	9.1
Overall mean	8.5	8.6	9.1	8.4	8.6

²Superscript lower case letters refer to canopy layers and subscript lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test ($P < 0.05$).

Table 4. Mean fruit weight (grams) of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the summer.^z

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 100.0 _a	^a 131.3 _{ab}	^a 119.5 _a	^a 112.3 _b	116.6
Middle	^a 130.0 _a	^a 145.9 _a	^a 122.8 _a	^a 151.2 _a	137.5
Upper	^a 123.2 _a	^a 109.4 _b	^a 118.4 _a	^a 124.3 _{ab}	118.6
Overall mean	119.0	128.9	120.3	129.6	124.2

^zSuperscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test (P < 0.05).

fruit in the north quadrant was significantly shorter than fruit in the other quadrants (Table 5). In the middle of the canopy, fruit in the east and west quadrants were longer than those in the north and south quadrants. There was no significant difference in fruit length among quadrants in the upper tree canopy. There was no significant difference in fruit length among canopy layers within the north and south quadrants (Table 5). In contrast, in the east quadrant the longest fruit were in the lower and middle canopy layers whereas in the west quadrant, the longest fruit were in the middle and upper layers (Table 5).

Winter Harvest

Number of fruit. The mean number of fruit produced per tree was 481.2 and ranged from 360 to 628. The mean number of fruit per quadrant and canopy layer was 40.1 and ranged from 14 to 65 (Table 6). Similar to the summer harvest (Table 2) there was no significant difference in the mean number of fruit among quadrants within the lower, middle, and upper canopy layers (Table 6). In the north tree quadrant the mean number of fruit was significantly greater in the middle and upper canopy layers than in the lower canopy. However, there was no significant difference in the mean number of fruit among the lower, middle, and upper canopy in the east, south, and west quadrants (Table 6). There was a trend for the middle canopy layer to produce more fruit than the upper and lower layers of the tree canopy.

Fruit maturity. On 2 Dec., horticulturally mature fruit were observed in the middle and upper canopy layers of the north and south quadrants. However, within approximately one week of the first harvest, several of the trees had mature fruit in the middle canopy layer in the east quadrant and in the

Table 5. Mean fruit length (centimeters) of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the summer.^z

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^b 9.8 _a	^a 11.1 _a	^{ab} 10.4 _a	^{ab} 10.3 _b	10.4
Middle	^b 10.5 _a	^a 11.9 _a	^b 10.4 _a	^a 11.8 _a	11.2
Upper	^a 10.5 _a	^a 9.9 _b	^a 10.9 _a	^a 11.2 _a	10.6
Overall mean	10.3	11.0	10.5	11.1	10.7

^zSuperscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different at, according to Waller-Duncan K-ratio t-test (P < 0.05).

Table 6. Mean number of fruit of 'Arkin' carambola counted from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the winter.^z

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 14.4 _b	^a 24.8 _a	^a 31.0 _a	^a 20.0 _b	22.6
Middle	^a 64.4 _a	^a 50.8 _a	^a 58.0 _a	^a 65.2 _a	59.6
Upper	^a 36.0 _{ab}	^a 34.4 _a	^a 38.6 _a	^a 43.6 _{ab}	38.2
Overall mean	38.3	36.7	42.5	42.9	40.1

^zSuperscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different at according to Waller-Duncan K-ratio t-test (P < 0.05).

lower canopy layer in the west and north quadrants. Approximately one month later (2 Jan.) mature fruit were harvested from nearly all canopy layers and quadrants because most of the trees had reached peak fruit production.

°Brix. The mean °Brix per quadrant and canopy layer ranged from 7.8 °Brix to 8.9 °Brix, and there was no significant difference among quadrants and canopy layers (Table 7). However, there was a trend for the highest to lowest °Brix to be in the north, west, south, and east quadrants, respectively.

Weight. Mean fruit weight per quadrant and canopy layer ranged from 116.4 g to 171.5 g during the winter (Table 8). Fruit weight was not significantly different among quadrants in the lower and middle canopy layers (Table 8). However, in the upper canopy layer, fruit weight was significantly greater in the north quadrant than in the south quadrant.

Length. Mean fruit length per quadrant and canopy layer varied from 10.5 cm to 11.9 cm (Table 9). There was no significant difference in fruit length among quadrants or canopy layers. However, there was a trend for longest fruit to be in the middle canopy layer (Table 9).

Discussion

The number of fruit during the summer (619.8 fruit per tree) was generally greater than during the winter (481.2 fruit per tree). Using the overall mean fruit weight during summer (124.2 g) and winter (145.0 g), an estimated 77.0 kg and 69.8 kg of fruit were produced per tree during summer and winter, respectively. These yields are typical for mature carambola trees of this age and size (J. H. Crane, personal observation). More fruit was produced in the middle canopy layer than in the upper and lower canopy layers (Tables 2 and

Table 7. Mean °Brix of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the winter.^z

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 8.2 _a	^a 7.9 _a	^a 8.0 _a	^a 7.8 _a	8.0
Middle	^a 8.9 _a	^a 8.1 _a	^a 8.3 _a	^a 8.4 _a	8.4
Upper	^a 8.5 _a	^a 8.0 _a	^a 7.9 _a	^a 8.4 _a	8.2
Overall mean	8.5	8.0	8.1	8.2	8.2

^zSuperscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test (P < 0.05).

Table 8. Mean fruit weight (grams) of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the winter.²

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 158.7 _a	^a 134.9 _a	^a 139.3 _a	^a 129.3 _a	141.1
Middle	^a 171.5 _a	^a 149.8 _a	^a 150.8 _a	^a 160.6 _a	158.2
Upper	^a 158.3 _a	^{ab} 125.8 _a	^b 116.4 _a	^{ab} 142.1 _a	135.6
Overall mean	162.8	136.8	135.5	145.0	145.0

²Superscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test ($P < 0.05$).

6). Similar observations were previously observed for carambola in south Florida (Crane et al., 1991).

In general, mature fruit were first observed in the middle and upper canopy layers in the west and south canopy quadrants during summer and in the middle and upper canopy layers in the north and south canopy quadrants during winter.

Fruit from the summer harvest had a slightly higher °Brix (overall mean of 8.6 °Brix) than fruit from the winter harvest (overall mean of 8.2 °Brix) (Tables 3 and 7). This contrasts with a previous comparison where 'Arkin' fruit harvested during July had a lower °Brix (6.8 °Brix) than fruit harvested during November (7.1 °Brix) (Crane et al., 1998). We cannot explain this discrepancy. In addition, °Brix was higher in the upper and middle canopy layers than in the lower canopy layer for summer and winter-harvested fruit (Tables 3 and 7). This occurrence may be expected since there were more hours of sun exposure in the middle and upper tree canopy compared to the lower tree canopy.

In general, fruit weights in winter were greater than in summer (Tables 4 and 8). This observation may be due to fewer fruit produced during the winter cropping season compared to the summer cropping season (Tables 2 and 6). During both cropping seasons, fruit weight in the middle canopy layer was greater than that in the lower and upper canopy layers (Tables 4 and 8). This observation may be due to greater sun exposure of the middle canopy compared to the lower

Table 9. Mean fruit length (centimeters) of 'Arkin' carambola fruit harvested from the lower, middle, and upper canopy layers in the north, east, south, and west quadrants during the winter.²

Canopy layer	Canopy quadrant				Overall mean
	North	East	South	West	
Lower	^a 11.5 _a	^a 10.8 _a	^a 11.0 _a	^a 10.6 _a	11.0
Middle	^a 11.9 _a	^a 11.2 _a	^a 11.8 _a	^a 11.7 _a	11.6
Upper	^a 11.4 _a	^a 10.5 _a	^a 10.5 _a	^a 11.2 _a	10.9
Overall mean	11.6	10.8	11.1	11.2	11.2

²Superscripted lower case letters refer to canopy layers and subscripted lower case letters refer to tree quadrants. Columns or rows with different letters are significantly different according to Waller-Duncan K-ratio t-test ($P < 0.05$).

canopy and less transpirational demand in the middle canopy layer compared to the upper canopy layer.

Fruit length did not appear to differ between summer and winter (Tables 5 and 9). However, during both seasons, the longest fruit were generally produced in the middle canopy layer.

Conclusions

Fruit yield of 'Arkin' carambola in winter and summer were within the range expected for mature trees (Crane, 1994). More fruit was produced during the summer harvest than the winter harvest however winter fruit were heavier and larger. The effect of canopy location on earliness of fruit maturation varied by season with the earliest fruit in summer observed in the middle canopy layer (all quadrants) and the upper canopy layers in the west and south canopy quadrants. The fruit that matured earliest in winter were observed in the middle and upper canopy layers in the north and south canopy quadrants.

Fruit °Brix, weight, and length varied among layers and position. However, in general, fruit weight and length were acceptable from all locations in the canopy during both harvest periods. Therefore, the "earliness" at which the fruit reached horticultural maturity and the °Brix were the most important criteria for determining the best location in the canopy for spot picking. In general, spot picking for the earliest fruit in the summer from all quadrants in the middle layer and upper canopy layer in the south, west, and east quadrants is recommended. In winter, the earliest picking should be from the middle and upper canopy layers in the north and south quadrants.

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