Yield and Fruit Quality Traits of Carambola Cultivars Grown at Three Locations in Puerto Rico

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Summary. There is a scarcity of information on how carambola (*Averrhoa carambola*) cultivars perform in various agroenvironments. Nine carambola cultivars—Arkin, B-10, B-16, B-17, Kajang, Kari, Lara, Sri Kembangan, and Thai Knight—grown on an Oxisol, an Ultisol, and a Mollisol were evaluated for 4 years under intensive management at Isabela, Corozal, and Juana Díaz, PR, respectively. There were no significant differences in number and weight of marketable fruit per hectare area among locations averaging 258,761 fruit/ha and 30,978 kg·ha^{-1}, respectively. There were no significant differences of marketable fruit weight per hectare among highest yielding cultivars B-17, Thai Knight, and Sri Kembangan between locations. The average marketable fruit weight for these highest-yielding cultivars was 36,060 kg·ha^{-1}. 'Arkin' and 'B-16' were the lowest yielding cultivars, averaging 23,490 kg·ha^{-1} of marketable fruit. 'Kari' produced significantly longer fruit at all locations, whereas 'B-16' produced the shortest fruit. Significantly higher soluble solids concentration values were obtained from fruit of 'B-17' at all locations, whereas lower values were obtained from those of 'Arkin'. Overall, cultivars were highly adaptable to the diverse agroenvironments in which they were planted. The fact that 'B-17' had high production of marketable fruit, high marketable yield, and high soluble solids concentration at all locations makes this cultivar suitable for planting in diverse agroenvironments.

Carambola or star fruit is native to Indonesia but has been cultivated throughout southeast Asia and Malaysia for many centuries (Shaw and Wilson, 1998). The tree adapts to a wide range of conditions in tropical and subtropical climates; however, better fruit quality and higher yields are produced under tropical conditions and annual rainfall of ≈1800 mm (Galan-Sauco et al., 1993). Carambola trees adapt well to almost any soil type, from sand to heavy clay loam to rocky calcareous soils (Nakasone and Paull, 1998). On alkaline soils, however, deficiencies of Fe, Mn, and Z may occur (Marler et al., 1994).

There is little information available on total production area of carambola worldwide. Taiwan, Malaysia, and Brazil are the largest producers of carambola, with estimated production ranging from 3000 to 40,000 Mg. Florida is the largest production area in the United States, with 260 ha under cultivation and a crop worth $17.4 million in 1996. In 2000, however, averages had declined to ≈100 ha (Mossler and Nesheim, 2002).

Commonly used cultivars for commercial production include 'Arkin', 'Kary', 'B-10' (Florida), 'Cheng Tsey' (Taiwan), 'B-17' (Malaysia), 'Fwang Tung' (Thailand), and 'Icambola' (Colombia) (Campbell, 1997; Galan-Sauco et al., 1993; Marler et al., 1994; Nakasone and Paull, 1998). However, replicated field trials to evaluate these and other carambola cultivars have been very limited. The purpose of this study was to evaluate yield performance and fruit quality traits of nine carambola cultivars grown in various agroenvironments.

Materials and methods

The study was conducted in Puerto Rico at the U.S. Department of Agriculture, Agricultural Research Service Research Farm in Isabela (Coto clay: clayey, kaolinitic isohyperthermic Typic Hapludox), at the Corozal Agricultural Expt. Sta. of the University of Puerto Rico (UPR) (Corozal clay: clayey, mixed, isohyperthermic Aquic Haplohumults), and at the UPR-Juana Diaz Agricultural Expt. Substation (San Anton: fine-loamy, mixed isohyperthermic Cumulic Haplustoll). Soil and climatic characteristics are described in Tables 1 and 2.

Six-month-old trees of cultivars Arkin, B-10, B-16, B17, Kajang, Kari, Lara, Sri Kembangan, and Thai Knight grafted onto 'Golden Star' rootstocks were transplanted to the field 9 Feb. 1999 (Isabela), 17 Mar. 1999 (Corozal), and 3 June 1999 (Juana Diaz), and were arranged in a randomized complete-block design with six replications at each location. Planting holes about 1.5 ft deep were dug with an auger connected by a drive shaft to the power take-off unit of a tractor. At transplanting, each plant received 11 g granular P provided as triple superphosphate. Within a replication, plots for each cultivar contained two trees spaced

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.5400	inch(es)	cm	0.3937
25.4000	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha^{-1}	0.8922
28.3495	oz	g	0.0353
1	ppm	mg·kg^{-1}	1
6.8948	psi	kPa	0.1450
0.9072	ton(s)	Mg	1.1023
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Table 1. Average preplant soil characteristics at three carambola test sites in Puerto Rico measured to a depth of 12 inches.

Soil characteristics	Location Corozal (Ultisol)	Juana Díaz (Mollisol)	Isabela (Oxisol)
pH in water	4.75	8.28	6.62
pH in calcium chloride	4.11	7.85	6.06
Ammonium nitrogen ($mg \cdot kg^{-1}$)[z]	23.01	14.00	11.05
Nitrate nitrogen ($mg \cdot kg^{-1}$)	9.17	14.00	6.60
Organic C (%)	1.19	0.41	1.20
P ($mg \cdot kg^{-1}$)	5.88	104.00	15.79
K ($mg \cdot kg^{-1}$)	53.67	650.00	469.80
Ca ($mg \cdot kg^{-1}$)	1551.00	3158.00	1654.00
Mg ($mg \cdot kg^{-1}$)	62.00	337.00	67.80

[z]1 $mg \cdot kg^{-1}$ = 1 ppm.

Table 2. Historical weather data at three carambola test sites in Puerto Rico (n = 58 years).

Site characteristic	Location (soil) Corozal (Ultisol)	Juana Díaz (Mollisol)	Isabela (Oxisol)
Rainfall (mm)[z]	1863	917	1649
Evaporation (mm)	1391	2149	1672
Temperature max. (°C)[z]	29.7	31.2	29.8
Temperature min. (°C)	19.8	20.8	19.9
Temperature mean (°C)	24.7	26.0	24.9
Elevation (m)[z]	195	21	126

[z]1 mm = 0.0394 inch; (1.8 × °C) + 32 = °F; 1 m = 3.2808 ft.

12 ft apart and 18 ft between adjacent rows in a triangular array. The experiments were surrounded by two guard rows of 'Golden Star' seedlings. Irrigation based on tensiometer readings was provided with spinner jets (model DXMAG368X; Maxijet, Dundee, FL) spaced 12 ft apart and providing 13.5 gal/h at 20 psi. Fertilization was provided every 3 months using a 15N–2.2P–16.3K–1.8Mg commercial mixture at a rate of 498 $kg \cdot ha^{-1}$. Herbicide for weed control was applied only in strips within the planting row.

Harvests were initiated in Aug. 2001 at all locations. At each harvest, number and weight of marketable and nonmarketable fruit were recorded and weighed. Deformed fruit and those measuring less than 10 cm in length and 5.5 cm in diameter were considered nonmarketable. Representative fruit totaling 10% of those harvested were used to determine fruit length and diameter. Soluble solids readings were also recorded with a temperature-compensated Packet PAL-1 digital refractometer (ATAGO Co., Ltd., Tokyo, Japan) when the fruit ripened, about 2 to 3 d after harvest. The experiment was ended in Aug. 2005.

Analysis of variance was carried out using the GLM procedure of SAS (release 9.0 for Windows; SAS Institute, Cary, NC). After significant F test at $P \leq 0.05$, means separation was performed with LSD.

Results and discussion

Location, cultivars, and year showed highly significant effects ($P \leq 0.01$) on most fruit parameters measured in the study. Exceptions were number of marketable fruit and marketable weight per hectare, which did not show a significant location effect. The cultivar × location interaction was significant for total number of fruit, number of nonmarketable fruit, nonmarketable fruit yield, and fruit soluble solids but not for number of marketable fruit, marketable fruit yield, total yield, fruit length, and fruit diameter (Table 3). Except for fruit length and diameter, the year × cultivar interaction was also highly significant for most fruit variables. Overall, cultivars exhibited an increase in the number of marketable fruit and weight during the first 3 years of production and then leveled off on the fourth year (Table 4). This response was expected as trees increased in age. However, the magnitude of this response varied among cultivars as expected by the significant year × cultivar interaction (Table 3). 'Arkin', 'B-10', 'B-16', 'Kajang', 'Lara', and 'Thai Knight' had an increase in the number of marketable fruit and marketable yield during the first 3 years and then declined or leveled off. In contrast, these variables increased in 'B-17,' 'Kari,' and 'Sri Kembangan' throughout the experimental period (Table 4).

'Sri Kembangan', 'Thai Knight', and 'B-17' had the three highest 4-year mean for number and yield of marketable fruit (Table 4). 'Sri Kembangan' had the highest number of marketable fruit and marketable yield in 2 of the 4 years the experiment lasted, and the highest 4-year mean for these variables. 'B-16' had the lowest 4-year mean for number of marketable fruit and marketable yield.

Total number of fruit was significantly different among locations, with more fruit produced in Corozal (793,735 fruit/ha) and less at Isabela (479,759 fruit/ha; Table 3). A possible explanation on why more fruit were produced at Corozal than at other locations may be that this site is less windy than Isabela and Juana Diaz. Windy conditions have been reported to be detrimental to carambola fruit production (Crane, 2005; Galan-Sauco et al., 1993), but the effects of wind on physiological processes of carambola are still unknown (Marler et al., 1994). The number of marketable fruit was not significantly different among locations averaging 258,761 fruit/ha. At Corozal, the number of marketable fruit constituted only 31% of the total fruit harvested whereas at Juana Diaz and Isabela it was 41% and 55% respectively (Table 3). Chemical fruit or flower thinning to reduce crop load and increase fruit size is not a standard cultural practice in carambola production. The potential of fruit thinning in carambola is being studied by the author to find out if this practice is a potentially profitable one for this crop. Studies in other crops have shown that fruit thinning often reduces returns to the growers (Davis et al., 2004). The average marketable fruit weight was also similar among locations averaging 30,978 $kg \cdot ha^{-1}$. Average fruit length and diameter were significantly greater at Isabela

Table 3. Yield and fruit quality traits of nine carambola cultivars planted at three locations in Puerto Rico.[z]

Location	Cultivar	Marketable fruit (no./ha)[y]	Non marketable fruit (no./ha)	Total fruit (no./ha)	Wt marketable fruit ($kg\cdot ha^{-1}$)[x]	Wt nonmarketable fruit ($kg\cdot ha^{-1}$)	Total fruit wt ($kg\cdot ha^{-1}$)	Fruit length (cm)[w]	Fruit diameter (cm)	Fruit soluble solids (%)
Corozal	Arkin	220,825	1,178,836	1,399,661	25,035	61,694	86,729	11.1	6.1	8.0
	B-10	267,080	486,338	753,417	35,383	30,397	65,780	11.1	6.5	8.6
	B-16	171,415	471,829	643,244	22,070	27,262	49,333	10.9	6.2	8.6
	B-17	323,952	487,137	811,088	39,510	30,358	69,869	11.5	6.2	9.2
	Kajang	212,201	284,671	496,871	24,069	15,996	40,065	11.9	6.2	8.7
	Kari	291,178	239,869	531,046	31,064	12,644	43,708	12.6	6.0	8.7
	Lara	164,742	636,218	800,959	19,458	36,101	55,558	11.1	6.8	8.5
	Sri Kembangan	273,079	351,464	624,542	30,107	20,245	50,352	12.0	6.0	9.1
	Thai Knight	310,616	772,171	1,082,787	33,107	40,473	73,580	11.6	6.4	8.5
	Average	248,343	545,393	793,735	28,867	30,574	59,442	11.5	6.3	8.7
	LSD (0.05)[x]	NS	68,287	88,011	NS	3,778	7,247	0.17	0.11	0.2
Isabela	Arkin	213,176	424,350	637,526	23,579	24,971	48,550	11.3	6.4	8.0
	B-10	252,561	208,402	460,963	34,709	15,655	50,364	11.4	7.2	8.9
	B-16	154,457	172,162	326,619	19,135	12,083	31,219	11.3	6.6	8.6
	B-17	264,527	164,929	429,456	32,693	11,379	44,072	11.8	6.4	9.6
	Kajang	268,574	109,053	377,627	34,517	7,624	42,141	11.9	6.7	8.5
	Kari	277,334	41,294	318,628	32,434	2,663	35,097	12.8	6.5	8.5
	Lara	224,706	393,278	617,984	27,749	25,333	53,082	11.3	7.2	8.4
	Sri Kembangan	372,978	133,203	506,181	46,650	9,486	56,137	12.4	6.5	8.7
	Thai Knight	353,696	289,154	642,850	42,514	18,179	60,693	11.9	6.8	8.3
	Average	264,668	215,092	479,759	32,664	14,153	46,817	11.8	6.7	8.6
	LSD (0.05)	NS	37,435	61,661	NS	2,525	NS	0.28	0.17	0.23
Juana Díaz	Arkin	209,067	570,037	779,104	24,632	39,116	63,747	11.4	6.4	8.3
	B-10	221,904	336,592	558,497	30,699	26,490	57,188	11.1	6.9	9.0
	B-16	201,491	355,439	556,930	26,488	27,182	53,670	11.0	6.6	9.0
	B-17	309,682	371,546	681,228	36,178	27,808	63,987	11.9	6.2	9.8
	Kajang	331,102	199,550	530,652	38,726	15,227	53,953	12.3	6.7	9.3
	Kari	274,397	120,863	395,260	30,465	8,631	39,096	12.5	6.2	9.4
	Lara	257,117	448,697	705,814	31,649	33,066	64,715	11.2	7.1	8.6
	Sri Kembangan	293,233	329,650	622,882	35,051	22,787	57,837	12.1	6.2	9.5
	Thai Knight	271,449	657,441	928,891	28,733	40,179	68,912	11.6	6.5	8.7
	Average	263,271	376,646	639,918	31,402	26,721	58,123	11.7	6.5	9.1
	LSD (0.05)	26,071	40,846	49,728	3,339	2,969	4,564	0.14	0.07	0.12
	LSD (0.05)[w]	11,821	16,822	22,651	1,484	1,038	2,010	0.07	0.04	0.060
	Cultivar (C)	**	**	**	**	**	**	**	**	**
	Location (L)	NS	**	**	NS	**	*	**	**	**
	C × L	NS	**	**	NS	**	NS	NS	NS	**
	Year (Y)	**	**	**	**	**	**	**	**	**
	L × Y	**	**	**	**	**	**	**	**	**
	Y × C	**	**	**	**	**	*	NS	NS	**
	C × L × Y	NS	**	**	NS	**	NS	*	NS	NS

[z]Values are means of six replications and 4 years (2001–05). Values of fruit length, width, and soluble solids are for marketable fruit only.
[y]1 fruit/ha = 0.4047 fruit/acre; 1 $kg\cdot ha^{-1}$ = 0.8922 lb/acre; 1 cm = 0.3937 inch.
[x]Least significant difference at $P = 0.05$.
[w]Compares means among locations.
NS,*,**Significant at $P \leq 0.05$ or 0.01 respectively.

Table 4. Number and yield of marketable fruit of nine cultivars of carambola grown in Puerto Rico.

	Marketable fruit (no./ha)[z]					Marketable wt ($kg\cdot ha^{-1}$)[z]				
Cultivar	4-yr	2002	2003	2004	2005	4-yr	2002	2003	2004	2005
Arkin	214,355	141,197	220,776	260,116	235,333	24,414	17,284	24,499	28,778	27,098
B-10	247,181	192,672	253,280	272,030	270,743	33,596	27,392	33,264	36,764	36,965
B-16	175,787	136,976	169,162	204,130	192,880	22,564	19,311	20,647	25,611	24,688
B-17	299,387	216,390	291,928	335,475	353,754	36,127	28,210	34,929	40,030	41,339
Kajang	270,625	189,974	264,336	322,993	305,198	32,437	24,051	31,772	37,626	36,299
Kari	280,969	170,422	243,857	334,340	375,257	31,320	20,026	26,946	36,382	41,927
Lara	215,521	175,555	215,144	240,093	231,292	26,285	22,287	25,856	29,130	27,866
Sri Kembangan	313,096	216,556	267,643	355,705	412,480	37,269	26,557	31,639	42,691	48,188
Thai Knight	311,920	210,647	324,986	373,790	338,256	34,784	24,786	35,149	40,332	38,869
LSD (0.05)[y]	20,475	47,023	57,942	76,120	93,606	2570	6442	7275	9339	12,120

[z]1 fruit/ha = 0.4047 fruit/acre; 1 $kg\cdot ha^{-1}$ = 0.8922 lb/acre.
[y]Least significant difference at $P = 0.05$.
Data are the average of three locations.

than at other locations whereas average soluble solids concentration was significantly higher at Juana Diaz (Table 3).

At all locations, total number of fruit was significantly higher in 'Arkin' and 'Thai Knight' than in other cultivars and significantly lower in 'Kari' (Table 3). The number of marketable fruit produced by each cultivar varied among locations. At Corozal, there were no significant differences in marketable fruit production among top-producing cultivars B-17, Thai Knight, and Kari, which averaged 308,582 fruit/ha. 'Kajang' and 'B-17' were the highest producers of marketable fruit at Juana Diaz, averaging 320,392 fruit/ha. The number of marketable fruit produced by each cultivar at Isabela was not significantly different (Table 3). 'B-16' produced the lowest number of marketable fruit at all locations, but differences between 'B-16' and 'Lara' at Corozal and 'Arkin' and 'B-10' at Juana Diaz were not statistically significant (Table 3). As a percentage of total fruit production, 'Arkin' produced a significantly higher percentage (75%) of nonmarketable fruit at all locations (data not shown) than other cultivars. This cultivar normally produced a large number of fruit, which may result in high sink demand for assimilates and smaller fruit.

Significantly higher yield of marketable fruit was obtained by 'Kajang', 'B-17', and 'Sri Kembangan' at Juana Diaz and 'B-17' at Corozal. 'Lara', 'B-16', and 'Kajang' produced significantly lower weight of marketable fruit per hectare than others at Corozal, whereas 'Arkin' and 'B-16' did so at Juana Diaz. Weight of marketable fruit at Isabela was not significantly different among cultivars.

Individual weight of marketable fruit averaged over locations and cultivars was 120.2 g (data not shown). However, there was considerable deviation from this weight. At all locations individual weight of marketable fruit was significantly higher in 'B-10' and 'B-16', averaging 132.3 g, whereas 'Kari' and 'Thai Knight' produced marketable fruit that weighed only an average of 111 g (data not shown).

'Kari' produced significantly longer fruit than other cultivars at all locations, whereas 'B-16' produced the shortest fruit overall (Table 3). 'B-10' and 'Lara' produced fruit with significantly greater fruit diameter than other cultivars at all locations, whereas those of 'Kari' and 'Sri Kembangan' produced fruit with the smallest diameter (Table 3). The highest soluble solids concentration values were obtained from fruit of 'B-17' at all locations, whereas the lowest values were obtained from 'Arkin' fruit.

In this study nine carambola cultivars were evaluated for the first time at three locations during 4 years of production. Overall, cultivars were highly adaptable to the diverse agroenvironments in which they were planted, although significantly higher yields of marketable fruit were obtained at Isabela (Oxisol) and Juana Diaz (Mollisol). The fact that 'B-17' had a high production of marketable fruit, high marketable yield, and significantly higher soluble solids concentration values than the rest of the cultivars at all locations makes this cultivar suitable for planting on various agroenvironments.

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