Yield Performance of Six Lychee Cultivars Grown at Two Locations in Puerto Rico

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Additional index words. tropical fruits, *Litchi chinensis*, soluble solids concentration

Summary. The globalization of the economy, increased ethnic diversity, and a greater demand for healthy and more diverse food production has increased the demand for tropical fruits. There is a lack of formal experimentation to determine yield performance and fruit quality traits of lychee (*Litchi chinensis*) cultivars. Six lychee cultivars (Bosworth-3, Brewster, Groff, Mauritius, Kaimana, Salathiel) grown on Mollisol and Inceptisol soils were evaluated for 8 years at the Adjuntas Agricultural Experiment Station of the University of Puerto Rico (UPR-Adjuntas) and La Balear farm, Adjuntas, Puerto Rico, respectively. At UPR-Adjuntas and La Balear, cultivar Groff had a significantly higher production (257,296 fruit/ha) of total fruit than other cultivars, whereas Salathiel had the lowest. However, total fruit production of 'Groff' was not significantly different from 'Kaimana' and 'Bosworth-3'at La Balear. At UPR-Adjuntas, cultivars Groff and Bosworth-3 had significantly higher number of marketable fruit than the rest of the cultivars averaging 171,760 fruit/ha. At La Balear, 'Kaimana' had a higher number of marketable fruit, but it was not significantly different from 'Groff', 'Bosworth-3', and 'Mauritius', averaging 291,360 fruit/ha. At both sites, individual fruit weight of marketable fruit was higher in 'Kaimana' than the rest of the cultivars. However, at La Balear, there were no significant differences between 'Kaimana' and 'Mauritius'. At both locations, cultivars exhibited erratic production patterns, which were characterized by lower production during 1 or 2 successive years following heavy cropping. At current farm gate prices and fruit yield reported in this study, cultivars Groff, Bosworth-3, and Kaimana can generate a good income for growers, and allow them to diversify crops as part of their farm operations.

Lychee belongs to the Sapindaceae family and is native to southern China. The crop is grown commercially from latitude 17° to 32° and is usually found at low elevation in the subtropics and from 300 to 600 m in tropical locations (Menzel and Simpson, 1994). Except for about 1200 acres grown in south Florida and about 330 acres in Hawaii (Nagao, 2009), lychee is virtually unknown in the western hemisphere.

The most common and recommended method of lychee propagation is by air layering. Trees propagated from air layering come into commercial production about 3 to 5 years after field planting. Trees propagated by seed are slow in growth, not true-to-type, and take many years to bear a crop. Experimentation on optimal plant spacing of lychee is scarce but it is generally recommended that trees be spaced 25 ft within and between rows, which is equivalent to about 170 trees/ha.

Yield varies with cultivar, age of tree, weather conditions, presence of pollinating insects, and management. Insects are necessary for pollination, and honeybees account for about 80% of pollinating insects. An average yield is considered 25–60 kg/tree per year, although yields as high as 90–140 kg/tree per year can be obtained (Crane et al., 2013). Pruning is carried out at harvest with the removal of 15 to 60 cm of the branch with the fruit clusters (Zee et al., 1998). The lychee is a nonclimacteric fruit and as such does not ripen once harvested; therefore, the fruit must be picked at optimal visual appearance and eating quality. Pericarp color is the most commonly used harvest index, but color and fruit maturity varies with cultivars, regions of cultivation, and cultural practices (Underhill et al., 2001). The fruit has a short shelf life of about 2 to 7 d at 25 °C (Underhill et al., 2001). The handling and storage of lychee postharvest are determined by the need to control pericarp browning, which is accomplished by reducing the rate of water loss by various methods (e.g., cooling at 5 °C, use of plastic films for packaging) or by chemical treatments such as sulfur dioxide followed by immersion of fruit in 1 N hydrochloric acid (HCl) for 2 min (Underhill et al., 2001).

There are about 70 known cultivars of lychee, but only a few have been studied or extensively cultivated. The most commercially used cultivars are Kwa Mi, an early cultivar with fruit of excellent quality; Kaimana from Hawaii; Bosworth-3 (Kwai May Pink) and Salathiel are Australian selections that bear fruit regularly; Brewster, a midseason commercial cultivar in Florida; and Groff, a late cultivar that bears regularly in the tropics (Galan-Sauco, 1987; Zee et al., 1998). Most cultivars require a chilling period of about 15 °C for about 10 weeks for flower induction and consequent fruit set although more tropical cultivars are known to flower after a period of 20 °C for 6–8 weeks. To our knowledge, replicated field trials to evaluate

We thank Edmundo Rivera, Tomás Soto, Tomás Miranda, and Pablo Ríos for their excellent field assistance, Francis Zee, and Felipe Ozonas for land use.

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement of the U.S. Department of Agriculture.

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doi: 10.21273/HORTTECH03488-16

Units

To convert U.S. to SI, multiply by	U.S. unit	S.I. 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
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	$kg \cdot ha^{-1}$	0.8922
28.3495	oz	g	0.0353
1	ppm	$mg \cdot kg^{-1}$	1
6.8948	psi	kPa	0.1450
(°F − 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

these and other lychee cultivars are nonexistent. The objective of this study was to evaluate yield performance and fruit quality traits of six lychee cultivars grown at two locations in the highlands of Puerto Rico.

Materials and methods

This study was conducted at the UPR-Adjuntas and at La Balear farm in the municipality of Adjuntas, Puerto Rico. The soil order at UPR-Adjuntas is a Mollisol (toa silty clay loam: fine, mixed, active, isohyperthermic, Fluventic Hapludolls) and at La Balear farm an Inceptisol (Alonso clay: very-fine, parasesquic, isohyperthermic, Oxic Dystrudepts). The soil at UPR-Adjuntas has a pH in water of 5.68, pH in calcium chloride ($CaCl_2$) of 4.82, 13 mg·kg^{-} ammonium nitrogen (NH_4-N), 11 mg·kg^{-1} nitrate-nitrogen (NO_3-N), 20 mg·kg^{-1} phosphorous (P), 204 mg·kg^{-1} potassium (K), 2160 mg·kg^{-1} iron (Fe), 72 mg·kg^{-1} manganese (Mn), 4 mg·kg^{-1} zinc (Zn), 0.75 mg·kg^{-1} aluminum (Al), and 1.46% organic carbon. At La Balear, the soil had a pH in water of 6.51, pH in $CaCl_2$ of 5.84, 8 mg·kg^{-1} NH_4-N, 13 mg·kg^{-1} NO_3-N, 426 mg·kg^{-1} P, 258 mg·kg^{-1} K, 2201 mg·kg^{-1} Ca, 132 mg·kg^{-1} Mg, 99 mg·kg^{-1} Fe, 40 mg·kg^{-1} Mn, 21 mg·kg^{-1} Zn, 0.17 mg·kg^{-1} Al, and 1.83% organic carbon. During the experimental period (2005–12) at UPR-Adjuntas mean monthly rainfall was 18.7 cm, mean evaporation 11.6 cm, average mean temperature 22.0 °C, average maximum temperature 28.3 °C, average minimum temperature 15.1 °C, and 584 m elevation. At La Balear, average mean temperature was 22.5 °C, average maximum temperature 30.6 °C, average minimum temperature 16.3 °C, and 449 m elevation. Soil samples from each site were taken about 6 weeks before planting by taking seven borings at a depth of 0–25 cm from each of the projected cultivar rows. Samples were air dried and passed through a 20-mesh screen. Soil pH in water and 0.01 M $CaCl_2$ (1 soil : 2 water) were measured with a glass electrode. Exchangeable cations (K, Mg, Ca) were extracted with neutral 1 N ammonium acetate and determined by atomic absorption spectroscopy (Sumner and Miller, 2007). Phosphorus was extracted with 1 N ammonium fluoride and 0.5 N HCl and determined using the ascorbic acid method (Benton, 2001). Organic carbon was determined by the Walkley–Black method (Nelson and Sommers, 2007). Soil ammonium and nitrate were determined by steam distillation (Mulvaney, 2007).

Before transplanting, the soil was chisel plowed to a depth of about 90 cm. Planting holes of about 1.5-ft deep were dug with an auger connected by a drive shaft to the power-take-off unit of a tractor. On transplanting, each plant received 11 g granular P provided in the form of triple superphosphate. Six-month-old air layered trees of cultivars Brewster, Bosworth-3 (Kwai May Pink), Groff, Mauritius, Kaimana, and Salathiel were transplanted to the field 13 May 1999 (UPR-Adjuntas) and 3 Apr. 2003 (La Balear farm) and arranged in a randomized complete block design with five replications at each location. Within a replication, plots for each cultivar contained three trees spaced 16 ft apart and 20 ft between adjacent rows (about 336 trees/ha) forming a triangular array. The experiments were surrounded by two rows of guard trees. Plots were irrigated as necessary with spinner jets (model DXMAG368X; Maxijet, Dundee, FL) providing 13.5 gal/h at 20 psi and spaced 12 ft apart (UPR-Adjuntas) or by overhead irrigation (La Balear). Fertilization was provided every 3 months using a 15N–2.2P–16.3K–1.8Mg fertilizer at a rate of 498 kg·ha^{-1}. Herbicide (glyphosate) for weed control was applied only in strips within the planting row. Weeds between rows were controlled with a brush mower.

Harvests were initiated in June 2005 at UPR-Adjuntas and June 2007 at La Balear farm about 6 and 4 years, respectively, after trees were field transplanted. At this time, trees were producing fruit in sufficiently large numbers for commercial harvest and sale. At harvest, telescopic long reach pruners (model 160ZR-3.0–5; ARS, Osaka, Japan) were used to cut fruit clusters on terminal ends of tree branches from each cultivar within a replication. Recommended pruning was carried out at harvest with the removal of 50–60 cm of branches with fruit clusters (Zee et al., 1998). The weight of fruit clusters attached to stem pieces was recorded in the field (fruit cluster yield). Fruit clusters were then brought to the laboratory where they were separated from stems, counted, and weighed again (fruit yield). Fruit from each tree were then composited by replication and cultivar. Fruit were placed in a basket having 25 × 25-mm holes at the bottom and those passing through the holes were considered too small and hence, nonmarketable. The number and weight of marketable and nonmarketable fruit were then recorded and weighed. Representative fruit totaling 10% of those harvested were then used to determine soluble solids with a temperature compensated digital refractometer (PAL-1; Atago, Tokyo, Japan) 1 d after harvest. Flowering normally occurred during January to February and fruit harvested from May to July; between two and four pickings per tree were made during the harvesting period. Representative fruit from each cultivar is shown in Fig. 1. Results are reported for harvests made from 2005–11 (UPR-Adjuntas) and 2007–11 (La Balear).

Analysis of variance was carried out separately for each location using the GLM procedure of SAS (version 9.4 for Windows; SAS Institute, Cary, NC). After significant F test at $P \leq 0.05$, means separation was performed with the Tukey's honestly significant difference range test.

Results and discussion

Cultivars and years showed highly significant effects ($P \leq 0.01$) on most fruit production parameters measured in the study. Exceptions were marketable yield and total yield at UPR-Adjuntas, and fruit soluble solids at La Balear, which did not show a significant cultivar effect. The year × cultivar interaction was significant for marketable, nonmarketable, and total fruit number at both locations but the year × cultivar interaction for the corresponding marketable, nonmarketable, and total yield was significant only at La Balear farm (Table 1). The year × cultivar interaction was also significant for fruit cluster yield and individual fruit weight of marketable fruit at both locations (Table 1).

In general, cultivars exhibited an increase in the number of total fruit produced from field transplanting until 2009 at both locations (Table 2). In 2010, there was a drastic decline in total fruit production followed by a sharp increase in 2011 and then a leveling off or another decline (Table 2). The increase in fruit production during the first few years was expected as trees increased in age. At La Balear, significantly higher total fruit production by all cultivars occurred in 2011, averaging 512,508 fruit/ha. At UPR-Adjuntas,

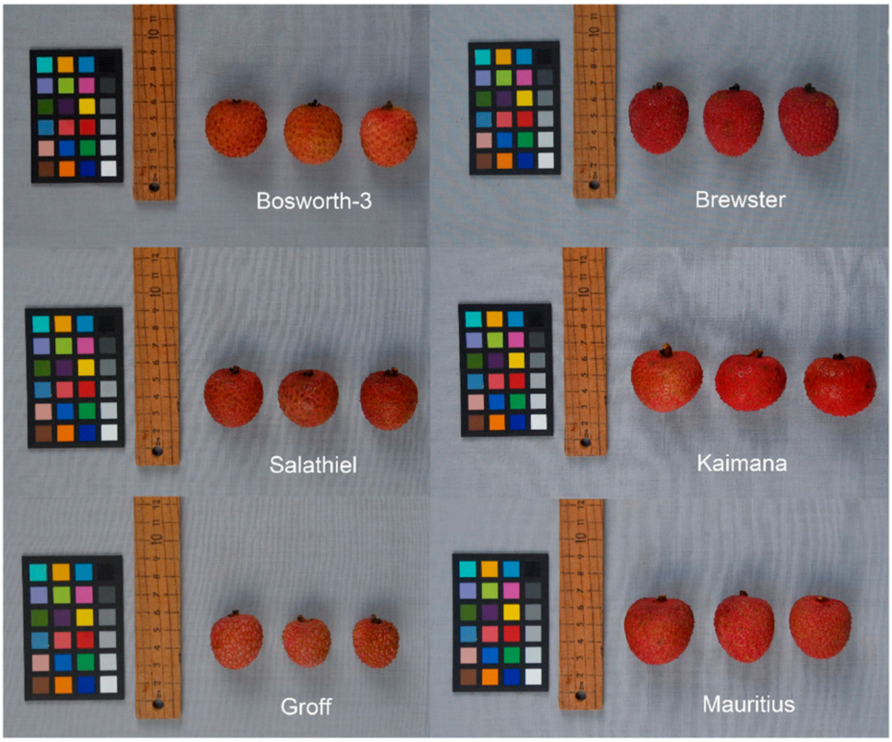

Fig. 1. Representative fruit of six lychee cultivars grown at two locations in Puerto Rico; 1 cm = 0.3937 inch.

higher total fruit production by all cultivars was obtained in 2009 but production did not differ significantly from that obtained in 2008, 2011, and 2012, averaging 216,428 fruit/ha.

The dramatic decline in fruit production by all cultivars in 2010 at both locations is noteworthy (Table 2). It is well accepted that cool temperatures promote flowering in lychee (Davenport and Stern, 2005; Paull and Duarte, 2011; Zee et al., 1998). Temperatures between 0 and 14 °C are known to induce flowering in lychee trees (Galan-Sauco, 1987; Nakata and Watanabe, 1966). In an elegant pot experiment, Menzel and Simpson (1988) subjected several lychee cultivars to maximum/minimum temperatures of 15/10, 20/15, 25/20, or 30°/25 °C. In general, trees subjected to 15/10 and 20/15 °C for 6 weeks showed panicle emergence, whereas those exposed to 25/20 or 30/25 °C did not flower. Lower temperatures in Adjuntas, Puerto Rico occurs during the months of January, February, and March with average (n = 21 years) maximum/minimum temperatures during these months being 25.3/10.7 °C at UPR-Adjuntas. In 2010, average maximum/minimum temperature at UPR-Adjuntas was 26.5/11.6 °C which is higher than average. Further, during Jan., Feb., and Mar. 2010 at UPR-Adjuntas, there were 51 d with temperatures below 13 °C and only 9 d with temperatures below 10 °C. In contrast, in 2009, a year of good fruit production at UPR-Adjuntas, there were 67 d with temperatures below 13 °C and 28 d with temperatures below 10 °C (data not shown). Unfortunately, 2010 weather data for La Balear is not available; however, this location is 4 km from UPR-Adjuntas. Therefore, a similar temperature response is to be expected. Drought or water deficits do not induce lychee flowering. Drought is only effective in promoting lychee flowering if it coincides with, or is followed by, low temperatures (Davenport and Stern, 2005). With rainfall being very similar at both locations during the cooler months in 2010, the authors suggest that the decline in fruit production at both locations in 2010 was associated with higher-than-normal temperatures during the cooler months which we hypothesize prevented trees from having an inductive flowering period.

At UPR-Adjuntas and La Balear, 'Groff' had the highest production mean for number of total fruit produced, whereas 'Salathiel' had the lowest (Table 1). However, at La Balear, total fruit production of 'Groff' was not significantly different from 'Kaimana' and 'Bosworth-3'. At both locations, cultivars exhibited erratic fruit production patterns, which were characterized by lower production during 1 or 2 successive years following heavy cropping (Table 2). For example, as compared with 2006 total number of fruit in cultivar Brewster declined 46% and 51% in 2007 and 2008, respectively, at UPR-Adjuntas, increased 148% from 2008 to 2009, declined by 100% in 2010, increased by 100% in 2011, and had a final decline of 92% in 2012 when the experiment ended. Similar patterns were observed for this cultivar in La Balear. Erratic fruit bearing has been mentioned as one of the major limitations to lychee production (Crane et al., 2013). Reasons for this response in production are not clear. Fruit set problems can occur in lychee even if flower production is consistent (Paull and Duarte, 2011). *Lasiodiplodia theobromae* was reported to cause inflorescence blight in longan (*Dimocarpus longan*), a close relative to lychee, in a field adjacent to this study (Serrato-Diaz et al., 2014). However, years of high production rules out *L. theobromae* being a major factor limiting flower development in this study. The possibility of water stress impeding flower induction or development is ruled out because supplemental irrigation was supplied when necessary. The high fruit load in some cultivars during 1 or 2 consecutive years may have resulted in depletion of assimilates, which then caused an "off-year" because of light blooming as trees built up carbohydrate reserves (Scholefield et al., 1985). Biennial production is not always characterized by an every-other-year cycle. An "on-year" can be followed by one or more "off-years" and vice versa (Paz-Vega, 1977).

At UPR-Adjuntas, cultivars Groff and Bosworth-3 had significantly higher numbers of marketable fruit per hectare than the rest of the cultivars, whereas at La Balear, 'Kaimana' had a higher number of marketable fruit, but it was not significantly different from that of 'Groff', 'Bosworth-3', and 'Mauritius' (Table 1).

Significantly higher yield of marketable fruit was obtained by 'Kaimana' at La Balear, whereas 'Brewster' and 'Salathiel' produced significantly lower weight of marketable fruit per hectare

Table 1. Number of fruit, fruit yield, fruit cluster yield, individual fruit weight, and total soluble solids of six lychee cultivars planted at two locations in Puerto Rico. Values are means of five replications and 8 years (2005–12) at the Adjuntas Agricultural Experiment Station of the University of Puerto Rico (UPR-Adjuntas) and four replications and 6 years (2007–12) at La Balear in Adjuntas, Puerto Rico.

Location	Cultivar	Marketablefruit (no./ha)[z]	Non marketable fruit (no./ha)	Total fruit (no./ha)	Marketable yield ($kg \cdot ha^{-1}$)[z]	Non marketable yield ($kg \cdot ha^{-1}$)	Total yield ($kg \cdot ha^{-1}$)	Fruit cluster yield ($kg \cdot ha^{-1}$)	Marketable individual fruit weight (g)[z]	Total soluble solids (%)
UPR-Adjuntas	Brewster	123,824	12,808	136,632	1,730	61	1,791	1,896	13.3	19.3
	Bosworth-3	148,339	10,911	159,250	1,843	54	1,897	2,002	12.1	19.9
	Groff	195,182	62,114	257,296	1,818	236	2,054	2,245	9.2	18.5
	Mauritius	108,424	6,798	115,222	1,838	44	1,882	2,025	15.3	18.7
	Kaimana	113,385	5,255	118,640	1,916	33	1,943	2,083	16.6	18.6
	Salathiel	74,023	8,260	82,283	955	51	1,006	1,073	12.7	17.9
	Average	127,196	17,691	144,887	1,683	80	1,762	1,887	13.2	18.8
	HSD (0.05)[y]	69,610	12,817	75,505	967	52	986	1,041	1.3	0.71
	Year (Y)	***	***	***	**	*	**	***	***	**
	Cultivar (C)	***	***	***	NS	***	NS	**	***	***
	Y × C	***	***	***	NS	NS	NS	***	**	NS
La Balear	Brewster	41,422	3,741	45,163	692	21	713	746	15.0	19.4
	Bosworth-3	264,012	15,601	279,613	3,215	73	3,288	3,518	12.2	19.2
	Groff	321,175	87,999	409,174	3,080	340	3,420	3,678	9.9	17.4
	Mauritius	223,403	10,305	233,708	4,423	96	4,519	4,801	17.1	19.1
	Kaimana	356,852	6,312	363,164	6,567	46	6,613	7,006	17.8	19.6
	Salathiel	21,303	995	22,298	303	6	309	331	12.2	17.3
	Average	204,694	20,825	225,220	3,047	97	3,144	3,347	14.3	18.8
	HSD (0.05)	139,697	28,552	155,085	2,058	122	2,085	2,189	2.7	3.4
	Y	***	***	***	***	**	***	***	***	NS
	C	***	***	***	***	***	***	***	***	NS
	Y × C	***	***	***	***	***	***	***	**	NS

[z] 1 fruit/ha = 0.4047 fruit/acre, 1 $kg \cdot ha^{-1}$ = 0.8922 lb/acre, 1 g = 0.0353 oz.
[y] Tukey's honest significant difference test at $P = 0.05$.
NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Number of total fruit of six lychee cultivars grown at the locations in Puerto Rico. Values are means of five replications at the Adjuntas Agricultural Experiment Station of the University of Puerto Rico (UPR-Adjuntas) and four replications at La Balear in Adjuntas, Puerto Rico.

Cultivar	Mean production	2005	2006	2007	2008	2009	2010	2011	2012
UPR-Adjuntas									
				Total fruit (no./ha)[z]					
Brewster	136,632	38,512	211,860	113,943	103,251	256,559	0	342,168	26,765
Bosworth-3	159,250	28,604	102,713	117,531	203,454	266,825	11,163	286,306	257,411
Groff	257,296	42,300	117,687	204,821	391,664	396,954	26,340	441,272	437,327
Mauritius	115,222	21,072	78,077	156,289	108,048	426,925	6,389	62,117	62,856
Kaimana	118,640	40,081	81,305	135,419	133,245	169,335	50,931	170,613	168,192
Salathiel	82,283	68,998	56,423	48,554	232,125	47,053	1,300	134,500	69,312
Average	144,887	39,928	55,094	129,426	195,298	260,608	16,020	239,496	170,310
HSD (0.05)[y]	75,505	NS	NS	NS	218,416	325,328	49,674	309,502	317,745
La Balear									
				Total fruit (no./ha)					
Brewster	45,163	—	—	3,867	135,425	0	0	107,852	23,832
Bosworth-3	279,613	—	—	182,752	340,201	444,691	0	665,187	44,847
Groff	409,174	—	—	6,473	404,635	45,562	0	923,469	1,074,907
Mauritius	233,708	—	—	2,564	59,096	110,164	2,059	756,815	471,549
Kaimana	363,164	—	—	250,716	559,394	443,346	0	621,726	303,802
Salathiel	22,298	—	—	3,320	114,619	15,846	0	0	0
Average	225,520	—	—	74,949	268,895	176,601	343	512,508	319,823
HSD (0.05)	155,085	—	—	NS	474,360	340,213	NS	677,236	449,420

[z]1 fruit/ha = 0.4047 fruit/acre.
[y]Tukey's honest significant difference test at $P = 0.05$; NS = not significant.

than other cultivars at the same location (Table 1). Weight of marketable fruit at UPR-Adjuntas was not significantly different among cultivars. At both locations, weight of nonmarketable fruit was significantly higher for 'Groff' (Table 1). This was the result of this cultivar producing a significantly higher number of nonmarketable fruit than other cultivars. However, as a percentage of total fruit production, 'Groff' produced a significantly higher percentage (+20%) of nonmarketable fruit at both locations than other cultivars (Table 1). The large number of total fruit produced by this cultivar at both locations may have resulted in high sink demand for assimilates and a corresponding reduction in individual fruit weight (Table 1).

Although lychee fruit are normally sold in grocery stores as individual units packed in plastic clamshells or in road stands in paper bags, the fruit is also sold in clusters in farmers' markets. In this instance, the fruit remains attached to small stem sections after harvest. In this study we found that on average, between 4.4% and 7.0% of the harvested clusters were composed of stem pieces (Table 1). Marketing fruit in clusters has the advantage of being less laborious and minimizing fruit damage because detaching stems from fruit may cause rupturing of the skin. However, because of bulkiness, marketing fruit as clusters make it unsuitable for packaging in clamshells. Clamshells can be refrigerated to reduce moisture loss of fruit and increase shelf life. Studies have shown that, after storing lychee in polyvinyl chloride film for 40 d at 10 °C, the fruit lost 6.4% in weight as compared with 1.7% when stored at 0 °C (Tongdee et al., 1982). Therefore, marketing lychee in fruit clusters is not conducive to prolonged shelf life.

Individual weight of marketable fruit averaged over cultivars was 13.2 and 14.3 g at UPR-Adjuntas and La Balear, respectively (Table 1). At both sites, individual fruit weight of marketable fruit was higher in 'Kaimana' than in other cultivars; however, at La Balear, there were no significant differences between Kaimana and Mauritius. Cultivars Bosworth-3 and Brewster had significantly higher concentration of soluble solids at UPR-Adjuntas, whereas there were no significant differences among cultivars for this variable at La Balear (Table 1).

In conclusion, six lychee cultivars were evaluated for the first time at two locations during 8 years of production at UPR-Adjuntas and 6 years at La Balear. Cultivars Groff and Bosworth-3 at UPR-Adjuntas and cultivars Groff, Bosworth-3 and Kaimana at La Balear produced significantly more marketable fruit per hectare than other cultivars. Assuming that a grower can achieve yields ranging from 1818 to 1916 $kg \cdot ha^{-1}$ (UPR– Adjuntas agroenvironment) or 3080 to 6567 $kg \cdot ha^{-1}$ (La Balear agroenvironment) with these cultivars (Table 1) and that farm gate prices are the current \$5.50/kg, then a gross income of \$9999 to \$10,538 per hectare or \$16,940 to \$36,118 per hectare can be obtained at each respective location. This is a good gross income per hectare but equally important, production of lychee allows the grower to diversify farm operations particularly in the mountain region of Puerto Rico, where cash crop alternatives are few. Reported results in the literature of erratic production in lychee were confirmed in this study. At both locations, individual fruit weight of marketable fruit was higher in 'Kaimana', making fruit of this cultivar perhaps more attractive to consumers.

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