Long-term Productivity of Three Rambutan Cultivars Grown in an Ultisol Soil in Puerto Rico

Ricardo Goenaga[1]

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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 fruit, including rambutan (*Nephelium lappaceum*). Replicated field trials to evaluate performance of rambutan cultivars have been very limited and as with many other tropical fruit crops, there is a scarcity of information on best management practices and optimal growing conditions for rambutan. The objective of this study was to determine the yield potential of three rambutan cultivars (Jitlee, R-134, R-162) when the age of grafted trees was ≈20 years. The data were compared with that obtained from an early production period when the age of the trees was ≈10 years. This information may help rambutan growers make expansion and/or investment plans. Number of fruit and yield in 2017 were significantly higher in 2017 than in 2016. In 2017, average fruit number and yield of cultivars were 582,774 fruit/ha and 19,528 kg·ha^{-1}, respectively, whereas in 2016 were 394,269 fruit/ha and 13,164 kg·ha^{-1}, respectively. There were no significant differences among cultivars for number of fruit produced, averaging 488,521 fruit/ha. This production is higher than the 5-year average obtained from the 2005–09 harvest period when grafted trees were about 9 years old. The results of this study demonstrate that grafted rambutan trees can remain prolific in mature orchards.

Rambutan is a member of the soapberry (Sapindaceae) family and along with other important fruit crops such as lychee (*Litchee chinensis*) and longan (*Dimocarpus longan*) is native to southeast Asia (Tindall, 1994). The edible portion of the rambutan fruit is a fleshy, translucent white sarcotesta, which arises from an integument surrounding a single oblong seed. The fruit are non-climacteric with little change in total soluble solids or titratable acidity after harvest (O'Hare, 1995). Currently, Thailand is the leading producer of rambutan worldwide (Dinh, 2016; Zee et al., 1998); however, Indonesia, Malaysia, Australia, and some countries in the Western Hemisphere also produce this fruit commercially. 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 fruit, including rambutan. Formal replicated field trials to evaluate performance of rambutan cultivars have been limited. There is a scarcity of information on best management practices and optimal growing conditions. Field and greenhouse studies have demonstrated that rambutan is highly tolerant to acid soils (Goenaga, 2011; Pérez-Almodovar and Goenaga, 2015). In a study lasting 10 years (5 years of fruit production), Goenaga and Jenkins (2011) found considerable genetic diversity among rambutan cultivars for economically important traits such as fruit production, yield, total soluble solids, and fruit characteristics, among others.

Erratic fruit production or "off-years" are typical in many tropical fruit crops (Goenaga and Jenkins, 2012; Goenaga et al., 2016). Wheelwright (1986) reported a wide year-to-year variability for fruit production among populations of 22 species in the laurel (Lauraceae) family. During a 7-year evaluation period, he found that overall fruit production was high during 3 nonconsecutive years and low during 4 years. Longer-term studies of orchards are needed to provide answers to critical production questions. Before recommending a particular cultivar to fruit growers it is therefore essential to carry out long-term research to assess the sustainability of crop productivity. Currently, few researchers working in fruit improvement programs in public and private institutions have the resources to carry such research.

The objective of this study was to determine the long-term productivity of three rambutan cultivars in an 18-year-old orchard.

Materials and methods

The experimental data were obtained from an experimental site established on Sept. 1999 at the Corozal Agricultural Experiment Station of the University of Puerto Rico (Goenaga and Jenkins, 2011) to evaluate eight rambutan cultivars for yield and fruit quality traits. The soil is an Ultisol (Corozal clay: clayey, mixed, isohyperthermic Aquic Haplohumults) typical of the humid tropics. After the termination of the 5-year evaluation experiment in 2009, the orchard continued receiving intensive management until most of the trees were destroyed by the 155-mph winds brought by Hurricane Maria on 20 Sept. 2017. Until that date, fertilization was provided every 3 months using a 15N–2.2P–16.3K–1.8Mg commercial mixture at a rate of 240 lb/acre. Irrigation was

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
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha^{-1}	0.8922
1.6093	mph	km·h^{-1}	0.6214
1	ppm	mg·kg^{-1}	1
6.8948	psi	kPa	0.1450
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

U.S. Department of Agriculture, Agricultural Research Service, Tropical Agriculture Research Station, 2200 P.A. Campos Avenue, Suite 201, Mayaguez, PR 00680-5470

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[1]Corresponding author. E-mail: Ricardo.Goenaga@ars.usda.gov.

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provided with spinner jets (model DXMAG368X; Maxijet, Dundee, FL) spaced 20 ft apart and providing 13.5 gal/h at 20 psi when the soil water tension at a depth of 30 cm exceeded 50 kPa. Weeds within the planting rows were suppressed with strip applications of herbicide (glyphosate). Weeds between rows were controlled with a tractor mower. Spray oil emulsion fungicide (Saf-T-Side; Brandt Consolidated, Springfield, IL) was occasionally used during rainy season to control sooty mold.

During the growing years 2010 to 2015 the experimental orchard was harvested similarly as in the evaluation trial (Goenaga and Jenkins, 2011), but cultivar yield data on many fruit traits were not recorded due to shortage in hand labor.

Because of lack of information and concern about the long-term productivity of grafted rambutan trees, the author resumed recording fruit production in 2016 from three selected cultivars: Jitlee, R-134, and R-162. These cultivars were selected for the study because they showed consistent high production of fruit and high yield during 2005–09 at the Corozal Agricultural Experiment Station (Goenaga and Jenkins, 2011). These cultivars were grafted onto 'R-167' rambutan rootstocks. Trees were arranged in a randomized complete block design with three replications. Within a replication, plots for each cultivar contained three trees spaced 20 ft apart and 20 ft between adjacent rows in a triangular array. Representative fruit from each cultivar are shown in Fig. 1. The experimental area was surrounded by two guard rows of 'R-134' seedlings.

Before initiating data recording in 2016, soil samples were taken 2 months before initiation of the experiment by taking borings at a depth of 0 to 25 cm from each of the tree rows. Samples were air-dried and passed through a 16-mesh screen. The soil has a pH of 5.71, 38.5 mg·kg^{-1} ammonium-nitrogen (NH_4–N), 17.7 mg·kg^{-1} nitrate-N (NO_3–N), 12.1 mg·kg^{-1} phosphorous (P), 468 mg·kg^{-1} potassium (K), 2513 mg·kg^{-1} calcium (Ca), 158 mg·kg^{-1} magnesium (Mg), 127 mg·kg^{-1} iron (Fe), 81 mg·kg^{-1} manganese (Mn), 6.1 mg·kg^{-1} zinc (Zn), 99 mg·kg^{-1} aluminum (Al), and 1.5% organic carbon. The 63-year mean annual rainfall is 1832 mm and Class A pan evaporation is 1320 mm. Mean monthly maximum and minimum temperatures are 29.8 and 19.5 °C. Samples were air-dried and passed through a 16-mesh screen. Soil pH in water and 0.01 M calcium chloride (1 soil : 2 water) were measured with a glass electrode. Phosphorous and exchangeable cations (K, Mg, and Ca) were extracted with Mehlich III solution [extract is composed of 0.2 M acetic acid, 0.25 M ammonium nitrate, 0.015 M ammonium fluoride, 0.013 M nitric acid, and 0.001 M ethylene diamine tetraacetic acid (EDTA) (Amacher, 2007)] and determined by inductively coupled plasma (ICP) spectrometry (Sumner and Miller, 2007). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers, 2007). Soil ammonium and nitrate were determined by steam distillation (Mulvaney, 2007).

During the 2016–17 harvest period, fruit clusters from the three

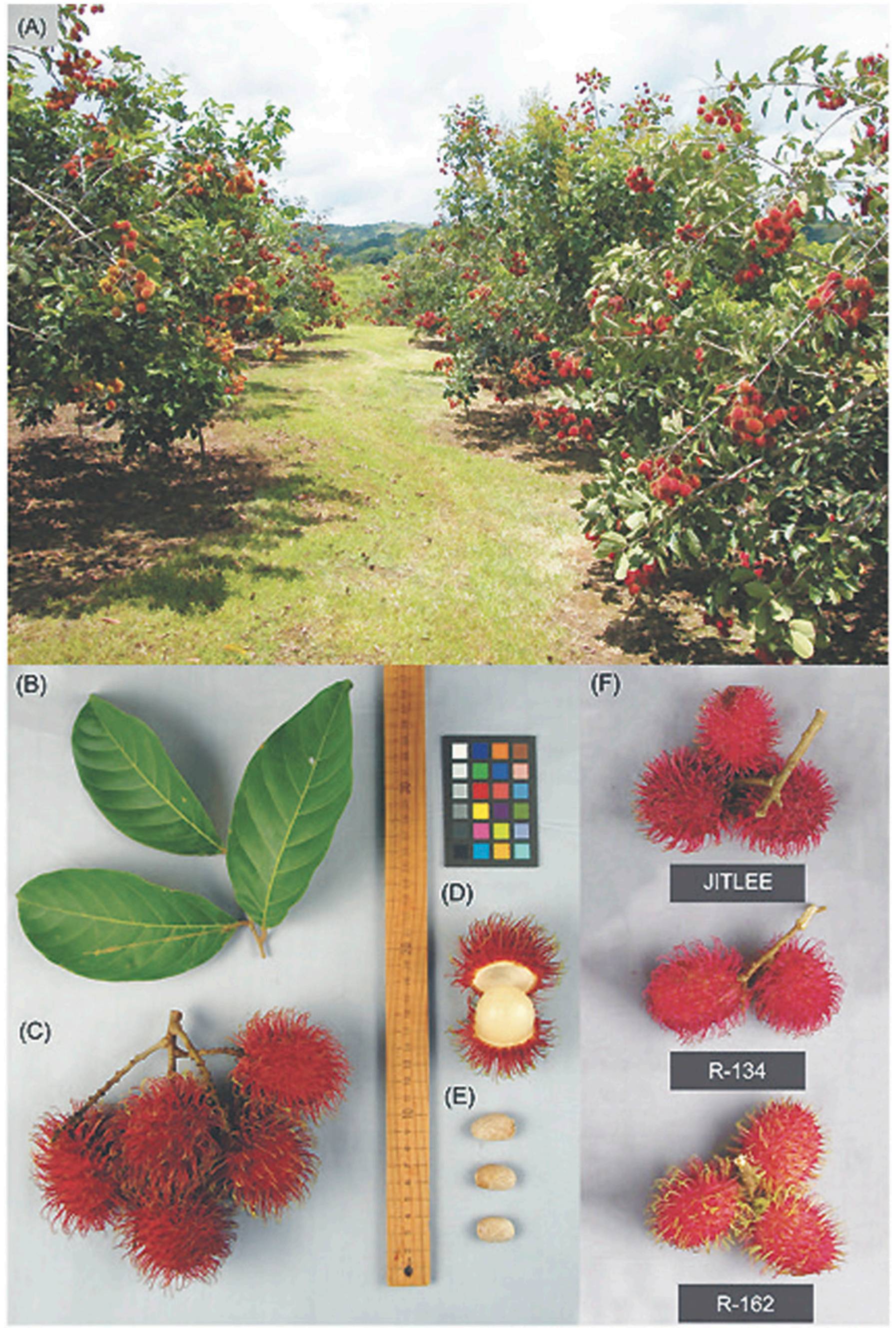

Fig. 1. Rambutan orchard, fruit components and cultivar differences: (A) experimental orchard in production, (B) leaves, (C) fruit cluster, (D) opened fruit with pulp (aril) exposed, (E) seeds, and (F) fruit clusters of cultivars used in the experiment; 1 cm = 0.3937 inch.

selected cultivars were harvested from three of the five replications in the original study (Goenaga and Jenkins, 2011). Harvests were initiated in August of each year. At harvest, telescopic long reach pruners (model 160ZR-3.0–5; ARS, Osaka, Japan) were used to cut fruit clusters on terminal ends of the branches from each of the three trees per replication and cultivar. 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. Flowering both years occurred during mid-March and fruit harvested from August to January; weekly harvests were made during the harvesting period. On the basis of trees in flower and immature fruit, it was estimated that ≈20% of the potential crop was lost in 2017 as a result of the hurricane. The original plan was to at least obtain yield data for 3 successive years, 2016–18. However, the arrival of Hurricane Maria shortened the evaluation period.

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

Results and discussion

Years showed a significant effect ($P < 0.01$) on average number of fruit and yield per hectare (Table 1). Cultivar had a significant effect on fruit yield but not fruit number. The cultivar × year interaction was not significant for yield parameters (Table 1).

Despite the experimental area being hit by a powerful hurricane, fruit number and yield were significantly higher in 2017 than in 2016. In 2017, average fruit number and yield of cultivars were 582,774 fruit/ha and 19,528 $kg{\cdot}ha^{-1}$, respectively, whereas in 2016, they were 394,269 fruit/ha and 13,164 $kg{\cdot}ha^{-1}$, respectively. Erratic production patterns characterized by relatively low production during 1 or 2 successive years following heavy cropping has been reported in mature rambutan trees. For example, Goenaga and Jenkins (2011) found that number of fruit and fruit yield in cultivar R-162 respectively declined by 15% and 17% from 2007 to 2008 and then increased by 37% and 27%, respectively, in 2009. Similarly, cultivar R-134 showed a 7% decline in fruit production in 2007, leveled off in 2008, and then had a 33% increase in fruit production in 2009. The possibility of water stress impeding flower initiation or development in 2016 was ruled out because supplemental irrigation was supplied when necessary. Retention of mature fruit on trees is sometimes practiced [e.g., avocado (*Persea americana*)] to obtain premium market prices. However, this practice can drive the tree into a biennial cropping cycle (Schaffer and Andersen, 1994). In this experiment, fruit were harvested periodically and was not a factor in inducing biennial cropping. Wheelwright (1986) proposed that in trees of laurel family, annual variation in fruit production results from a combination of life-history trade-offs, such as previous reproductive efforts, vegetative growth competing with reproductive growth, responses to climatic variation, and changes in pollinator abundance and behavior. In this study, high fruit load before 2016 most probably 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; Stander and Cronje, 2016). 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, 1997).

There were no significant differences among cultivars for number of fruit produced, averaging 488,521 fruit/ha (Table 1). This figure is higher than the 5-year average obtained for harvest period 2005 to 2009 for 6.5 to 10.5-year-old trees of the same cultivars (Goenaga and Jenkins, 2011). Considering that ≈20% of the 2017 crop was lost as a result of hurricane damage and the discovery of new fungal diseases associated with rambutan production in Puerto Rico (Rossman et al., 2007, 2010; Serrato-Diaz et al., 2011, 2012), the potential fruit production during the 2016–17 harvest period would have been even higher than that of the earlier production period, 2005–09 (Goenaga and Jenkins, 2011).

Cultivar Jitlee had significantly higher fruit yield per hectare than R-

Table 1. Number of fruit, fruit cluster yield, and fruit yield of three rambutan cultivars evaluated in Puerto Rico during two harvest periods.[z]

	2-yr avg (2016–17)			5-yr avg (2005–09)[y]		
Cultivar	Fruit (no./ha)[x]	Fruit cluster yield ($kg{\cdot}ha^{-1}$)[x]	Fruit yield ($kg{\cdot}ha^{-1}$)	Fruit (no./ha)	Fruit cluster yield ($kg{\cdot}ha^{-1}$)	Fruit yield ($kg{\cdot}ha^{-1}$)
Jitlee	577,722	23,023	21,035	453,850	16,462	15,171
R-134	458,625	15,221	13,979	448,670	16,210	14,873
R-162	429,216	15,315	14,023	478,204	17,537	15,906
Avg	488,521	17,853	16,346	460,241	16,736	15,317
HSD(0.05)[w]	206,299	7,575	7,022			
Year (Y)	**	**				
Cultivar (C)	ns	*	*			
Y × C	ns	ns	ns			

[z]Values are means of three replications and 2 years (2016–17).
[y]Values obtained from Goenaga and Jenkins (2011).
[x]1 fruit/ha = 0.4047 fruit/acre; 1 $kg{\cdot}ha^{-1}$ = 0.8922 lb/acre.
[w]Tukey's honest significant difference test at $P = 0.05$.
[NS], *, **Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

134, but it did not differ statistically from the yield obtained by R-162 (Table 1). As with number of fruit, average yield of cultivars Jitlee and R-162 (17,529 kg·ha^{-1}) was higher in the 2016–17 evaluation period than the 5-year average obtained from 2005–09 (Goenaga and Jenkins, 2011). An even higher yield increase would also have resulted if the same assumption of a 20% potential crop loss is taken into consideration for these two cultivars.

Although rambutan fruit are normally sold as individual units packed in plastic clamshells in groups of 8–10 fruit, 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, it was found that on average, about 8% of the harvested clusters were composed of stem pieces (Table 1). This is the same percentage as that found by Goenaga and Jenkins (2011) during the 2005–09 harvest period. 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. Moisture loss through fruit spinterns can be significant. Studies have shown that, after storing rambutan for 6 d at an ambient temperature of 27 °C, the fruit lost 45% in weight as compared with 29% when stored at 10 °C. When fruit was stored for the same period in perforated bags at 10 °C, weight loss was only 2.8% (Mendoza et al., 1972). If relative humidity is kept at 95% and fruit at 7–10 °C, rambutan have a storage life of ≈10–15 d (O'Hare, 1995). Therefore, marketing rambutan in fruit clusters is not conducive to prolonged shelf life.

In conclusion, this study is the first to report long-term performance of rambutan cultivars almost 20 years after field establishment of an experimental orchard. Fruit production averaged 488,521 fruit/ha, which is higher than average production previously obtained from the same, younger trees during the harvest period 2005–09. These results demonstrate that rambutan production can remain prolific in mature orchards.

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