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Yield and fruit quality traits of rambutan cultivars grafted onto three rootstocks and grown in a Mollisol soil in Puerto Rico[1,2]

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ABSTRACT

With increasing ethnic diversity and demand for healthy and more varied foods, globalization has opened a window of opportunity for new tropical fruits, including rambutan (*Nephelium lappaceum*), to be offered to consumers in the Western Hemisphere. The lack of formal experimentation on rambutan performance using various scion/rootstock combinations prompted a study, conducted in Santa Isabel, Puerto Rico, using a randomized complete block design to assess the yield and fruit quality of three cultivars ('Gula Batu', 'Jitlee', 'R-162') when grafted onto three different rootstocks ('Binjai', 'Gula Batu', 'R-134') in an alkaline Mollisol soil. From 2011 to 2015, there was an increase in the number and yield of fruit for cultivar/rootstock treatments. Regardless of rootstock, 'R-162' and 'Jitlee' had a higher number of fruit and yield than 'Gula Batu'. The cultivars produced significantly more fruit and had significantly higher yields when 'Gula Batu' was used as a rootstock. Cultivar/rootstock treatments did not have a significant effect on individual fruit weight which averaged 32 g. Cultivar 'R-162' grafted onto 'Gula Batu' had a higher concentration of soluble solids, but it was not significantly different than the rest of the treatments except for 'Gula Batu' grafted onto 'Binjai' and 'Gula Batu' grafted onto 'R-134', which had significantly lower soluble solids concentration. Individual fruit weight and rind weight did not vary among cultivar/rootstock treatments, and pulp weight

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varied very little. Seed weight differences were mainly associated with cultivar 'Gula Batu'. This study confirms previous work by the author showing 'R-162' as a highly productive cultivar and, for the first time, shows that 'Gula Batu' is a superior rootstock, performing very well under alkaline soil conditions.

Keywords: yield, fruit number, soluble solids concentration, *Nephelium lappaceum*

RESUMEN

Rendimiento y calidad de la fruta de cultivares de rambután injertados en tres portainjertos y cultivados en un suelo Mollisol en Puerto Rico

Con el aumento en diversidad étnica y una creciente demanda de alimentos saludables y más variados, la globalización ha abierto una ventana de oportunidad para que nuevas frutas tropicales, incluyendo el rambután (*Nephelium lappaceum*), estén disponibles para los consumidores en el hemisferio occidental. La falta de experimentación formal sobre el rendimiento del rambután utilizando diversas combinaciones de injerto/portainjerto nos llevó a realizar un estudio en Santa Isabel, Puerto Rico, utilizando un diseño de bloques completos al azar para evaluar el rendimiento y la calidad de la fruta de tres cultivares ('Gula Batu', 'Jitlee', 'R-162') cuando se injertan en tres portainjertos ('Binjai', 'Gula Batu', 'R-134') en un suelo Mollisol alcalino. Desde 2011 hasta 2015, hubo un aumento en el número y rendimiento de frutas para los tratamientos de cultivar/portainjerto. Los tratamientos de cultivar/portainjerto no tuvieron un efecto significativo en el peso individual de la fruta que promedió 32 g. El cultivar 'R-162' injertado en 'Gula Batu' tuvo una mayor concentración de sólidos solubles, pero no fue significativamente diferente que el resto de los tratamientos excepto para 'Gula Batu' injertado en 'Binjai' y 'Gula Batu' injertado en 'R-134' que tuvieron una concentración de sólidos solubles significativamente menor. El peso individual de la fruta y el peso de la cáscara no variaron entre los tratamientos de cultivar/portainjerto, y el peso de la pulpa varió muy poco. Las diferencias en el peso de las semillas estuvieron principalmente asociadas con el cultivar 'Gula Batu'. Este estudio confirma trabajos anteriores del autor que muestran a 'R-162' como un cultivar altamente productivo y, por primera vez, muestra que 'Gula Batu' es un portainjerto superior, que se desempeña muy bien en condiciones de suelo alcalino.

Palabras clave: rendimiento, número de frutas, concentración de sólidos solubles, *Nephelium lappaceum*

INTRODUCTION

As ethnic diversity increases and the demand for healthier and more varied foods grows, globalization has created opportunities for new tropical fruits, such as rambutan (*Nephelium lappaceum*), to reach consumers in the Western Hemisphere. Rambutan, a member of the Sapindaceae family, is native to Malaysia and Indonesia (Tindall, 1994). The tree thrives in tropical climates with well-drained, clayey soil and an annual rainfall of around 2,000 mm (Goenaga and Jenkins, 2011; Tindall, 1994). The edible part of the fruit is a white, translucent sarcotesta that covers a single oblong seed. In 'freestone' cultivars, the sarcostesta and integument can be easily separated from the seed, which is a desirable trait. In 'clingstone' cultivars, separating the pulp from the seed is more difficult (O'Hare, 2001). There is limited information available on global production of rambutan. The top three producers of rambutan worldwide are Indonesia, Thailand, and Malaysia, with respective fruit production totals of approximately 676,000; 519,000; and 130,000 metric tons (Ahmad and Chua, 2013). Rambutan is propagated by bud grafting and inarching (Zee et al., 1998), using selected cultivars or open pollinated seedlings as rootstocks adapted to local conditions. For commercial production, cultivars such as 'R-134', 'R-156', 'R-162', 'R-167', 'Gula Batu' from Malaysia; 'Binjai' and 'Lebak-bulus' from Indonesia; 'Seechompoo' and 'Rongren' from Thailand; and 'Jitlee' from Singapore are commonly used (Tindall, 1994). Fruit production per tree has been estimated at 750 to 1,500 fruits, depending on the cultivar (Chakraborty et al., 2015). Average yield of fully matured trees in commercial orchards in Northern Queensland, Australia, is 3,908 kg/ha (Diczbalis, 2008). Yield data from replicated field trials are very limited. Rincón-Rabanales et al. (2015) reported yields of 6,350 kg/ha in trees caged with pollinators. Depending on the location and cultivar, Goenaga and Jenkins (2011) reported average yields ranging from 5,149 to 13,826 kg/ha, when trees were grafted onto rootstock 'R-167'. A long-term replicated experiment reported that cultivar yields varied from 13,900 to 21,000 kg/ha nearly two decades after the establishment of an experimental orchard using 'R-167' as rootstock (Goenaga, 2018).

During recent years, rambutan has been commercially cultivated as a profitable cash crop in small farming systems traditionally devoted to plantain and coffee production in the mountain region of Puerto Rico. The existence of fruit flies is an obstacle to the export of many fruits. In Puerto Rico, a thorough investigation of ripe rambutan fruit from the field found no infestation by the West Indian fruit fly (*Anastrepha obliqua*) (Jenkins and Goenaga, 2008). Furthermore, no adult fruit flies emerged from ripe rambutan fruit with partially removed peels that were exposed to fertile female fruit flies. This indicates that rambutan is not a host for this fruit fly, allowing its export to locations where the fruit fly is not present. Research indicates that rambutan thrives in the acidic Ultisols commonly found in humid tropical regions (Goenaga, 2011; Perez-Almodovar and Goenaga, 2015). However, little is known about yield performance of rambutan grown in alkaline (pH>8.0) soils in Puerto Rico where arable land with an irrigation infrastructure previously used for sugarcane production is available to small landholders.

To our knowledge, no formal research has been conducted to determine yield performance of rambutan cultivars grafted onto different rootstocks. Hence, this research focuses on yield and fruit quality characteristics of three cultivars grafted onto three rootstocks and grown in an alkaline Mollisol soil.

MATERIALS AND METHODS

Location, Climate, and Soil Conditions

We conducted our study at Martex Farms (18°00'59"N 66°27'50"W) in Santa Isabel, Puerto Rico. The average monthly maximum, minimum, and mean temperatures were 33.4° C, 19.5° C, and 26.2° C, respectively. The soil is classified as a fine loamy, mixed isohyperthermic Cumulic Haplustoll and has the following chemical properties: a pH of 7.9; organic carbon content of 0.98%; P content of 135 µg/g; K content of 154 µg/g; Ca content of 5,468 µg/g; and Mg content of 625 µg/g.

Treatments

Scionwood from cultivars 'Gula Batu', 'Jitlee', and 'R-162' was grafted onto open-pollinated seedlings of the rootstocks 'Binjai', 'Gula Batu', and 'R-134' using the side-veneer grafting technique. 'Binjai' is a cultivar from Indonesia, 'Jitlee' from Singapore, and 'Gula Batu', 'R-162' and 'R-134' are cultivars from a selection program initiated in Malaysia in the late 1970s (Tindall, 1994). The source of scionwood and open-pollinated seed was an experimental orchard established at the USDA-ARS Research Farm, Isabela, PR (Goenaga and Jenkins, 2011).

One-year-old grafted trees were transplanted to the field 5 April 2005 and were arranged in a randomized complete-block design with four replications. Within a replication, plots contained two trees per cultivar/rootstock treatment spaced 5.8 m apart and 6.1 m between adjacent rows in a triangular array, 283 trees/ha.

The soil was prepared for transplanting by chisel-plowing it to a depth of about 90 cm. Holes for planting, with a depth of roughly 0.5 m, were made using an auger connected to a tractor's power-take-off unit through a drive shaft. During transplanting, each plant received 57 g of granular phosphorus in the form of triple superphosphate.

The experiment had a guard row of mixed open-pollinated seedlings of 'R-162', 'Jitlee', 'R-156', and 'Rongren' rambutan. When tensiometer readings exceeded 50 kPa at a depth of 30 cm, irrigation was provided through two 8 L/h drip emitters per plant, spaced 61 cm apart. A commercial mixture of 15N–2.2P–16.3K–1.8Mg was used to fertilize the plants every three months at rates of 31, 142, and 212 kg/ha until 2007, 2008, and 2015, respectively. Weed control was achieved by applying herbicide (glyphosate) in strips within the planting row and mowing weeds between rows with a tractor mower. Soil applications of 6% EDDHA iron chelate (Sprint 138, BASF Corp., 26 Davis Dr., Research Triangle Park, NC)[5] at a rate of 28 grams per tree were supplied at the beginning of February of each year starting in 2010 to correct for a mild iron deficiency.

Harvests

Yield data collection began in August 2011, when the grafted trees were about seven years old. At harvest, fruit clusters on the terminal ends of branches from each of the two trees per replication and treatment were cut using telescopic long reach pruners (model 160ZR-3.0–5; ARS, Osaka, Japan). The weight of the fruit clusters attached to stem pieces was recorded in the field as fruit cluster yield. The fruit clusters were then taken to the laboratory where they were separated from stems, counted, and weighed again as fruit yield. Fruit from each tree was then combined by replication and cultivar/rootstock treatment. Representative fruit totaling 10% of those harvested were used to determine soluble solids with a temperature-compensated digital refractometer (PAL-1; Atago, Tokyo, Japan) one day after harvest. These fruits were also used to determine the weight of rind (rind plus spinterns), pulp, and seed after cutting the fruit with a sharp knife and separating the parts.

Statistical Analyses

The general linear model (GLM) procedure of SAS (version 9.4 for Windows; SAS Institute, Cary, NC) was used to carry out analysis of variance. If the F test was significant at $P < 0.05$, the Tukey's honestly significant difference range test was used to perform mean separation.

RESULTS AND DISCUSSION

Treatment Effects Interactions

Year, cultivar, and rootstock showed highly significant effects ($P \leq 0.01$) on most production and fruit parameters measured in the study (Table 1). The cultivar x rootstock interaction was significant for yield variables indicating that cultivars yielded differently depending on the

[5]Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply a recommendation or endorsement of the U.S. Department of Agriculture or the Agricultural Experiment Station of the University of Puerto Rico.

rootstocks they were grafted onto. The year x cultivar, year x rootstock, and year x cultivar x rootstock interactions were not significant, indicating that cultivars and rootstocks responded similarly each year. There were no visual symptoms of incompatibility between scion and rootstock for any treatment.

Year Effects

Overall, cultivar/rootstock treatments exhibited an increase in fruit number and yield, but it varied with the year (Table 2). The magnitude of this response was very similar among treatments as expected by the lack of significant year x cultivar interaction (Table 1). Most scion/rootstock treatments had the highest number of fruit and yield during the second and third year of production. From 2013 to 2014 cultivar/rootstock treatments exhibited a decrease in the number of fruit which ranged from a 1.7% decline for cultivar 'Gula Batu' grafted onto 'R-134' to 55% for 'Gula Batu' grafted onto itself (data not shown). This decline occurred after significant increases in fruit production from 2011 to 2013. It is likely that the high fruit load in all cultivar/rootstock treatments from 2011 to 2013 depleted the assimilates, leading to an "off-year" in 2014 evidenced by light blooming as the trees replenished their carbohydrate reserves (Kour et al., 2018; Scholefield et al., 1985). A biennial production cycle does not always follow an every-other-year pattern. Instead, there may be one or more "off-years" following an "on-year," and vice versa (Paz-Vega, 1997). Biennial production in tropical fruit crop systems is not uncommon and has been reported in many crops (Goenaga and Jenkins, 2012; Goenaga et al., 2016; Goldsmith and Sadka, 2021).

Treatment Effects

Cultivar 'R-162' grafted onto 'Gula Batu' had the highest average number and yield of fruit over a five-year period. However, these results were not significantly different from other treatments, except for 'Gula Batu' grafted onto 'Binjai' and 'Gula Batu' grafted onto 'R-134' , which had significantly lower number of fruit and yield (Table 1). Averaged over rootstocks, 'R-162' and 'Jitlee'consistently had higher number of fruit and yield (Table 1). By contrast, 'Gula Batu' had significantly lower number of fruit and yield, particularly when grafted on 'R-134' (Table 1). In a previous study conducted at two locations in Puerto Rico, eight rambutan cultivars grafted onto 'R-167' were evaluated. Cultivar 'R-162' was found to have the highest yield at one location and the second highest at the other (Goenaga and Jenkins, 2011). In the same study, cultivar 'Gula Batu' had a significantly higher number of fruit at one of the two locations and showed some tolerance to stem

TABLE 1.—*Number of fruits, fruit yield, and fruit weight, total soluble solids as well as fruit quality traits of three rambutan cultivars grafted onto three rootstocks and planted in a Mollisol soil in Puerto Rico. Values are means of four replications and five years of production (2011-2015).*

Cultivar	Rootstock	No. of Fruit (No./ha)	Fruit cluster yield (kg/ha)	Fruit yield (kg/ha)	Fruit soluble solids (%)	Individual fruit weight (g)	Pulp weight (g)	Seed weight (g)	Rind weight (g)
Gula Batu	Gula Batu	228,593 ab	6,751 ab	6,348 ab	20.2 abc	32.4 a	13.9 ab	1.9 b	16.7 a
Gula Batu	Binjai	162,726 bc	4,650 b	4,366 b	20.1 bc	32.2 a	13.7 ab	1.8 b	16.6 a
Gula Batu	R-134	84,806 c	2,191 c	2,043 c	19.4 c	30.9 a	13.2 b	1.8 b	15.9 a
Jitlee	Gula Batu	221,005 ab	6,302 ab	5,949 ab	21.2 ab	31.5 a	13.7 ab	2.2 a	14.9 a
Jitlee	Binjai	204,596 ab	6,047 ab	5,752 ab	21.6 ab	30.9 a	13.9 ab	2.2 a	15.5 a
Jitlee	R-134	226,824 ab	6,514 ab	6,202 ab	20.5 abc	31.5 a	13.4 ab	2.1 a	15.9 a
R-162	Gula Batu	289,911 a	8,260 a	7,722 a	22.0 a	33.5 a	14.9 ab	2.3 a	16.3 a
R-162	Binjai	193,586 ab	5,631 ab	5,457 ab	21.7 ab	32.1 a	14.8 ab	2.3 a	15.0 a
R-162	R-134	228,721 ab	6,638 ab	6,299 ab	21.3 ab	33.5 a	15.4 a	2.2 a	15.9 a
HSD		106,768	2,946	2,800	1.8	5	2.1	0.2	3.3
Mean		204,530	5,888	5,571	20.9	32.0	14.1	2.1	15.8
Year (Y)		***	***	***	**	**	NS	*	***
Cultivar (C)		***	***	***	***	NS	**	***	NS
Rootstock (R)		***	***	***	***	NS	NS	NS	NS
C x R		*	**	*	NS	NS	NS	NS	NS
Y x C		NS	NS	NS	NS	NS	NS	NS	NS
Y x R		NS	NS	NS	NS	NS	NS	NS	NS
Y x C x R		NS	NS	NS	NS	NS	NS	NS	NS

Within a column, means followed by a common letter are not different according to Tukey's honestly significant difference (HSD) at the 0.05 level of probability.

NS, *, **, *** Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

TABLE 2.—*Average yearly production and fruit quality traits of three rambutan cultivars grafted onto three rootstocks and planted in a Mollisol soil in Puerto Rico.* Values are means of four replications and five years of production (2011-2015).

Trait	2011	2012	2013	2014	2015	5-year mean	HSD[1]
No. of fruit (No./ha)	98,031	245,846	254,146	186,132	238,209	204,473	69,301
Fruit cluster yield (kg/ha)	3,102	7,076	7,174	5,509	6,567	5,885	1,927
Fruit yield (kg/ha)	2,935	6,643	6,847	5,200	6,205	5,566	1,831
Fruit soluble solids (%)	20.4	20.3	21.8	20.7	21.1	20.9	0.8
Individual fruit weight (g)	36.5	31.5	30.9	31.1	30.5	32.1	3.3
Pulp weight (g)	14.9	13.5	14.4	13.4	14.2	14.1	1.3
Seed weight (g)	2.2	2.1	2.0	2.0	2.0	2.1	0.15
Rind weight (g)	19.4	15.9	14.4	15.6	14.2	15.9	2.2

[1]Tukey's honestly significant difference test at $P = 0.05$.

canker caused by the fungus *Dolabra nepheliae* (Rossman et al., 2007; Rossman et al., 2010). As a result, it was suggested as an alternative for areas where this fungus is a serious problem. Currently, there is no effective fungicidal treatment against this fungus. In our study, cultivars had 24% and 26% significantly higher number of fruits and yield, respectively, when 'Gula Batu' was used as a rootstock rather than 'Binjai' or 'R-134' (Table 1). This study thus confirms that 'Gula Batu' can be considered a superior rootstock for rambutan and 'R-162' a superior, highly productive scion cultivar.

Leaf tissue samples collected from 2008 to 2010 showed nutrient average values of 2.05±.29% N, 0.17±.06% P, 0.95±.27% K, 0.29±.07% Mg, 94.0±28.5 mg/kg Fe, 259.6±188.9 mg/kg Mn, 21.0±8.6 mg/kg Zn. The concentration of these elements was in the sufficiency range for rambutan (Sosa-Rodrigues and Garcia-Vivas, 2020).

Rambutan fruit is usually sold in plastic clamshells, containing eight to ten individual fruits. However, it can also be found in clusters at farmers' markets, where the fruit remains attached to small stem sections. This study showed that about 5% of harvested clusters were composed of stem pieces (Table 1). Marketing fruit in clusters is less labor-intensive and minimizes damage, but it is not suitable for packaging in clamshells due to bulkiness. Clamshells can be refrigerated to reduce moisture loss and increase shelf life. Significant moisture loss can occur through fruit spinterns. Studies have shown that storing rambutan at 10° C in perforated bags results in only 2.8% weight loss after six days, compared with 45% weight loss when stored at 27° C (Mendoza et al., 1972). If relative humidity is kept at 95% and fruit at 7 to 10 °C, rambutan can be stored for 1 to 15 days (O'Hare, 2001). Hydrocooling fruit prior to storage can also reduce pericarp browning and increase shelf life from 4 to 6 days to 10 to 14 days (Nampan et al., 2006). Therefore, marketing rambutan in fruit clusters is not conducive to prolonged shelf life.

Cultivar/rootstock treatments did not significantly affect the weight of individual fruits (Table 1). The average weight of individual fruits among treatments was 32 g, which is higher than the average weight of 27.4 g for 10 selected rambutan cultivars from the Association of South East Asian Nations (Tindall, 1994). This weight also exceeded the marketable weight criteria of 30 g (Pohlan et al., 2008).

Averaged over rootstocks, cultivar 'R-162' had significantly higher soluble solid values (21.7%) than Jitlee (21.1%), and 'Gula Batu' (19.9%). Cultivar 'R-162' grafted onto 'Gula Batu' had a higher soluble solids concentration but it was not significantly different than the rest of the treatments except for 'Gula Batu' grafted onto 'Binjai' and 'Gula Batu' grafted onto 'R-134' which had significantly lower soluble solids concentrations

(Table 1). These results are similar to those obtained earlier which showed cultivars 'R-162' and 'Gula Batu' having the highest and lowest soluble solids concentrations, respectively, among eight cultivars grown at two locations (Goenaga and Jenkins, 2011). Pulp (aril) weight was higher in fruit of 'R-162' grafted onto 'R-134', but not significantly different from the rest of the cultivars, except for 'Gula Batu' grafted onto 'R-134' (Table 1). As a percentage of total fruit weight, average pulp weight among scion/rootstock treatments was 44.3%. This value is smaller than the 49.7% observed by Goenaga and Jenkins (2011), most likely because cultivars 'R-156Y' and 'Rongren', which had high pulp weight, were not part of this experiment. Significantly lower seed weight was obtained by 'Gula Batu' grafted onto 'R-134', onto 'Binjai', and itself, averaging 1.8 g (Table 1). This average for 'Gula Batu' is the same as that found in previous studies (Goenaga and Jenkins, 2011). Usually, it is recommended to use fast growing, vigorous seedlings for rootstock cultivars. In our study, the use of a rootstock originating from small open-pollinated seed such as 'Gula Batu' was not an impediment to producing healthy vigorous seedlings. There were no significant differences in seed weight among the rest of the treatments, averaging 2.1 g. There were no significant differences in rind weight among treatments.

CONCLUSIONS

Averaged over rootstocks, 'R-162' and 'Jitlee' had a higher number of fruit and yield than 'Gula Batu'. Cultivars 'R-162' and 'Gula Batu' produced more fruit and had higher yields than others when 'Gula Batu' was used as a rootstock. This study confirms previous work (Goenaga and Jenkins, 2011) showing 'R-162' as a highly productive cultivar and for the first time, shows 'Gula Batu' as a superior rootstock, performing very well under alkaline soil conditions.

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