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UAV color images for determination of citrus plant parameters[1]

Sunil K. Mathanker[2], Consuelo Estévez de Jensen[3], Andrés M. Pagán-López[4] and Luis R. Pérez-Alegría[5]*

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ABSTRACT

Unmanned aerial vehicles (UAVs) or drones are being studied for many agricultural applications. One application is plant phenotyping to reduce the time and effort required in collecting field data. This study aims to explore the use of a UAV, 4K-color camera and a commercial image analysis service to measure citrus plant parameters that are important to a crop scientist or grower with limited technical background and resources. *Citrus* spp. are important crops in Puerto Rico and the United States. Currently, the citrus industry is struggling to contain the devastating effects of citrus greening or Huanglongbing disease. The disease is associated with a phloem-limited bacteria, *Candidatus* Liberibacter asiaticus (CLAs), vectored by the Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama. The use of insecticides for vector control is the primary strategy used in nurseries and orchards. However, once the citrus plant is infected, there is no effective control available for the disease. In Puerto Rico this disease has reduced *Citrus* spp. yields by more than 50%; studies are underway to find effective control measures such as supplemental nutrients, vector management practices, planting disease-free vegetative material and protective screen structures. An experiment at the Fortuna Agricultural Experiment Substation, in

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Juana Díaz, Puerto Rico, was conducted to address the challenges posed by citrus greening. The experiment was established in a four-year-old grove of Tahiti lime (*Citrus latifolia* Tan.) on Cleopatra mandarin (*Citrus reshni* hort. ex Tanaka), naturally infected with *Candidatus* Liberibacter asiaticus. The experiment was arranged in a randomized complete block design with four replicates and three treatments: supplemental nutrients, supplemental nutrients + salicylic acid, and granular fertilization. Tree growth parameters were measured, and laboratory analyses were carried out to determine nutrient levels and disease severity levels from the leaf samples. The color camera, on board the UAV, was employed to acquire images of the experimental plot. Drone Deploy application was used for planning the UAV flights and image analysis. Field-measured plant height and canopy diameter compared well with the parameters determined from the color images. The average errors in measuring canopy diameter (14.5%) and plant height (22.4%) could be considered within an acceptable range, especially for comparing different treatments or crop varieties. However, the average errors in measuring canopy volume (47.5%) were high and can be considered unacceptable. It appears that the assumed conical shape of the trees could be one of the main reasons, besides the algorithms used in calculating plant volume, and built-in inaccuracies of the single frequency GPS (global positioning system) used in estimating altitude. Further studies could help in reducing errors and exploring other applications. The method used can be of importance in evaluating fruit trees.

Key words: UAV, drone, citrus, plant phenotype, automation, image processing

RESUMEN

Imágenes a color tomadas por drones para determinar parámetros fenológicos en cítricos

El uso de vehículos aéreos no tripulados (UAV, por sus siglas en inglés) o drones en aplicaciones agrícolas se está estudiando. Una de las aplicaciones es determinar parámetros fenológicos de las plantas para reducir el tiempo y los esfuerzos requeridos en la recolección de datos de campo. Este estudio tiene como objetivo explorar el uso de un UAV, una cámara de color 4K y un servicio de análisis de imágenes disponible comercialmente para medir los parámetros de las plantas de cítricos que son importantes para un científico agrícola o para el agricultor con recursos técnicos y recursos limitados. Los cultivos de *Citrus* spp. son importantes en Puerto Rico y Estados Unidos de América. Actualmente, la industria de los cítricos está luchando por contener el efecto devastador del enverdecimiento de los cítricos o la enfermedad de Huanglongbing. Esta enfermedad se asocia a la bacteria, *Candidatus* Liberibacter asiaticus (CLA), que se aloja en el tejido del floema y es acarreada por el psílido asiático de los cítricos (ACP), *Diaphorina citri* Kuwayama. El uso de insecticidas para el control de vectores es la estrategia principal utilizada en viveros y huertos. Sin embargo, una vez la planta de cítricos está infectada, no hay control efectivo disponible para la enfermedad. En Puerto Rico, esta enfermedad ha reducido el cultivo de *Citrus* spp. en más del 50%, y se están realizando estudios para encontrar medidas de control efectivas, como la aplicación de nutrientes suplementarios, prácticas de manejo de vectores, el uso de material vegetativo libre de enfermedades y estructuras protegidas. Este trabajo presenta los resultados parciales de un experimento que se llevó a cabo en la Subestación Experimental Agrícola de Fortuna en Juana Díaz, Puerto Rico, para abordar los desafíos

planteados por el enverdecimiento de los cítricos. El experimento se estableció en un huerto de lima Tahití de cuatro años (*Citrus latifolia* Tan.) injertado en mandarina Cleopatra (*Citrus reshni* hort. Ex Tanaka), infectada naturalmente con *Candidatus* Liberibacter asiaticus. El experimento se organizó en un diseño de bloques completos al azar con cuatro repeticiones y tres tratamientos: aplicación de nutrientes suplementarios, nutrientes suplementarios + ácido salicílico y fertilización granular. Se midieron los parámetros de crecimiento de los árboles y se llevaron a cabo análisis de laboratorio para determinar los niveles de nutrientes y los niveles de gravedad de la enfermedad a partir de las muestras de hojas. La cámara a color, a bordo del UAV, se empleó para adquirir imágenes del experimento. La aplicación 'Drone Deploy' se utilizó para planificar los vuelos del UAV y el análisis de imágenes. En el campo se tomaron medidas de la altura de la planta y el diámetro del dosel y se compararon con los parámetros determinados a partir de las imágenes en color. Los errores promedio en la medición del diámetro del dosel (14.5%) y la altura de la planta (22.4%) podrían considerarse dentro del rango aceptable, especialmente para comparar diferentes tratamientos o variedades de cultivos. Sin embargo, los errores promedio en la medición del volumen del dosel (47.5%) fueron altos y pueden considerarse inaceptables. Al parecer, la forma cónica asumida para el cálculo del volumen de los árboles podría ser una de las principales razones para el margen de error, además de los algoritmos utilizados para calcular el volumen de la planta. Estudios adicionales podrían ayudar a reducir los errores, como también explorar otros algoritmos y aplicaciones. El método utilizado puede ser importante para realizar evaluaciones de árboles frutales.

Palabras clave: UAV, drones, cítricos, fenotipos de plantas, automatización, procesamiento de imágenes

INTRODUCTION

The UAVs (Unmanned Aerial Vehicles), or UAS (Unmanned Aerial Systems), or drones promoted for agricultural applications are inexpensive and comparable to hobbyist grade UAVs (Freeman and Freeland, 2015). Yet, they have potential because of lower initial cost, easy availability of software and global positioning system (GPS) based navigation control. Further, they provide higher resolution images with less processing related delays compared to satellite and manned aircraft based imaging systems. It appears that by employing UAVs, even specialty crop growers will be able to practice precision agriculture at an affordable cost (Ehsani, 2011). A typical UAV-based system of remote sensing is shown in Figure 1 (Rokhmana, 2015). Similar to conventional manned aerial mapping, a UAV system uses an aerial vehicle with a remote controller for directing digital cameras to acquire aerial images at predetermined positions, or time intervals as per the flight plan configurations and satellite based navigation. The aerial images are processed by digital photogrammetric techniques to produce an ortho-mosaic image and a point cloud of digital elevation model.

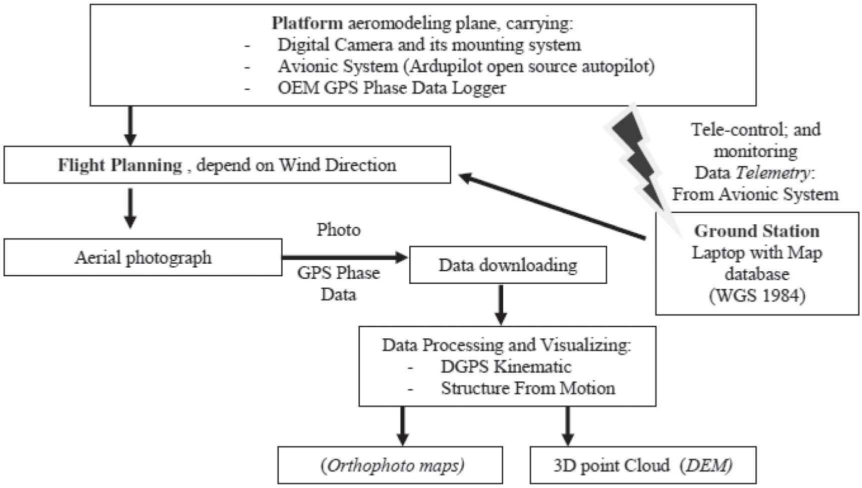

FIGURE 1. Typical architecture of UAV- (unmanned aerial vehicle) based remote sensing system (Adapted from Rokhmana, 2015).

There are numerous studies deploying UAVs for agricultural application and some relevant ones are briefly described here. "Monitoring water stress and fruit quality in an orange orchard under regulated deficit irrigation using narrow-band structural and physiological remote sensing indices" was the topic of research by Stagakis et al. (2012). In grapefruit, Romero-Trigueros et al. (2017) reported significant correlations between: red (R) wavelength with chlorophyll and potential turgor; near infra-red (NIR) wavelength with gas exchange; and normalized difference vegetation index (NDVI) with gas exchange. Similarly, significant correlations were found in mandarin between NIR with stem water potential and gas exchange, and NDVI with stem water potential (Romero-Trigueros et al., 2017). Weed classification accuracy from the UAV images was 94.5% and the coefficient of determination was 0.89 between the detected weeds and their ground truth densities (Gao et al., 2018). Thermal images obtained from a UAV were used to correlate soil moisture and water stress in sugar beet with limited success (Quebrajo et al., 2018). A multi-temporal study showed that caution must be taken when results from one sensor are compared to results from a different sensor or image processing scheme (Aasen and Bolten, 2018).

Another application of UAVs studied is plant phenotyping (i.e., measurement of plant observations such as plant height, canopy diameter, canopy volume and others). Comparable accuracies in detecting citrus greening symptoms were found for manned and unmanned aerial imaging systems using the same sensor (Garcia-Ruiz et al., 2013). Sankaran et al. (2015) published a comprehensive review of the technological aspects of integrating unmanned aerial vehicles with imaging systems to enhance field phenotyping capabilities, the state-of-the-art of unmanned aerial vehicle technology and many agricultural applications. Furthermore, the review discussed the potential of using aerial imaging to evaluate resistance/susceptibility to biotic and abiotic stress for crop breeding and precision agriculture (Sankaran et al., 2015). A study investigated black sigatoka disease detection from plantain images (Mathanker and Pérez-Alegría, 2016). A field phenotyping system was developed to assess potato late blight resistance with a coefficient of determination 0.73 (Sugiura et al., 2016). Detection of citrus greening and determination of plant parameters were investigated using a color camera (Mathanker et al., 2017a, 2017b). The vegetation fraction and plant height determined from UAV imagery and actual measurement showed a correlation of 0.7 for white radish and napa cabbage vegetables (Kim et al., 2017).

Citrus is an important agricultural crop in both Puerto Rico and the USA, valued at roughly $3.3 billion in 2015-2016, out of which fresh market oranges alone were valued at $861 million (USDA, 2016). However, citrus yield and fruit quality are adversely affected by citrus greening, also known as Huanglongbing (HLB) or yellow dragon disease. Citrus greening has emerged as one of the most serious citrus plant diseases and has devastated millions of acres of citrus crops throughout the United States and abroad (USDA, 2018). There appears to be no cure, but some control measures have been developed such as spraying insecticides (Chen et al., 2017) and horticultural mineral oil (Tansey et al., 2015) for vector control, use of tolerant rootstocks (Bowman et al., 2016), better nutrition (Estévez de Jensen et al., 2010), removal of infected trees (Bassanezi et al., 2013) and improved irrigation (Kadyampakeni and Morgan, 2017). Furthermore, there are other research studies underway to develop measures for controlling citrus greening. One such study was conducted at the Fortuna Agricultural Experiment Substation in Puerto Rico to evaluate the effect of different nutrient treatments in improving *Citrus* sp. nutrition and ameliorating the effect of the disease. Besides laboratory analysis, the study involved measuring citrus plant phenotypes such as plant height, canopy diameter, canopy volume and others. This process is quite cumbersome and time consuming. To reduce scouting and field data collection costs, the objective of this preliminary study was to explore the possibility of determining plant parameters by analyzing color images of the citrus experiment taken from a UAV.

MATERIALS AND METHODS

An unmanned aerial vehicle, DJI Phantom 3 Professional, with a 4K-color camera (DJI Corporation, China)[6] (Figure 2), was used to acquire images of an experimental orchard at the Fortuna Substation. The experiment was established in a four-year-old grove of Tahiti lime (*Citrus latifolia* Tan.) on a Cleopatra mandarin (*Citrus reshni* hort. ex Tanaka), naturally infected with *Candidatus* Liberibacter asiaticus. The experiment was arranged in a randomized complete block design with four replicates and three treatments: 1) a standard essential nutrients supplement applied to the foliage; 2) the standard essential nutrients

FIGURE 2. The unmanned aerial vehicle, DJI Phantom 3 Professional with 4K-color camera on board, used to acquire images of the citrus experiment.

[6]Company or trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute an endorsement by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

supplement + salicylic acid; and 3) a control consisting of a standard granular fertilizer applied to the soil at the tree base. The plants were spaced at about 4.6 x 6.8 m. Disease severity was assessed using a modified scale of 1 to 6 where: 1 = healthy, no symptoms and 6 = dead tree (Rouse et al., 2010). The trees were tested for CLAs using an HLB detection kit (Enviroloxic) at the beginning of the experiment. Plant height and canopy diameter were measured for 48 plants that were part of the experiment. The canopy volume was assumed to be conical and was calculated using the cone volume formula (canopy volume = 22/7 x canopy diameter^2 x plant height). The plant parameters were recorded on the same day of the UAV flights employing the Drone Deploy application.

The Drone Deploy is an application for UAV image analysis that includes an automated flight module and image data processing on a cloud server (https://www.dronedeploy.com). The acquired UAV images tagged with GPS (Global Positioning System) coordinates are uploaded to the cloud server for image stitching and calculating three dimensional point clouds. After image analysis, the application provides an ortho-mosaic, terrain elevation map and three-dimensional map. The application supports a variety of interactive tools for analysis and visualization. One of the tools lets a user measure distance, area and volume of a desired area on the map.

The UAV was flown around noon to avoid shadow effects, at three flight altitudes: 20, 27.4 and 36.6 m (66, 90 and 120 ft) with an 80% image overlap using the Drone Deploy application. The images acquired were uploaded to the Drone Deploy cloud server to create image mosaics and elevation maps. An interactive tool was used to select an individual plant's canopy on the image mosaic or the elevation map. The selected individual plant canopy was used to record canopy diameter calculated, plant height calculated and canopy volume calculated.

RESULTS AND DISCUSSION

The data analysis consisted of comparing the field measured and cloud server calculated plant parameters from the images that were acquired employing the UAV and color camera. Some of the individual images acquired from the 20 m altitude are shown in Figure 3. The image mosaic generated by the Drone Deploy application using the images similar to those shown in Figure 3, taken at 20 m altitude is shown in Figure 4A, and the elevation map generated is shown in Figure 4B. In the elevation map, the red color intensity shows higher elevation and blue color intensity shows lower elevation. The image mosaics and elevation maps at 27.4 and 36.6 m flight altitudes were of poor quality and were not used in further analysis.

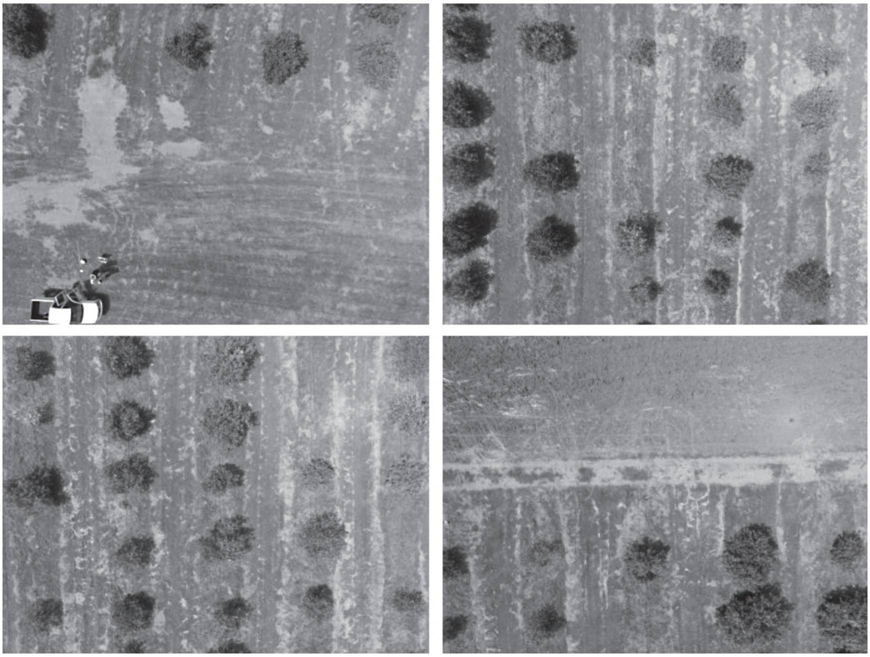

FIGURE 3. Selected images taken of the citrus greening experiment at 20-m altitude.

The measured canopy diameter compared well with the calculated canopy diameter (Figure 5A), and the average error was 14.5% with a standard deviation of 9.9% (Table 1). The measured average canopy diameter was 2.32 m and calculated average canopy diameter was 2.01 m. The errors may be due to human bias, analysis methodology and other factors, and the errors could be further improved by better image acquisition and data analysis.

Similarly, the measured plant height compared well with the calculated height (Figure 5B). The average error was 22.4% with a standard deviation of 8.3% (Table 1). The measured average plant height was 1.87 m and calculated average plant height was 1.40 m. The errors may be due to human bias, land topography and analysis methodology, and the errors could be further reduced by better image acquisition and data analysis.

Conversely, the measured canopy volume did not consistently compare well with the calculated canopy volume (Figure 5C). The average error was 47.5% with a standard deviation of 73.8% (Table 1). It appears that for some plants the error was very high, such as for plant no. 10, 34, 40, and others. The measured average canopy vol-

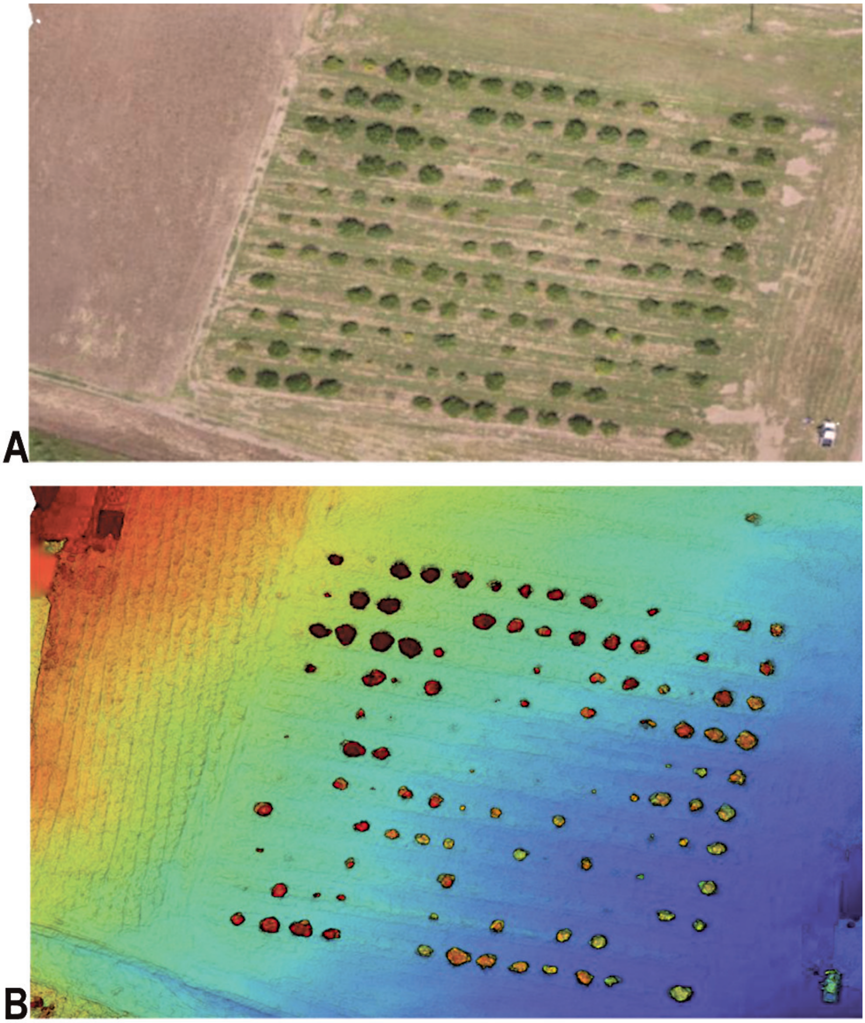

FIGURE 4. A) Generated ortho-mosaic image, and B) Generated elevation map, using Drone Deploy Application, from the images acquired during the 20-m altitude flight over the citrus greening experiment.

ume was 0.059 m^3 and calculated average canopy volume was 0.075 m^3. The errors may be due to the conical shape assumed by the plant, analysis methodology and inaccuracies in the single frequency GPS used. Single frequency GPS systems are not very accurate in estimating altitudes, and using GPS corrections from a nearby GPS base station or using a double frequency GPS can improve the accuracy of altitude estimation and thereby canopy volume estimates.

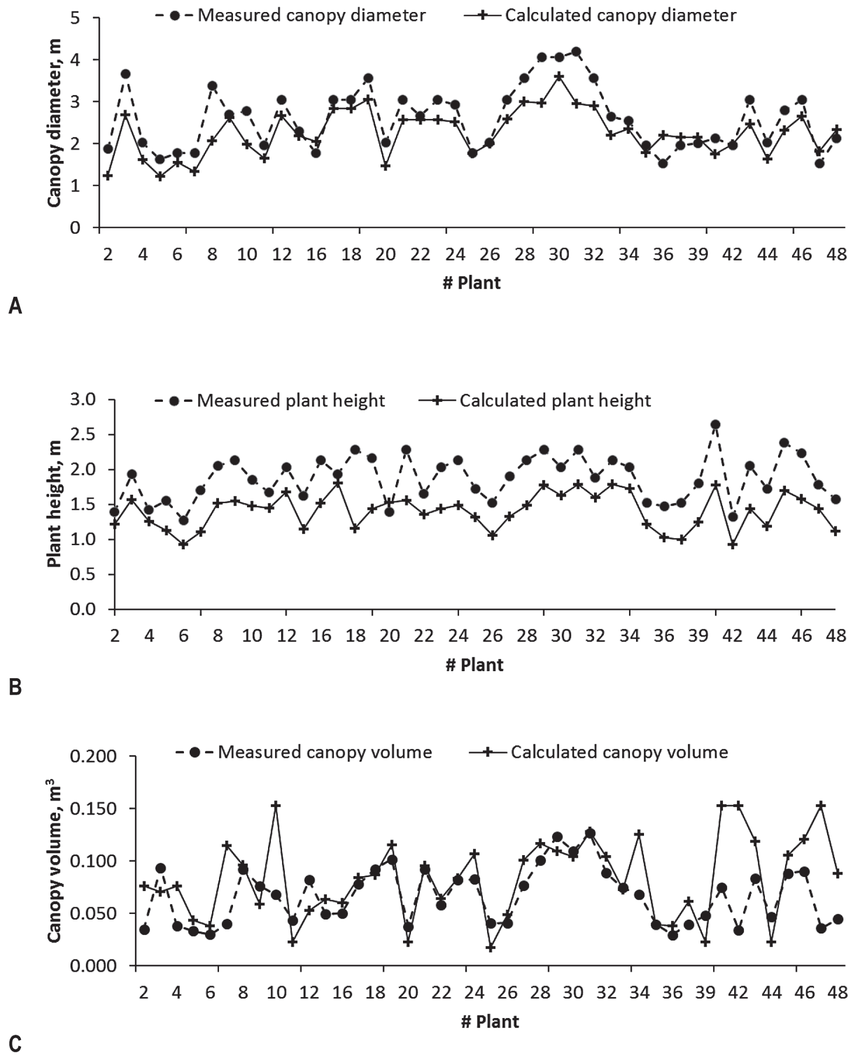

FIGURE 5. Comparison of A) canopy diameter, B) plant height, and C) canopy volume of field-measured and calculated values using the Drone Deploy application for the 20-m altitude flight.

An analysis of variance showed no correlation between plant parameters and disease severity levels and nutrient levels (Table 2). However, the significant difference (< 5%) was found in disease severity levels between both the supplemental nutritional programs and the granular fertilization. After two years, no differences were found in plant height and canopy diameter with the application of the supplemental nutrients

TABLE 1.— *Average errors and standard deviation of the errors between the field-measured plant parameters and calculated plant parameters using the Drone Deploy application at 20-m altitude.*

Plant parameter	Average error (%)	Standard Deviation (%)
Canopy diameter	14.5	9.9
Plant height	22.4	8.3
Canopy volume	47.5	73.8

with and without salicylic acid or the standard granular fertilizer. This is in accordance with research conducted on Valencia sweet orange over a two-year period where no significant differences in bacterial titer dynamics, fruit yield [number of fruit per tree, fruit weight (kg) per tree, proportion of fruit dropped], or juice quality between treated trees and non-treated control trees were found (Gottwald et al., 2012). Differences found in disease severity levels between both the supplemental nutritional programs and the standard granular fertilization soil application showed an effect in the symptoms observed. There was no significant impact on macronutrient accumulation on the leaves in the different treatments. Also, no significant variations were found in the micronutrients with the exception of a slight increase of Zn and Mn in treatments 1 and 2 with the supplemental nutrients plus salicylic acid.

CONCLUSION

This study demonstrated use of an automated plant phenotyping method for measuring citrus canopy diameter, plant height and canopy volume for individual trees employing a UAV, color camera

TABLE 2.—*Significance levels for nutrient treatments as affected by plant parameters and citrus greening severity levels.*

Variable	Treatment	Mean	Significance level
Plant height	Foliar + SA	74.79 a	LSD 11.6 CV. 9.8%
	Granular fertilizer	73.31 a	
	Foliar	72.90 a	
Canopy diameter	Foliar + SA	113.96 a	LSD 32.9 CV. 20.4%
	Granular fertilizer	97.33 a	
	Foliar	90.63 a	
Disease severity	Foliar + SA	4.38 a	LSD 1.3 CV. 22.1%
	Granular fertilizer	2.95 b	
	Foliar	4.50 a	

and commercially available image analysis service. The average errors in measuring canopy diameter (14.5%) and plant height (22.4%) could be considered within acceptable range, especially for comparing different treatments or crop varieties, and for the technology used in this study. However, the average errors in measuring canopy volume (47.5%) were high and are unacceptable. Using a double frequency GPS on board the UAV and a local GPS base station are recommended for improving canopy volume estimates. Further studies could help in reducing errors and also exploring other applications. The demonstrated method can be used to assess phenotypic data for investigations and to reduce scouting costs for citrus greening control measures.

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Postharvest quality of achachairú (*Garcinia gardneriana*) stored at ambient temperature[1,2]

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ABSTRACT

Achachairú is a tropical fruit that is being evaluated for its potential as a new fruit crop for Puerto Rico. More information is needed concerning postharvest aspects of this fruit. In this paper we describe the physical and chemical characteristics of achachairú during storage at ambient temperature. During each of three harvest years, 75 to 100 fruits were harvested, washed and dried, then divided into five groups. Each group was placed in an open cardboard box and randomly assigned to one of five storage treatments (0, 5, 10, 15, and 20 days at 25 ± 2 °C, 75 ± 5% relative humidity). Physical and chemical properties, including sugar content, were determined for each storage period. Sensory panels evaluated fruits after 0 and 15 days of storage. Over the 20-day storage period fruit weight, size (length and diameter), firmness and pulp weight decreased by 1.5% to 2.5% per day. The rating of external fruit appearance (evaluated on a hedonic scale) deteriorated in a curvilinear fashion over time, initially changing little, and then showing increased deterioration (dark spots and wrinkling) starting at 15 days post storage. Total soluble solids (°Brix) (TSS) increased over time by 0.8 to 1.6% per day, while total titratable acid (TTA) decreased 1.4 to 3.0% per day, resulting in an increase of the sugar-acid ratio (TSS/TTA) of 2.1 to 12.4% per day over 20 days of storage. Sucrose was the most abundant sugar (7.19 g/100 g), followed by fructose (3.38 g/100 g) and glucose (3.18 g/100 g). Panelists judged the sweetness, aroma, acidity, juiciness and overall flavor not to have changed after 15 days of storage. Results of this study suggest that achachairú can be stored at ambient temperature for 15 days and maintain fruit quality acceptable to the consumer.

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Key words: ***Garcinia*** **spp.,** ***G. humilis,*** **physicochemical characteristics, sugars, postharvest quality, tropical fruits**

RESUMEN

Calidad poscosecha de achachairú (*Garcinia gardneriana*) almacenado a temperatura ambiente

El achachairú es una fruta tropical que está siendo evaluada por su potencial como un nuevo cultivo frutícola para Puerto Rico. Se necesita más información sobre los aspectos poscosecha de esta fruta. En este artículo presentamos las características físicas y químicas de achachairú durante el almacenamiento a temperatura ambiente. Durante cada uno de los tres años de cosecha, se cosecharon, lavaron y secaron de 75 a 100 frutas, luego se dividieron en cinco grupos. Se ubicó cada grupo en una caja de cartón sin cerrar y se asignó al azar a uno de los cinco tratamientos de almacenamiento (durante 0, 5, 10, 15 y 20 días a 25 ± 2 °C, 75 ± 5% de humedad relativa). Las propiedades físicas y químicas, incluido el contenido de azúcar, se determinaron para cada período de almacenamiento. Los paneles sensoriales evaluaron las frutas después de 0 y 15 días de almacenamiento. Durante el período de almacenamiento de 20 días, el peso, el tamaño (longitud y el diámetro) de la fruta, la firmeza y el peso de la pulpa disminuyeron de 1.5 a 2.5% por día. La clasificación de la apariencia externa de la fruta (evaluada en una escala hedónica) se deterioró de manera curvilínea con el tiempo, inicialmente cambió poco y luego mostró un mayor deterioro (manchas oscuras y arrugas) a partir de los 15 días posteriores al almacenamiento. Los sólidos solubles totales (° Brix) (TSS, por siglas en inglés) aumentaron con el tiempo entre un 0.8 y un 1.6% por día, mientras que el ácido titulable total (TTA, por siglas en inglés) disminuyó entre un 1.4 y un 3.0% por día, lo que resultó en un aumento en la relación azúcar-ácido (TSS/TTA) de 2.1 a 12.4% por día durante 20 días de almacenamiento. La sacarosa fue el azúcar más abundante (7.19 g/100 g), seguido de fructosa (3.38 g/100 g) y glucosa (3.18 g/100 g). El panel sensorial consideró que la dulzura, el aroma, la acidez, la jugosidad y el sabor en general no habían cambiado después de 15 días de almacenamiento. Los resultados de este estudio sugieren que el achachairú puede almacenarse a temperatura ambiente durante 15 días y mantener la calidad de la fruta aceptable para el consumidor.

Palabras clave: ***Garcinia*** **spp.,** ***G. humilis,*** **características fisicoquímicas, azúcares, calidad poscosecha, frutas tropicales**

INTRODUCTION

Achachairú is a tree species of tropical regions of South America. The edible white, fleshy pulp usually surrounds one or two seeds and has a pleasing sweet-sour flavor. Achachairú is a member of the genus *Garcinia* (previously *Rheedia*) and originates in the eastern part of Bolivia. Almost all species of this genus are of Asian origin, including the well-known mangosteen (*G. mangostana*). In the Americas, various species of *Garcinia* are known from places as diverse as Guyana, Panama, Dominica, Trinidad, Grenada and Haiti (Lim, 2012).

Considerable confusion surrounds the correct botanical classification of achachairú. Ardaya (2009), working in Bolivia, classified the achachairú fruits used in his study as *G. humilis.* Da Fonseca (2012), working in Brazil, used the same species name [*G. humilis* (Vahl) C. D. Adam]. However, a review of the botanical literature suggests that this designation might be incorrect and that *G. gardneriana* (Planch. & Triana) Zappi might be the more appropriate name for what is generally known in Spanish as achachairú and sometimes known in Portuguese as bacupari (see multiple references in International Plant Names Index, 2019). Lim (2012) and Duarte (2011) recognized other synonyms of *G. humilis* including *R. achachairu* Rusby and *R. lateriflora* L. In Puerto Rico, Barragán-Arce (2011) looked at floral structures in the same trees used for our study. He noted that these trees had been previously referred to as *G. brasiliensis* or *G. laterifolia*. However, he concluded that the flowers most resembled those of *G. gardneriana* because the carpel number was three rather than the four carpels found in *G. brasiliensis.* Various international plant species databases indicate that some, if not all, of these species names are synonymous. Based on our review of the literature, and especially in consideration of the work of Barragán-Arce (2011), we have chosen to accept the designation *G. gardneriana* (Planch. & Triana) Zappi.

Achachairú is widely produced and commercialized in Bolivia and Brazil (Barbosa et al., 2008). The largest commercial production is in northern Australia where the common name is achacha (Achacha Fruit Management of Australia, 2013). About 16,000 trees have been in production since 2009 (International Tropical Fruit Network, 2019). They are expected to produce about 250,000 kg of fruit in the 2019 production year. Individual trees can produce up to 100 kg of fruit and the fruit sells for $10 to $25 per kilogram.

The fruit has a low fat and protein content (Janick and Paull, 2008). In Bolivia it is considered to have curative digestive and laxative properties and has been used to treat gastritis, rheumatism and inflammation (Barbosa and Artiole, 2007). Its pulp is used in the preparation of jelly, juice, sorbet and ice cream, and its rind has been used to make liquors and wine (Lim, 2012).

Very limited studies are found in the literature concerning the effects of storage on fruits of achachairú. Janick and Paull (2008) report that, for fresh-fruit consumption, achachairú keeps for one week at room temperature and for two to three weeks for industrial use. According to Achacha Fruit Management of Australia (2013), fruits can be maintained at 20° C for several days in an open container and several weeks in a closed container or bag. Duarte (2011) reported that 12° C is an adequate temperature for storage of achachairú but found that fruit damage occurs at 6° C. Wills et al. (1982) indicates that mechanical damage reduces visual quality by leaving spots and wounds that increase fruit metabolism and transpiration.

The unique sensorial characteristics of achachairú have awakened an interest among local growers to consider the possibility of commercializing this fruit crop in Puerto Rico. It is important to document postharvest changes that occur in fruits in order to define management practices that will provide the consumer with a quality product. Therefore, our objective was to characterize the physical and chemical changes that occur in achachairú during storage at room temperature.

MATERIALS AND METHODS

Mature fruits (full orange color) were harvested from a private farm in Las Marías, Puerto Rico, from June to August of 2012, 2013 and 2014. Hand harvesting was carried out in order to minimize mechanical damage. Harvesting was done early in the morning. In each year's harvest, fruits of a uniform size (about 4 cm in diameter) were selected. All physical and chemical evaluations were carried out in laboratories of the Food Science and Technology program of the College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus (UPRM). In the laboratory fruits were washed with water and dried, then divided into five groups of 15 (2012) or 20 (2013 and 2014) fruits. Fruits were placed uncovered in cardboard boxes and each group was randomly assigned to one of five storage periods [0, 5, 10, 15 and 20 days of storage at 25 ± 2° C, 75 ± 5% relative humidity (RH)]. Day 0 (0 days of storage) corresponded to the day of harvest.

After each storage time, the external appearance of the fruit rind was evaluated using the 0 to 4 scale of Fontenele (2007), where 0=absence of dark spots and wrinkles, 1=few dark spots, 2=many dark spots and some wrinkles, 3=many dark spots and wrinkles and 4=completely dark and wrinkled. Fruit length, diameter and weight were measured. Fruit firmness [force in Newtons (N) needed to penetrate the fruit rind] was measured with a texturometer (Texture Analyzer model TA.XT2, Texture Technologies, MA, USA)[6] with a 2 mm stainless steel tip. Pulp thickness was determined by averaging four measurements taken between the fruit poles and equator using a Vernier digital caliper (Mitutoyo, Japan). Pulp weight was measured and the number of large

[6]Company or trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute an endorsement by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

(fully formed) and atrophied (small) seeds were counted as suggested by Cavalcante et al. (2006).

For each harvest year and storage time, chemical analyses were carried out using a composite of pulp from three fruits. Total soluble solids (TSS) were measured as °Brix with a digital refractometer (model PAL-BX/RI, ATAGO Co., LTD, Tokyo, Japan). The pH was measured (model Docu-pH Meter, Sartorius, New York, USA.). Total titratable acid (TTA) was determined by titration with 0.1 *N* NaOH to a pH of 8.2 and expressed as a percentage of citric acid. Maturity relationship was established as the ratio between TSS and TTA.

Sugars were measured only in years 2013 and 2014. For reducing sugars percentage, a 2.5 g sample was placed in either a 50 mL or 100 mL volumetric flask, depending on the concentration of sugars. The flask was filled with distilled water and the contents vacuum filtered with Whatman® #4 filter paper. For each sample, a Lane-Eynon titration was done in triplicate in combination with Association of Official Analytical Chemists (AOAC) method 923.09C for the concentration of unknown sugars (Horwitz and AOAC International, 2003). The percentage of reducing sugar in a sample was calculated using AOAC table 930.44. Sucrose, fructose and glucose were determined following the method of Salman et al. (2011). High performance liquid chromatography (HPLC) was used with a refraction index detector (RID) model 1100, and a thermostatted column compartment (TCC) model 1200 (Agilent Technologies, Santa Clara, California, USA) and a Waters Sugar Pak™ II column (Waters Corporation, Milford, MA, USA). Sugars were separated using a 300 mm x 6.5 mm Waters Sugar Pak™ I column (Waters Corporation, Milford, MA, USA). A 0.0001 M Ca-EDTA solution (Millipore-Sigma, St. Louis, MO, USA) was used for the mobile phase at 45° C with 0.5 mL/min flow. Oven temperature for the TCC was set to 80° C and the injection volume to 10 µL.

For each storage time and harvest year, a proximate analysis was conducted on a composite sample of 10 fruits. A total of nine determinations was taken on this bulk sample. Pulp composition was determined following AOAC methods (Horwitz and AOAC International, 2003). Moisture, protein, ash, fiber and fat were determined following AOCS (American Oil Chemists' Society, 2004) methods. Results for the analysis of protein, ash, fat and fiber were corrected for the percentage of volatile compounds lost during the drying of samples. The percentage of available carbohydrates was determined by the difference between 100% and the sum of the percentages of moisture, protein, ash, fiber and fat.

For the 2012 harvest, consumer acceptability of fresh fruits (0 days of storage) was evaluated by 50 untrained volunteer panelists using a 9-point hedonic scale (Meilgaard et al., 2007), where 1=dislike very greatly, 5=neither like nor dislike, and 9=like very greatly. For fruits stored 0 or 15 days after the 2013 and 2014 harvests, a panel of 16 consumers evaluated sweetness, aroma, acidity, juiciness and general flavor, using a 7-point hedonic scale (1=dislike extremely, 4=neither like nor dislike, and 7=like extremely). The sensory analysis was reviewed and approved by the Institutional Review Board of the UPRM.

Regression was used to analyze data collected over the 20-day storage period. Linear and quadratic models were tested. With the main exception of external fruit appearance, the addition of the quadratic term did not usually improve the fit of the model in the regression analyses of the effect of days of storage on the various physical and chemical attributes of achachairú fruit. Therefore, a quadratic model was used for external fruit appearance while only estimates from linear regression appear in tables for the other traits. For traits analyzed by linear regression, the means that are reported correspond to adjusted means at day 0, which are equivalent to the intercept of the linear regression line.

RESULTS AND DISCUSSION

External fruit appearance

The effect of days of storage on the external appearance of achachairú fruit was curvilinear, with little change in appearance occurring in the first five days of storage (scores of 0 or 1, no or few spots or wrinkles), and deterioration increasing more rapidly over the next 15 days (Figure 1). After 20 days of storage, no fruit had a score of 0 or 1, and more than 50% of the fruit had scores of 3 (large number of dark spots and severe wrinkling) or 4 (fruit severely wrinkled and entire surface covered with dark spots).

Teixeira et al. (2005) observed that in bacuri (*Platonia insignis*), a fruit related to achachairú, fruit shrinkage resulting in wrinkling was the most important factor impacting appearance although they also indicated that dark spots play a role. A weight loss of 5% is enough to cause shrinkage in fruits and vegetables, and this shrinkage affects quality (Pantastico et al., 1979). Thorp and Bieleski (2002), working with another fruit from the American tropics, feijoas (*Acca sellowiana)*, noted that changes in fruit appearance can occur during fruit maturation and senescence as well as a result of mechanical damage during harvest and postharvest operations. Browning of the fruit surface occurs when epidermal tissues break, and oxygen is introduced allowing activation of enzymes. The enzymes involved in surface blotching or

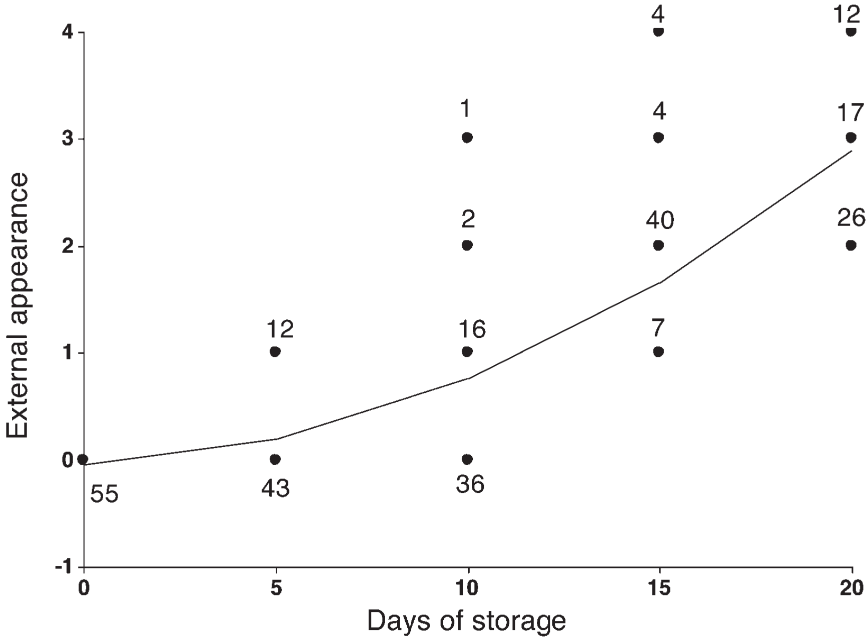

FIGURE 1. Quadratic regression analysis (Appearance = -0.043 + 0.013Days+ 0.007Days^2 [R^2=0.741; p=<0.0001]) of the effect of days of storage at 25° C and 75% relative humidity on the external appearance of fruits of achachairú (*Garcinia gardneriana*) harvested in 2012, 2013 and 2014 in Las Marías, Puerto Rico. (Scoring scale: 0 to 4, where 0 = no defects). Numbers within the graph refer to the number of fruits with the indicated score. For each storage period, 15 fruits were sampled in 2012, and 20 fruits each in 2013 and 2014 (n=55 for each storage period).

browning include polyphenol oxidases, polyphenolases and phenolases (Gutiérrez, 2000). The action of polyphenolases generally diminishes the attractiveness of fruits although it can be beneficial in some cases such as with tea and coffee (Deman, 1999).

Physical attributes of the fruit

Days of storage almost always exhibited a significant linear effect on achachairú fruit traits (with the exception of fruit length in 2012 and fruit diameter in 2014) (Table 1). While there were some differences among years, for a given trait the direction of the response (slope) was always negative (indicating poorer quality over time), and the magnitude of the response was usually similar. Nevertheless, for most traits there was considerable unexplained variability in the regression analyses. The highest coefficient of determination, for rind weight in 2012, was R^2=0.56, indicating that only 56% of the variation in this trait could be explained by the linear regression of rind weight

TABLE 1.—*Parameter estimates (intercept, slope), coefficients of determination (R^2) and probabilities of the linear regression analysis of physical traits of fruits of achachairú (*Garcinia gardneriana*) harvested in 2012, 2013 and 2014 in Las Marías, Puerto Rico, and stored for 0, 5, 10, 15 and 20 days at 25° C and 75% relative humidity.*

Trait[z]	Year	Intercept[y]	Slope	R^2	Probability
Fruit weight (g)	2012	44.86	-1.06	0.51	<0.0001
	2013	53.12	-1.10	0.51	<0.0001
	2014	45.51	-0.71	0.38	<0.0001
Fruit length (mm)	2012	55.45	-0.12	0.04	0.1032
	2013	56.06	-0.20	0.13	0.0003
	2014	56.70	-0.18	0.09	0.0025
Fruit diameter (mm)	2012	41.05	-0.24	0.24	<0.0001
	2013	44.23	-0.19	0.18	<0.0001
	2014	41.23	-0.10	0.08	0.2657
Firmness (N)	2012	16.15	-0.25	0.19	<0.0001
	2013	13.51	-0.30	0.47	<0.0001
	2014	15.58	-0.24	0.34	<0.0001
Rind weight (g)	2012	20.66	-0.56	0.56	<0.0001
	2013	21.93	-0.52	0.45	<0.0001
	2014	20.77	-0.39	0.47	<0.0001
Rind thickness (mm)	2012	—	—	—	<0.0001
	2013	3.05	-0.06	0.37	<0.0001
	2014	3.35	-0.05	0.42	<0.0001
Pulp weight (g)	2012	13.54	-0.33	0.37	<0.0001
	2013	16.79	-0.37	0.46	<0.0001
	2014	14.11	-0.25	0.44	<0.0001

[z]At the end of each of the five storage periods, 15 (2012) or 20 (2013 and 2014) fruits were sampled.
[y]The intercept is equivalent to the adjusted mean at 0 days of storage (intercept of linear regression model).

to days of storage. Unknown factors apart from number of days in storage clearly played a role in changes in fruit traits over time. Initial variability in fruit weight or size may have contributed to the observed variability. Although an attempt was made to sample fruits of a similar size, when sampling 75 (2012) or 100 fruits (2013 and 2014) it is unlikely that all fruits will initially be the same.

Over the three years of the study, weight loss averaged 0.71 to 1.10 g per fruit per day, resulting in an overall weight loss of more than 40% after 20 days (Table 1). On average, fruit length diminished by 0.12 mm to 0.20 mm per day over 20 days of storage, although the loss in length was not significant in 2012. Average fruit diameter also diminished over the study period by 0.10 mm to 0.24 mm per day, but the loss was not significant in 2014. Overall, these losses correspond to about 4% to 7% of length and 9% to 12% of diameter over the 20-day period. As is typical in all photographs we have seen of achachairú fruits, in our study fruits were slightly elongated as evident by length being greater (55.45 mm to 56.70 mm) than diameter (41.05 mm to 44.23 mm).

Fruit firmness, rind weight and thickness, and pulp weight were also greatly reduced during storage (Table 1). Fruit firmness diminished 0.24 to 0.30 N per day, or 31 to 44% over the 20 days of storage. Rind weight was reduced by 0.39 g to 0.56 g per day, a reduction of 37 to 54% over 20 days of storage. Rind thickness was reduced by 0.05 to 0.06 mm per day, equivalent to 30 to 39% loss over 20 days. Pulp weight diminished by 0.25 g to 0.37 g per day, a reduction of 35 to 44% over 20 days of storage. Overall, these four traits suffered a 30 to over 50% reduction in firmness, thickness or weight over 20 days of storage.

Fruit weight loss during storage occurs due to the loss of water via transpiration. This water loss causes changes in the appearance, texture and nutritional quality of the fruit (Kader and Barrett, 2004). The loss of water provoked the formation of wrinkles in the fruit rind, which in turn resulted in the observed reduction in fruit length and diameter. However, despite fruits being completely wrinkled by the end of the 20-day storage period, fruit pulp remained intact, with a normal white color and generally in good condition. This observation has important implications for fruits used in processing rather than used for fresh fruit consumption.

Average weight of achachairú fruits in this study (47.8 g at the beginning of the storage period) was slightly less than that of the "Selecto" type from Bolivia which averaged 50.0 g (Ardaya, 2009), but greater than that of achachairú from Brazil which averaged 40.6 g (Da Fonseca, 2012). In a similar manner, fruit length (55.7 mm) and diameter (41.9 mm) in our study was somewhat smaller than the average length (61.1 mm) and diameter (45.0 mm) observed by Ardaya (2009) and greater than achachairú from Brazil (48.0 mm in length and 40.2 mm in diameter) (Da Fonseca, 2012). Following the same trend, average pulp weight (14.8 g) and rind weight (3.7 g) in our study was intermediate between Ardaya's study (2009) in Bolivia and Da Fonseca's study (2012) in Brazil.

Fruits of the achachairú species from Brazil (specifically identified as *G. humilis* (Vahl) C. D. Adam) were also considerably rounder (length to diameter ratio of 1.17) than the fruits in our study which were more elongated (length to diameter ratio of 1.33). This latter ratio was similar to that of fruits studied by Ardaya (2009) in Bolivia (length to diameter ratio of 1.36). Ardaya (2009) also identified the species as *G. humilis.* It is likely that there are genetically based differences between trees from the various studies. The fruits in our study had an average rind thickness of 3.1 mm which was intermediate between that of fruits in Janick and Paull (2008) (2.0 mm) and Da Fonseca (2012) (3.9 mm). As in our study, Arjona et al. (1992) also observed a linear effect of weight loss in achachairú over storage time at various temperature levels.

Janick and Paull (2008) indicate that storage increases fruit shrinkage and firmness in achachairú, but unless fruits suffer physical damage or have been stored under too humid conditions, fruit will not rot. Previous studies on a variety of fruits, including blueberries (Proctor and Miesle, 1991), passionfruit (Aponte and Guadarrama, 2003; De la Cruz et al., 2010), avocado (Cerdas-Araya et al., 2014) and bacuri (*P. insignis* Mart.), a native Brazilian fruit, yielded results similar to our study where firmness decreased with time in storage. These researchers suggest that loss of firmness is related to enzymatic changes in the middle lamina and cell walls of the fruits which principally consist of pectin, cellulose and hemicellulose.

Full-size and atrophied seed

Over the three harvest years there were on average 1.5 full-size seeds per fruit (Table 2). The number of seeds per fruit varied most in 2013 with 0 to 3 full-size seeds per fruit. In the other years only 1 or 2 full-size seeds per fruit were observed. Fruits also contained smaller, atrophied seeds, varying from 0 to 5 seeds per fruit and averaging 1.6 seeds per fruit. Total (full-size and atrophied) seed weight averaged 8.8 g over the three harvest years, or about 11% of fruit weight. The

TABLE 2.—*Minimum and maximum value, mean and standard deviation (SD) of number of full-size, atrophied seed and total seed weight in samples of fruits of achachairú (*Garcinia gardneriana*) harvested in 2012, 2013 and 2014 in Mayagüez, Puerto Rico.*

Trait[z]	Statistic	2012	2013	2014
Number of full-size seed	Minimum	1	0	1
	Maximum	2	3	2
	Mean	1.17	1.98	1.25
	SD	0.38	0.62	0.44
Number of atrophied seed	Minimum	0	0	0
	Maximum	5	4	4
	Mean	1.88	1.11	1.95
	SD	1.04	0.87	1.05
Total seed weight (g)	Minimum	1.40	0.90	3.70
	Maximum	13.70	19.40	14.40
	Mean	7.51	10.43	8.59
	SD	2.45	2.77	1.91

[z]A total of 75 fruits were sampled in 2012; 100 fruits were sampled in 2013 and 2014.

presence of one or more large seeds in fruits of achachairú presents a challenge since consumers prefer fruits with small or no seeds. Ardaya (2009) generally observed a single full-size seed and two atrophied seeds in fruits of achachairú "Selecto" from Bolivia. The atrophied seeds were cylindrical and light brown as they also were in our study. Average seed weight in our study was greater than that in Bolivia (6.4 g) (Ardaya, 2009) and Brazil (8.25 g) (Da Fonseca, 2012).

Total Soluble Solids (TSS), Total Titratable Acid (TTA), pH, and TSS/TTA

Total soluble solids (TSS) (as measured by °Brix), pH and the sugar-acid ratio (TSS/TTA) of the pulp of achachairú fruits increased over the 20-day storage period as indicated by their consistently positive slopes (Table 3). In contrast, TTA decreased over time. The degree of change varied depending on the harvest year, but for each pulp trait, the general trend was the same. Initial values of TSS ranged from 15.43 to 16.55 °Brix, and these values increased 16 to 33% over the 20-day storage period (0.8 to 1.6% increase per day). Total titratable acid started at 0.69 to 0.93% citric acid and then decreased by 29 to 60% of the percentage of citric acid over 20 days (no change was observed in 2014). This corresponded to a decrease of 1.4 to 3.0% in citric acid content per day. The change in pH was small but significant, beginning at pH 3.41 to 3.7 and increasing by 2 to 10% over 20 days. The sugar-acid ratio (TSS/TTA) ranged from 16.03 to 30.34 at day 0, and then increased by 41 to 248% over the 20-day storage period (2.1 to 12.4% increase per day).

The increase in TSS content during maturation of fruits is related to the breakup of carbohydrates stored as simple sugars which occurs during respiration (Siddiqui and Dhua, 2010). During maturation fruits become soft, change color and develop their characteristic aroma and flavor. There is also a decrease in acidity and an increase in sweetness (Wills et al., 2007; Wills et al., 1982). The reduction in acidity during maturation is a result of organic acids being used in respiration or being converted to sugars (Kader and Barrett, 2004). The sugar-acid relationship (TSS/TTA) is more often associated with the palatability of a fruit than the contents of sugar or acid by themselves (Wills et al., 1982).

The initial values of TSS in our study (16.1 °Brix, averaged over three harvest years) was somewhat lower than that observed by Da Fonseca (2012) in achachairú from Brazil (16.4 °Brix) and by Ardaya (2009) in the "Selecto" type in Bolivia (16.28 °Brix). The TTA in our study (0.81%) was much less than the TTA=1.27% reported by Da Fonseca (2012), but similar to that of Ardaya (2009) (TTA=0.80%). Like-

TABLE 3.—*Parameter estimates (intercept, slope), coefficients of determination (R^2) and probabilities of the linear regression analysis of total soluble solids (TSS), total titratable acid (TTA), pH and the ratio of TSS to TTA in fruit of achachairú (*Garcinia gardneriana*) harvested in 2012, 2013 and 2014 in Las Marías, Puerto Rico, and stored for 0, 5, 10, 15 and 20 days at 25° C and 75% relative humidity.*

Trait[z]	Year	Intercept[y]	Slope	R^2	Probability
Total soluble solids (TSS) (°Brix)	2012	16.27	0.2700	0.42	<0.0001
	2013	15.43	0.1200	0.09	0.0028
	2014	16.55	0.2500	0.35	<0.0001
Total titratable acid (TTA)	2012	0.82	-0.0247	0.75	<0.0001
(% citric acid)	2013	0.93	-0.0133	0.73	0.0001
	2014	0.69	-0.0024	0.07	0.3461
pH	2012	3.70	0.0180	0.26	0.0540
	2013	3.47	0.0030	0.72	0.0001
	2014	3.41	0.0130	0.85	<0.0001
TSS/TTA	2012	19.43	1.7700	0.77	<0.0001
	2013	16.03	0.5200	0.49	<0.0001
	2014	30.34	0.6300	0.36	<0.0001

[z]In each year, three fruits were sampled at the end of each of the five storage periods.
[y]The intercept is equivalent to the adjusted mean at 0 days of storage (intercept of linear regression model).

wise, pH in the Da Fonseca (2012) study (pH=3.78) was somewhat higher than in our study (pH=3.53). The sugar-acid ratio (TSS/TTA) in our study was 21.9 averaged over three harvest years. In comparison, fruits in the Brazilian study (Da Fonseca, 2012) had a much smaller ratio (12.65) while fruits in the Bolivian study (Ardaya, 2009) had a very similar ratio (20.35).

Palapol et al. (2009) and Castro et al. (2012) studied the effects of storage on mangosteen (*G. mangostana* L.), a fruit related to achachairú. In both studies, TSS increased over the 21-day storage period (from 17.2 to 17.9 °Brix, and from 16 to 19 °Brix), an increase of 4 to 19% in TSS. In our study we observed a somewhat greater increase in TSS over 20 days, from 16 to 33%.

Sugars

In at least one of two harvest years (sugars were not measured in 2012), all sugars except sucrose increased during the time that fruits were in storage (Table 4). The percentage of reducing sugars (beginning at 5.62% at day 0 in 2013 and 4.29% in 2014) consistently increased in both harvest years by a factor of 107% to 153% over the 20-day period of the experiment. Total sugar content (13.62 and 13.89 g/100 g in 2013 and 2014, respectively) increased by 32% only in year 2014. There was no significant change over time in year 2013. Three sugars were identified in the pulp of achachairú: sucrose (t = 7.6 min), glucose (t = 9.5 min) and fructose (t = 11.8 min). Glucose content (4.22 and 2.14 g/100 g, in 2013 and 2014, respectively) increased by 65% in year 2014 but did not change in 2013. Fructose content (4.28 and 2.49 g/100 g in 2013 and 2014, respectively) did not change in 2013 and increased by 48% in 2014.

According to Chitarra and Chitarra (2005), the hydrolysis of starch, the degradation of polysaccharides of the cell walls and water loss by the fruit can all result in an increase in sugar during storage. Sucrose is metabolized during storage producing fructose and glucose (Jeffery et al., 1984). Total sugars at the beginning of our study (13.62 to 13.89 g/100 g) were less than that observed by Da Fonseca (2012) in achachairú in Brazil (16.92 g/100 g) and what was observed by Ardaya (2009) in achachairú in Bolivia (16.11 to 16.27 g/100 g). Sucrose content was also lower in our study (5.12 g/100 g and 9.26 g/100 g) than in the Brazilian study (11.39 g/100 g) (Da Fonseca, 2012).

Chemical composition

Except for moisture content, the proximate analyses of achachairú fruit varied depending on harvest year and, in some cases, the differences among years were large (Table 5). Protein, in particular, var-

TABLE 4.—*Parameter estimates (intercept, slope), coefficients of determination (R^2) and probabilities of the linear regression analysis of sugars in fruit of achachairú (*Garcinia gardneriana*) harvested in 2013 and 2014 in Las Marías, Puerto Rico, and stored for 0, 5, 10, 15 and 20 days at 25° C and 75% relative humidity.*

Trait[z]	Year	Intercept[y]	Slope	R^2	Probability
Reducing sugars (%)	2013	5.62	0.43	0.98	0.0011
	2014	4.29	0.23	0.93	0.0084
Total sugars (g/100 g)	2013	13.62	0.12	0.58	0.1358
	2014	13.89	0.22	0.86	0.0241
Sucrose (g/100 g)	2013	5.12	-0.03	0.02	0.8247
	2014	9.26	0.10	0.69	0.0812
Glucose (g/100 g)	2013	4.22	0.74	0.27	0.3729
	2014	2.14	0.07	0.86	0.0242
Fructose (g/100 g)	2013	4.28	0.76	0.33	0.3074
	2014	2.49	0.06	0.79	0.0448

[z]In each year, three fruits were sampled at the end of each of the five storage periods and their juice was bulked.

[y]The intercept is equivalent to the adjusted mean at 0 days of storage (intercept of linear regression model).

ied from 0.42 to 0.65%, fiber from 0.27 to 0.50%, and ash from 0.24 to 0.51%, while fat and carbohydrates showed less year-to-year variation.

The moisture percentage in "Selecto" fruits from Bolivia (Ardaya, 2009) (80 to 84%) was somewhat greater than in our study, possibly due to differences in moisture content at the time of harvest itself. In studies by both Ardaya (2009) and Da Fonseca (2012), protein and ash content of fruits fell into a range similar to that of our study. But the fiber percentage in fruits in Ardaya's study (2009) was somewhat higher (0.56 to 1.0%), as was the percentage of fat (0.1 to 0.5%), compared to our study.

Sensory analysis

In 2012 a sensory panel of 50 persons gave fruits at day 0 an average rating of 8.3 (8 = "like very much") on a hedonic scale of 1 to 9. In years 2013 and 2014 consumers rated fruits on a 1 to 7 hedonic scale at both day 0 and day 15 of storage for overall flavor and other traits (Table 6). There was no significant difference in ratings at 0 and at 15 days and all characteristics were rated between 5.7 (5 = "liked") and 6.4 (6 = "liked a lot").

Marsh et al. (2006) indicated that consumer fruit preferences are based on sweetness, acidity and the expectation of how a particular type of fruit should taste. We could find only one other sensory study done with a fruit similar to achachairú: Chávez-Cury et al. (2012) studied

TABLE 5.—*Proximate analysis of pulp of achachairú (*Garcinia gardneriana*) fruit harvested in 2012, 2013 and 2014 in Las Marías, Puerto Rico.*

	Percentage of total component[z]		
Component	2012	2013	2014
Moisture	77.70 a ± 2.73	78.25 a ± 1.10	77.97 a ± 0.98
Protein	0.42 b ± 0.08	0.65 a ± 0.14	0.58 a ± 0.05
Fiber	0.27 c ± 0.02	0.50 a ± 0.01	0.32 b ± 0.05
Ash	0.30 b ± 0.05	0.51 a ± 0.06	0.24 c ± 0.02
Fat	0.08 a ± 0.02	0.05 b ± 0.01	0.07 a ± 0.02
Carbohydrates	21.23	20.04	20.82

[z]Mean of nine determinations ± standard deviation. The nine determinations were made on a bulked sample of 10 fruits.

consumer acceptance of the sweet-sour fruit camururu (*G. madruno*). It was rated as "agreeable" (score of 5) to "very agreeable" (score of 6).

CONCLUSIONS

Achachairú is an exotic tropical fruit with much potential. The fruits have attractive physical and chemical traits that can make this species useful in the food industry both for fresh and processed products. As would be expected, physical traits of fruits of achachairú deteriorate over time in storage. Fruit deterioration manifests itself principally as a loss in weight, size, and firmness, all due principally to water loss over time. Most traits followed a linear (constant) progression of deterioration although the rate (slope) of deterioration varied depending on the trait. A notable exception was the case of external appearance where deterioration was curvilinear, beginning slowly and then accel-

TABLE 6.—*Average sweetness, aroma, acidity, juiciness and overall flavor of achachairú (*Garcinia gardneriana*) harvested in 2013 and 2014 in Las Marías, Puerto Rico, and stored for 0 and 15 days at 25° C and 75% relative humidity. Attributes were scored on a 1 to 7 hedonic scale where 1=dislike extremely and 7= like extremely by a panel of 16 consumers in each of two years (2013 and 2014).*

Storage period (days)	Sweetness	Aroma	Acidity	Juiciness	Overall flavor
0	6.1 a	5.7 a	5.9 a	6.1 a	6.2 a
15	6.2 a	5.7 a	6.0 a	6.0 a	6.4 a
p-value	0.5696	0.8075	0.4860	0.4937	0.2177
SE	0.12	0.18	0.16	0.13	0.11
LSD-Tukey	0.33	0.51	0.45	0.36	0.30
CV (%)	10.63	17.77	14.90	11.91	9.49

SE = standard error
LSD-Tukey = Tukey's least significant difference at the 0.05 probability level

erating, especially after 15 days of storage. In contrast, traits associated with flavor, including TSS (which is mostly sugars), TTA and the sugar-acid ratio (TSS/TTA) may improve over time. Sugar concentration increased with fruit water loss over time while the percentage of citric acid (TTA) decreased over time. This resulted in a sugar-acid ratio increase of 40% to more than 200% over the 20-day storage period. Sensory panelists rated fruits to be equally sweet, aromatic, acidic, and juicy at both 0 and 15 days of storage. Overall flavor was also rated the same at day 0 and at day 15. Panelists apparently did not notice the increase in sweetness and decrease in acidity in stored fruit that was determined by direct measurements. Other researchers (Wills et al., 1982) have noted that it is the TSS/TTA ratio, rather than the actual percentage of sugar or acidity, which often influences consumers.

Given the excessive loss in fruit weight and firmness at 20 days of storage, and considering that consumers in sensory tests in two harvest years judged 15-day-old fruit to be as good as fresh fruit and that its external appearance remains good up to 15 days of storage at ambient temperature, we recommend that achachairú fruits be stored for no longer than this time period if they are to be used for fresh fruit consumption. For processing purposes, such as in jellies, juice or ice cream, fruits could be stored for 20 days at ambient temperature or possibly longer.

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Ganancia de peso en ovinos de pelo tipo Sudán: Efecto de la granja, sexo y tipo de parto[1]

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RESUMEN

Se evaluó la ganancia diaria de peso (GDP) de ovinos de pelo tipo Sudán en crecimiento utilizando 1,090 registros tomados durante dos años en tres granjas localizadas en el trópico seco en la región del Caribe de Colombia. En cada una de las granjas se registró el tipo de parto de la oveja y el sexo de los corderos. Para determinar la GDP, los corderos se pesaron semanalmente desde el nacimiento hasta los 240 días de edad. Los datos se analizaron según un diseño estadístico completamente aleatorizado con arreglo factorial 3 (granjas) x 2 (sexo del cordero) x 3 (tipo de parto, sencillo, doble o triple). Se utilizó la prueba de Tukey para la separación de medias. La GDP fue similar entre las tres granjas evaluadas con un promedio general de 112 g. Se observó en promedio una mayor (P<0.05) GDP en hembras que en machos (115 versus 103 g) y tal como esperado, la GDP individual de corderos producto de partos sencillos (117 g) fue mayor (P<0.05) que la de corderos nacidos de partos dobles (106 g) o triples (23 g). La mayor GDP de corderas se observó en dos de las tres granjas. La GDP fue similar en machos o hembras nacidos de partos sencillos, sin embargo, en corderas nacidas de partos dobles la GDP fue mayor (P<0.05) que en corderos, y lo contrario se observó en partos triples donde la GDP fue 32 g mayor (P<0.05) en machos que en hembras. En resumen, la GDP de ovinos de pelo tipo Sudán en la región del Caribe de Colombia es buena dado su sistema de crianza extensivo. La GDP fue similar entre fincas pero difirió entre el sexo de la cría y el tipo de parto.

Palabras clave: ovino de pelo, crecimiento, trópico seco

ABSTRACT

Weight gain in Sudan hair sheep: Effect of farm, sex and type of parturition

The daily weight gain (DWG) of growing Sudan-type hair sheep was evaluated using 1,090 records taken over two years at three farms located in the dry tropics of the Colombian Caribbean region. On each farm, the type of

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birth (single or multiple) and the sex of lambs were recorded. To determine DWG, 1,090 lambs were weighed weekly from birth to 240 days of age. The data were analyzed according to a completely randomized statistical design with factorial arrangement 3 (farms) x 2 (sex of the lamb) x 3 (type of delivery, single, double or triple). The Tukey test for the separation of means was used. The DWG was similar among the three farms averaging 112 g. A higher (P <0.05) DWG was observed in females than in males (115 versus 103 g), and as expected, the individual DWG of lambs from single calving (117 g) was higher (P <0.05) than twin (106 g) or triple (23 g). The highest DWG of ewe lambs than in males was observed on two of the three farms. The DWG was similar in males and females born from single births; however, in ewe lambs born from double births, DWG was higher (P <0.05) than in males, and the opposite was observed in triple deliveries where DWG was 32 g higher (P <0.05) in males than in females. In summary, DWG of Sudan hair sheep in the Caribbean region of Colombia is good given its extensive sheep raising system. The DWG was similar among farms but differed between the sex of the lamb and the type of parturition.

Key words: hair sheep, growth, dry tropics

INTRODUCCIÓN

En Colombia, el ovino de pelo criollo es también conocido con el nombre de camuro, africana, o pelona, según las regiones donde se críe. En este tipo de ovino, se han reportado altos niveles de variabilidad genética debido principalmente a las diversas rutas de ingreso al continente americano, probablemente durante el descubrimiento y la conquista. Similar a los bovinos, el banco genético de ovinos de pelo incluye animales provenientes de la península Ibérica, otros países de Europa y las islas Canarias (Vivas-Ascue, 2013). El ovino de pelo se caracteriza por su alta fertilidad y capacidad prolífica, su baja presencia de enfermedades y su virtud de utilizar fuentes alimenticias alternas como subproductos de cosecha (Arcos et al., 2002). Se ha reportado la presencia de ovinos de pelo tipo Sudán, Etíope y Abisinio en el continente americano, mayormente en la región del Caribe (Vivas-Ascue, 2013). Los tres tipos poseen similar número de alelos, lo que indica la alta diversidad genética (Vivas-Ascue, 2013). En Colombia, están presentes los tipos Etiope y Sudán, de adaptación al medio ambiente seco tropical y que se caracterizan por su rusticidad, mansedumbre, prolificidad y excelente comportamiento. Estas características convierten a estos ovinos en una innegable alternativa para contribuir al desarrollo de las comunidades, especialmente las menos favorecidas que son las que más conocen y mantienen la especie.

Actualmente para la producción de ovinos, predominan sistemas de producción de trashumancia, nómadas, estancias, sistemas extensivos en zonas marginales, sistemas intensivos y sistemas mixtos (Herrera et al., 2010). Estos sistemas se catalogan como aquellos con media incorporación de tecnología y son considerados de economía familiar, con integraciones de actividades agrícolas y pecuarias como fuente de ingresos y que poseen un mediano nivel de adopción de tecnología, que solo les permiten incorporar algunos aspectos de manejo zootécnico, sanitario y administrativo (Castellanos et al., 2010).

En la región del Caribe de Colombia, los ovinos de pelo se críani principalmente en sistemas de producción extensivos o mixtos combinados con la ganadería bovina. Sin embargo, es poca la información documentada sobre el comportamiento productivo de ovinos de pelo tipo Sudán criado bajo estas condiciones. Es además bien conocido que el entorno o granja, el sexo del animal y el tipo o cantidad de crías por parto son factores extrínsecos o intrínsecos que influyen sobre el crecimiento de los corderos durante los períodos de lactancia y engorde (De Lucas et al., 2003). Diversos estudios han demostrado que corderos provenientes de partos simples presentan una mayor tasa de crecimiento pre y post-destete con respecto a aquellos provenientes de partos gemelares y que los machos presentan un mayor peso al nacimiento así como una mayor ganancia de peso pre y post-destete que las hembras (González-Garduño et al., 2002). Otros trabajos, sin embargo, realizados con distintas razas y bajo diferentes sistemas de producción no indican diferencias atribuidas al sexo para el peso al nacimiento de los corderos (Quintero et al., 1997) ni para el crecimiento pre-destete (González-Garduño et al., 2010). Inclusive algunos autores encontraron mayores tasas de crecimiento a los 30 y 60 días para las hembras, no existiendo diferencia en el peso al destete para los corderos de ambos sexos (Gbangboche et al., 2006).

Dada la importancia del ovino de pelo, debido a su mayor resistencia al estrés por calor, para el desarrollo del sector ovino en Colombia, el objetivo de esta investigación fue determinar el efecto de la granja, el sexo del animal y el tipo de parto de la oveja sobre la ganancia diaria de peso de corderos de pelo tipo Sudán.

MATERIALES Y MÉTODOS

Se utilizaron 1,090 datos recolectados en tres granjas con características similares de sistema de producción durante los años 2013 y 2014. Las granjas evaluadas se encuentran ubicadas en el corregimiento de Mariangola a 10° 10’ 53.3” de latitud norte y 73° 35’ 45.6” de longitud oeste, en el municipio de Valledupar en la microrregión Valle del César del departamento del César, República de Colombia, región Caribe. La zona presenta una temperatura promedio anual de 28.4° C, humedad relativa que oscila entre 56 y 74%, precipitación anual promedio de 970 mm, con distribución bimodal de los meses de mayo a junio y de agosto a noviembre y altura sobre el nivel del mar de 100 metros. Se considera una microrregión de sucesión ecológica: bosque seco tropical, sabanas (Grajales et al., 2016).

En la granja A, el área total es de 950 hectáreas dedicadas a la ganadería bovina (carne y leche) y ganadería ovino-caprina (carne). El sistema de alimentación para los ovinos es pastoreo extensivo mixto (bovinos, ovinos y caprinos), los ovinos y caprinos pastorean de manera independiente en las áreas dedicadas a la producción bovina bajo un manejo rotacional diseñado según la temporada seca y lluviosa. Las praderas están cubiertas de gramíneas introducidas (*Panicum maximum* cv. Tanzania), gramíneas arvenses, arbóreas y arbustivas nativas. En la ganadería ovina el fenotipo racial es el ovino criollo de pelo Sudán.

En la granja B, el área total es de 550 hectáreas dedicadas a la ganadería bovina de hembras y machos (carne) y ganadería ovino-caprina (carne). El sistema de alimentación para los ovinos es también el pastoreo extensivo mixto (bovinos, ovinos y caprinos), los ovinos y caprinos pastorean de manera independiente en las áreas dedicadas a la producción bovina bajo un manejo rotacional de acuerdo a la temporada seca y lluviosa. Las praderas están cubiertas de gramínea nativa (*Bothriochloa pertusa*), arvenses, arbóreas y arbustivas nativas, observándose baja oferta forrajera aparentemente por la calidad de sus suelos y menor incidencia de precipitaciones. En la ganadería ovina el fenotipo racial es el ovino criollo de pelo Sudán en un 21%, ovinos de la raza Blackbelly en un 33% y cruzamientos de hembras criollas de pelo Sudán con machos de la raza Dorper y BlackBelly en un 46%.

En la granja C, el área total es de 550 hectáreas dedicadas al cultivo de palma de aceite bajo sistema de riego por aspersión, ganadería bovina de engorde (carne) y ganadería ovina (carne). El ganado ovino pastorea los corredores del cultivo de palma para el control de arvenses, alcanzando a consumir gramíneas nativas (pastoreo conducido); y se alterna pastoreando con los bovinos (pastoreo mixto) en praderas cubiertas de gramínea introducida (*Panicum maximum* cv. Tanzania), gramíneas, arvenses, arbóreas y arbustivas nativas bajo manejo rotacional. En la ganadería ovina el fenotipo racial es el ovino criollo de pelo Sudán en un 38% y cruzamientos de hembras criollas de pelo Sudán con machos de la raza Dorper y Kathadin en un 62%.

En las tres granjas evaluadas los corderos son retenidos en el corral de manera permanente durante los primeros 10 a 15 días de nacidos, permitiendo que la oveja salga a pastoreo durante el día y regrese en el momento que desee. El manejo reproductivo se realiza en temporadas de montas y de partos (cinco grupos de animales divididos en cinco temporadas de monta durante el año), adaptado del sistema STAR (Lewis et al., 1996) sin la clasificación por lotes. La proporción machos:hembra es de 1:33 a 1:35 y el producto de venta es el cordero (hembras y machos) de 30 a 35 kilogramos de peso, con una edad entre ocho y diez meses. En los machos se realiza castración con elastrador entre los tres a siete días de vida. De igual manera en las tres granjas los ovinos son suplementados con sal mineralizada formulada según los minerales presentes en el suelo y con adición de coccidiostato, vitaminas, arcillas y jabones cálcicos, en una dosis de 10 gramos por animal por día.

En cada finca, en ambos años, se documentó la fecha de parto de cada oveja y se registró la información de los factores sexo y tipo de parto. Para la variable de ganancia de peso diario, se realizaron pesajes mensuales de los machos y hembras desde el nacimiento hasta los 240 días de edad (edad promedio en la que se alcanza el peso al sacrificio) utilizando una báscula de reloj.

Los datos de ganancia en peso se analizaron según un diseño completamente aleatorizado con arreglo factorial de tratamientos 3 (granja) x 2 (sexo del cordero) x 3 (tipo de parto) utilizando el paquete estadístico de SAS (2009). Se utilizó la prueba de Tukey para la separación de medias.

RESULTADOS Y DISCUSIÓN

Los valores promedio de ganancia diaria de peso (GDP) de los efectos principales se presentan en el Cuadro 1. La GDP fue similar entre las tres granjas evaluadas (117, 105 y 114 g/d para la granja A, B y C, respectivamente), lo que se explica por la similitud en animales, en prácticas de manejo y en condiciones climáticas entre localidades. En las tres granjas en conjunto, la GDP tuvo un promedio de 112 g, valor que se considera excelente para el crecimiento de corderos criados bajo

CUADRO 1.—*Efecto de la granja, el sexo del cordero y el tipo de parto sobre la ganancia diaria de peso (GDP) en ovinos de pelo con genotipo tipo Sudán.*

Componente		N	GDP	P
Granja	A	179	117 ± 0.46	NS
	B	340	105 ± 0.46	
	C	571	114 ± 0.54	
Sexo	Hembra	812 a[1]	115 ± 0.51	0.01
	Macho	278 b	103 ± 0.49	
Tipo parto	Sencillo	599 a	117 ± 0.51	0.01
	Doble	468 b	106 ± 0.50	
	Triple	23 c	99 ± 0.45	

[1]Medias con diferente letra en el mismo componente difieren $P<0.05$

sistemas extensivos de producción y coincide con GDP de 80 a 160 g reportados para Colombia por la Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO, por sus siglas en inglés) relacionados con nivel tecnológico medio (Garay y Correa, 2013). Se observó también una mayor ($P<0.05$) GDP en hembras que en machos (115 vs. 103 g, respectivamente), resultado que coincide o difiere de estudios anteriores que evaluaron la ganancia en peso en corderos bajo condiciones extensivas. Tal como esperado, la GDP individual de corderos producto de partos sencillos (117 g) fue mayor ($P<0.05$) que la de corderos nacidos de partos dobles (106 g) o triples (23 g).

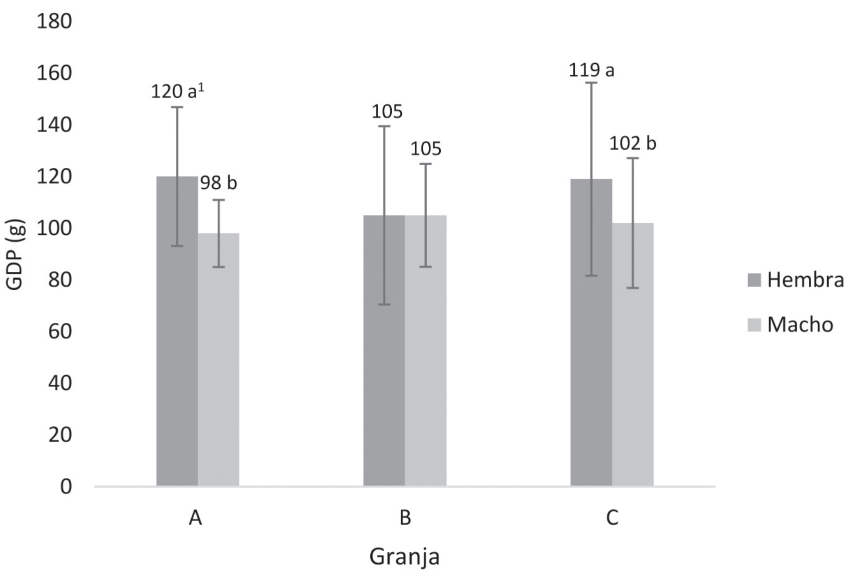
Otros estudios efectuados en ovinos criados en sistemas de producción tanto extensiva como intensiva con o sin suplementación proteica, energética o mineral reportaron valores de GDP similares a los de este experimento. En Venezuela se realizó un estudio con corderos pre-destete de la raza Africana Oeste criados en condiciones agroecológicas clasificadas como bosque tropical muy seco (Dickson et al., 2004). Los ovinos en el citado estudio se criaron bajo condiciones de pastoreo y fueron suplementados con una ración comercial de alimento concentrado con el 17% de proteína cruda a razón de 300 g/d y obtuvieron una GDP de 101 g/día, valor por debajo de los observados en este estudio. En ovinos de pelo raza Pelibuey de cuatro a ocho meses y de ocho a 12 meses de edad y alimentados en sistemas semi-intensivos con dietas con una proporción de forraje a concentrado de 40:60, se reportaron GDP de 104 y 112 g/d, respectivamente (Fonseca, 2003). En otro estudio, también con ovinos Pelibuey pero criados bajo condiciones intensivas, se observó efecto de sexo y el tipo de parto sobre la GDP de corderos (Macedo y Arredondo, 2008). En el citado estudio la GDP de corderos de partos sencillos, dobles y triples fue de 117, 106 y 99 gramos, respectivamente, resultados similares a los reportados en este estudio. Rastogi (2001) también reportó mayores GDP en corderos de la raza Black Belly nacidos de partos sencillos versus la de aquellos producto de partos dobles y triples.

El peso al nacimiento de animales de partos sencillos es mayor que en crías de partos múltiples (dobles o triples) ya que durante la gestación no tiene ninguna competencia por nutrientes y espacio en el útero de su madre (Macedo y Arredondo, 2008). Sin embargo, el peso total en conjunto de las crías favorece aquellos animales producto de partos múltiples.

En otra investigación (González-Garduño et al., 2002), los promedios de GDP de la etapa predestete y posdestete en corderos Blackbelly se encuentran dentro de los valores que se reportan en este estudio para las tres granjas. En ese estudio anterior se reportaron GDP de 88 g para hembras, 100 g para machos, 97 g para partos sencillos y 93 g para partos dobles.

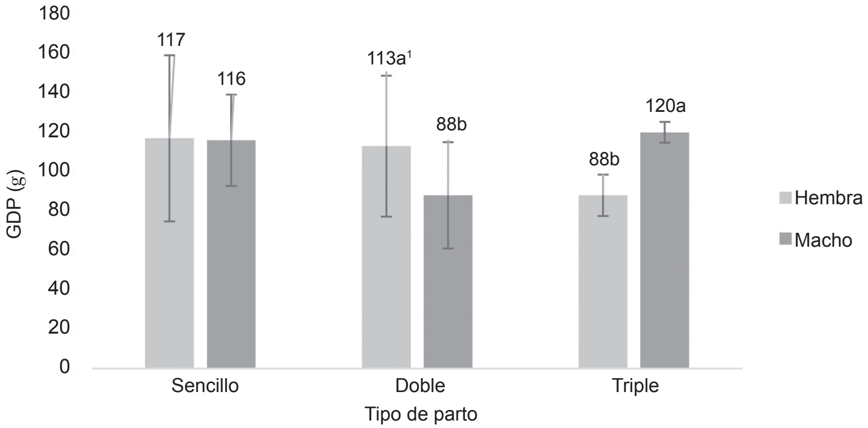
En el presente estudio, la GDP en las hembras fue mayor (P<0.05) que en los machos en dos de las tres fincas evaluadas (Figura 1). Estos resultados difieren de los reportados en ovinos Pelibuey criados en el clima cálido húmedo mexicano, donde las ganancias pre-destete en machos fue mayor que en hembras (104 vs. 90 g) (González-Garduño et al., 2010). En otro estudio con corderos de la raza Pelibuey (Hinojosa-Cuellar et al., 2012) también se observó que el peso al nacimiento y al destete y la GDP pueden estar influenciados por el sexo de la cría. En el último estudio la GDP fue mayor en hembras que en machos (200 vs. 100 g, respectivamente). En ovinos tipo West África, Persa Cabeza Negra, Blackbelly y Bergamasca, en pastoreo y suplementados eventualmente con pasto de corte, caña de azúcar y la leguminosa *Leucaena leucochephala*, se observó GDP post-destete de 104.8 g para machos y de 93.9 g para hembras.

La Figura 2 muestra los valores de GDP de la interacción sexo y tipo de parto. La GDP fue similar en animales nacidos de partos sencillos. En hembras nacidas de partos dobles la GDP fue mayor (P<0.05) que en machos, sin embargo, lo contrario se observó en partos triples, donde la GDP fue 32 g mayor (P<0.05) en machos que en hembras. Este tipo de comportamiento en GDP entre sexos como respuesta al parto podría estar relacionado a muchos factores no evaluados en este experimento, como el índice de condición corporal de las ovejas, su ali-



[1]Medias con diferente letra en la misma granja difieren P<0.05

FIGURA 1. Interacción entre la granja y el sexo sobre la GDP de ovinos de pelo tipo Sudán.

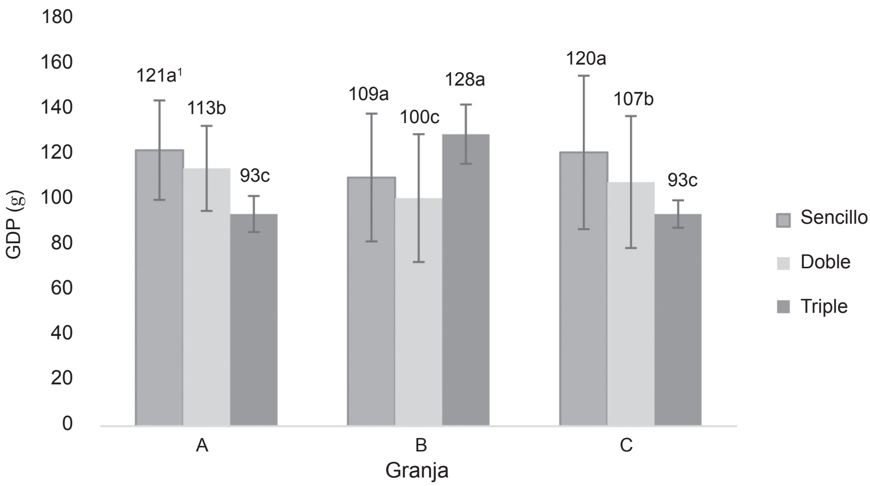


[1]Medias con diferente letra en el mismo tipo de parto difieren P<0.05

FIGURA 2. Interacción entre el tipo de parto y el sexo sobre la GDP de ovinos de pelo tipo Sudán.

mentación durante el último tercio de la gestación, su capacidad de producción de calostro y leche y su instinto materno. Estos factores han sido asociados al peso al nacer de corderos nacidos de ovejas criadas en sistemas de producción extensivos (Martin et al., 2004).

En la Figura 3 se puede observar la interacción entre granja y el tipo de parto sobre la GDP de corderos tipo Sudán. Excepto en la granja



[1]Medias con diferente letra en la misma granja difieren P<0.05

FIGURA 3. Interacción entre el tipo de parto y la granja sobre la GDP de ovinos de pelo tipo Sudán.

B, y tal como esperado, la GDP de los corderos nacidos de partos sencillos fue mayor (P<0.05) que en aquellos nacidos de partos gemelares o triples. La diferencia en ganancia en peso entre partos sencillos y múltiples fue de 8 (doble) y 28 (triple) g/d en la granja A y de 13 (doble) y 27 (triple) g/d en la granja C. Sin embargo, un comportamiento atípico se observó en la granja B, donde la GDP de animales nacidos de partos triples fue 18 g mayor (P<0.05) que en aquellos de partos dobles y 19 g mayor que en animales nacidos de partos sencillos. En estudios relacionados, Carrillo y Segura (1993) reportaron GDP de 85 gramos para partos sencillos, 74 gramos para dobles y 72 gramos para partos múltiples en ovinos de raza Blackbelly y Pelibuey en México. En general, en este experimento los valores medios de GDP encontrados corresponden a los observados por otros autores en ovinos de pelo, donde los ovinos hembras y machos producto de nacimientos múltiples tienen una GDP individual menor que la de los nacidos de partos sencillos.

CONCLUSIONES

Dado el sistema de crianza y las condiciones climáticas prevalecientes, la GDP de ovinos de pelo tipo Sudán en la región del Caribe de Colombia puede considerarse como buena (>75 g). Se observó consistencia en los resultados obtenidos entre las fincas evaluadas y se observó efecto del sexo de la cría y el tipo de parto sobre la GDP. Los resultados demuestran que este tipo de ovino representa una alternativa para sistemas de producción extensivos en regiones tropicales.

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Research Note

HAIR DIAMETER COMPARISON BETWEEN SLICK- AND WILD TYPE-HAIRED PUERTO RICAN HOLSTEIN COWS[1, 2]

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Induced by multiple anecdotes of local farmers associating a shorter hair coat with greater productivity in dairy cows, the author's group has dedicated the last four years to characterizing Puerto Rican dairy cattle according to hair coat type. Based on these efforts we have established that Puerto Rican slick-haired dairy cows (SLICK) demonstrate superior adaptation to tropical weather than their wild type-haired counterparts (WT; Castro et al., 2015; Sánchez et al., 2015; Sánchez-Rodríguez et al., 2016; Sánchez and Domenech, 2018). This thermoregulatory advantage has been associated with greater reproductive (personal communication with Rafael López, dairy farmer of Camuy, Puerto Rico) and productive performance (Contreras-Correa et al., 2016). It is known that a shorter hair coat allows for greater heat dissipation (Hansen, 2004), which may positively impact productivity in cattle. However, such superiority should be multifactorial in nature. For instance, it has also been determined that Puerto Rican SLICK cows have larger sweat glands than their WT relatives (Contreras-Correa et al., 2017; Muñiz-Cruz et al., 2018), similar to other cattle breeds highly adapted to the tropics (Hansen, 2004). In addition to a shorter hair coat, others have suggested a larger hair diameter as one of the adaptations of tropical cattle (Gaughan et al., 2009). However, such a characteristic had not been evaluated by the author's group. Another group at UPR-Mayagüez measured hair length and width (Jiménez-Cabán et al., 2015). The present study aimed to compare hair diameter values between SLICK and WT Puerto Rican Holstein cows.

Following aseptic procedures, a skin biopsy (6 mm in diameter; Integra, Miltex Standard Biopsy Punches, Plainsboro, NJ)[4] was collected immediately cranial to the right shoulder from 15 SLICK and 19 WT Puerto Rican Holstein cows injected with a local anesthesia. All cows were obtained from the lactating herd at the Agricultural Research Station in Lajas, Puerto Rico. The skin biopsies were fixed in 10% formalin in individual biopsy cassettes (Shandon Biopsy Processing/Embedding Cassettes) previously identified by cow and hair coat type. Cows were phenotypically selected and genomically confirmed for hair coat type. The fixed biopsies were individually photographed by a Canon EOS 7D Mark II camera and the Camlift V2.7.0 software. The Zerene Stacker (64-bit) software was used to compress multiple photographs of each biopsy. A measurement scale of 0.5 mm was set by Photoshop 6.0

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[2]The author acknowledges José Almodóvar (University of Puerto Rico at Mayagüez Campus, Department of Biology) for his assistance with the biopsy photographs, and Juliana Nieves, Melanie Rivera, Victoria Blas, Yaneska Sein and Carolina Luciano for taking the hair diameter measurements.

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[4]Company or trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute an endorsement by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

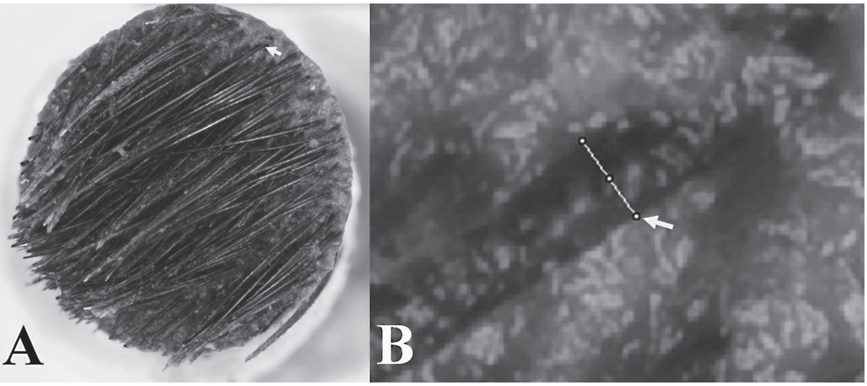

FIGURE 1. One of the skin biopsies evaluated from a slick-haired cow (A) and its magnification showing the longitudinal caliper used to measure the hair diameter (B, see arrows). Note that calipers were placed perpendicular to the hair shaft and at the base of the hair. Hairs were clipped to facilitate cleaning and disinfection during biopsies sampling.

(Adobe, San Jose, CA). Hair diameter was measured at the base of five hairs (perpendicular to the hair shaft; Figure 1) in each biopsy by the ImageJ software (v. 1.31; accessible free from http://rsbweb.nih.gov/ij/). The hairs to measure in each biopsy were randomly selected by the author, so that the same five hairs were independently evaluated by five different technicians (a total of 25 diameter values / skin biopsy were obtained). The obtained hair diameters were averaged by each skin biopsy – technician combination, resulting in a dataset containing five diameter values per cow. Normal distribution was verified by the Proc Univariate, and comparisons between hair coat types were carried out by Proc GLIMMIX, both in SAS. Hair diameter and hair coat type were included as the dependent variable and fixed effect in the model, respectively. The cow identification and technician name were considered random effects. Significant differences were established at a $P \leq 0.05$.

In this study, no differences in hair diameter were observed between SLICK and WT Puerto Rican Holstein cows (0.0858 ± 0.0014 and 0.0838 ± 0.0015 mm, respectively; P=0.6291). Respective hair diameter ranges of 0.0555 to 0.1182 mm and 0.0590 to 0.1208 mm were observed. Table 1 shows a literature review of the hair diameter values previously published by others who evaluated tropically adapted Holstein cattle from Brazil (Bertipaglia et al., 2005; Campos et al., 2005a, 2005b; Campos et al., 2009). In our study, the mean hair diameter values observed in both the SLICK and the WT cows fall within the range of those in the literature. Based on assumptions made from the literature, Campos et al. (2005a, 2005b) suggested that hair diameter should be larger in tropically adapted than in temperate cattle breeds. According to the present study, however, the Puerto Rican WT and SLICK cows had similar hair diameters, and both hair coat group values were similar to those previously published in the literature for tropical Holstein cattle, suggesting that considerable adaptation to hot weather has also been achieved by the Puerto Rican WT group. The term adaptation has been defined by Bligh and Johnson (1973) as "a change which reduces the physiological strain produced by a stressful component of the total environment" that may be "the result of genetic selection." Thus, because substantial importations of Holstein cattle to Puerto Rico began during the 1950s (Sánchez-Rodríguez, 2019) and the experimental animals were obtained from a closed herd (i.e., with no introductions of cattle for considerable time), adaptation through multiple generations of selection may be reasonably expected in both hair coat groups, probably resulting in the observed similar hair diameter values. Much like the

TABLE 1.—*Literature review of hair diameter values in tropically adapted Holstein cattle.*

Animals	n	Hair diameter, mm (mean ± standard error)	Hair diameter range, mm	Reference
Holstein cows	939	0.0625 ± 0.0056	0.0441 - 0.0977	Bertipaglia et al., 2005
Holstein cows	973	0.0608 ± 0.0005	0.0576 - 0.0643	Campos et al., 2005a
Holstein cows	449	0.0622 ± 0.0002	—	Campos et al., 2005b
Holstein heifers and cows	973	0.0620 ± 0.0001	—	Campos et al., 2009

Note. All evaluated animals were obtained from the tropical region of Brazil. Hair samples were obtained from the thorax, 20 cm below dorsal line, in the studies of Bertipaglia et al. (2005), Campos et al. (2005a) and Campos et al. (2005b); and from the flank, 20 cm below dorsal line, in the Campos et al. (2009) study.

anecdotes of Puerto Rican dairy farmers regarding the reproductive performance of their cattle, in the tropical Holstein cows evaluated by Bertipaglia et al. (2005) and Campos et al. (2005b), a shorter hair coat resulted in superior fertility; however, hair diameter was not associated with reproductive performance in these studies. The analysis of hair samples from Holstein cows imported from northern United States at the time of arrival in Puerto Rico may help to clarify this theory.

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Research Note

HORTICULTURAL EVALUATION OF 'FHIA-21' (AAAB) PLANTAIN IN PUERTO RICO[1,2]

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Control of black Sigatoka disease in plantains is imperative for adequate yield. Black Sigatoka is caused by the fungus *Pseudocercospora fijiensis* (Morelet) Deighton, formerly known as *Mycosphaerella fijiensis* Morelet. The disease does not immediately kill the plants, but by reducing the effective leaf area it interferes with photosynthesis (Churchill, 2011). If not controlled, the disease has the potential to devastate plantain fields.

In Puerto Rico, the main plantain cultivar is 'Maricongo', a false-horn clone which is susceptible to black Sigatoka. Locally, a combination of synthetic pesticides and the sanitary removal of leaves, or parts of them, are used to control the disease. As suggested by Goenaga and Irizarry (2006), the use of French-type plantain clones may result in increased yield via increased production of fruits and by the tolerance of these clones to black Sigatoka. Resistance to this disease appears to be associated with French-type parents as the source of resistance in Musaceae breeding programs (Goenaga and Irizarry, 2006).

A French-type tetraploid (AAAB) plantain cultivar, 'FHIA-21' was developed by the "Fundación Hondureña de Investigación Agrícola" (FHIA) at La Lima, Honduras. Major attributes of this cultivar are its high tolerance to black Sigatoka and higher yields than false-horn clones (Rowe, 1997; Hauser, 2010; Calvo, 2010); details for the plant characteristics of 'FHIA-21' were summarized in its patent (Rowe, 1997). However, 'FHIA-21' is susceptible to the Banana Streak Virus (Martínez et al., 2015), a virus that limits plant development and consequently reduces its yield potential

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(González-Vélez, 2014; Hausser, 2010). The Banana Streak Virus infection in Musaceae is characterized by discontinuous chlorotic areas that turn into necrotic streaks on leaves and the split of the pseudostem (Lockhart, 1995). Nonetheless, because of its high yield potential, 'FHIA-21' continues to be used for processed plantain products especially in the Dominican Republic (Garming et al., 2013). Thus, the Department of Agriculture of Puerto Rico was interested in evaluating 'FHIA-21' to increase local raw material for processed plantain products. This study was conducted to evaluate 'FHIA-21' for plant characteristics, susceptibility to important diseases, and its production potential in four agricultural zones of Puerto Rico as compared to the local cultivar 'Maricongo'.

Field trials were conducted between 2013 and 2015 at the Corozal, Gurabo, Isabela and Juana Díaz research farms of the Agricultural Experiment Station of the University of Puerto Rico. Locations differ in geographical conditions and in soil characteristics (Table 1).

Soil in the planting area was prepared conventionally (University of Puerto Rico, 1995). Planting corms were obtained from sword suckers weighing 0.45 to 1.81 kg. Prior to planting, suckers with similar weight were arranged as replicates. Each plot consisted of a bed 3.05 m wide and 10.97 m long containing six 'FHIA-21' and two 'Maricongo' plants. The plot accommodated three bunch-pruning treatments for 'FHIA-21' plants. 'Maricongo's bunches were not pruned. Thus, within the plot, two plants represented each treatment. The number of replicates varied by location as follows: Corozal, 25; Isabela, 35; Juana Díaz, 20. At Gurabo the experiment was planted three times with 30, 25 and 12 replicates.

At planting, each plant received 50 g of triple superphosphate. Each plant was individually side-dressed with 57 g of 12-5-20 fertilizer applied approximately at two, five and eight months after planting. Weeds were controlled by hoeing around the plant and the use of registered herbicides for the rest of the field. Nematodes and soil-borne insects were controlled by following current recommended practices. Drip irrigation was used. Because a major objective of this study was to evaluate 'FHIA-21' for its tolerance to black Sigatoka, no practices were carried out to control this disease.

At flowering (inflorescence apical emission) functional leaves were counted, and the height of the plant and diameter of the pseudostem were measured. The height was measured as the distance from the ground to the point where the flower emerged. The diameter of the pseudostem was measured at one meter above ground.

At six months after planting, and at flowering, plants were evaluated for susceptibility to black Sigatoka following procedures summarized by Carlier et al. (2003) and by Viljoen et al. (2017). Evaluations were made at Corozal, Gurabo and Isabela considering plantings made on similar dates. At each location, plots at the center of the field were selected, and among these plots 12 plants per cultivar were marked for sampling. For each of the 12 plants, the youngest leaf spotted (YLS) was identified, number of functional leaves and number of standing leaves (NSL) were counted, and the index of non-spotted leaves (INSL) calculated. The youngest leaf spotted is the first (youngest) leaf from the top of the plant having at least ten black Sigatoka necrotic lesions. Functional leaves were those with an erect petiole and more than 50% free of black Sigatoka lesions. The INSL refers to the proportion of standing leaves without the typical late-stage symptoms of black Sigatoka and was calculated as $INSL = (YLS - 1) / NSL \times 100$. This index provides an estimation of available photosynthetic leaf area prior to fruit filling and is an estimate of black Sigatoka tolerance for cultivated Musaceae (Viljoen et al., 2017).

Plants with symptoms associated with the Banana Streak Virus were identified and counted throughout the crop cycle. Symptoms included necrotic streaks on the

Table 1.—*Eco-geographical and soil characteristics of the locations used to evaluate 'FHIA-21' plantain.*

Location[1]	Geographical Zone	Soil Series and Soil Properties									
		Series	Family	pH	EC[2]	OM[3]	CEC[4]	P	K	Ca	Mg
					µS/cm	%	meq/ 100g	--------- mg/kg ---------			
Corozal	Eastern humid mountains	Corozal	Typic Haplohumults	5.5	147.0	2.6	1.1	3.7	25.8	177.0	12.4
Gurabo	Caguas Valley	Toa	Fluventic Hapludolls	6.5	105.6	1.7	1.8	16.2	10.8	213.4	71.6
Isabela	Northern coastal plains, subhumid section	Coto	Typic Hapludox	6.5	86.5	1.9	0.6	7.8	11.4	90.8	8.0
Juana Díaz	Alluvial southern plains (subarid)	San Antón	Cumulic Haplustolls	8.4	206.8	1.8	25.5	37.0	309.8	4393.0	212.5

[1]Research farms of the Agricultural Experiment Station of the University of Puerto Rico.
[2]Electrical Conductivity
[3]Organic Matter
[4]Cation Exchange Capacity

leaves, stunted plants, splitting of the pseudostem, cigar leaf necrosis, absence of bunch or underdeveloped (abnormally-shaped) bunch. Many of these symptoms were described by Lockhart (1995).

Yield results were from the three plantings at Gurabo. Treatments for bunch pruning were applied between the second and third week after bunch emergence. Pruning consisted in the removal of the male floral bud and the apical hands. The pruning of hands in 'FHIA-21' was done so that their bunches retained six, five and four hands. Bunches for the 'Maricongo' plants were not pruned because this cultivar has an inflorescence that disintegrates as the bunch matures. Bunches were harvested when estimated ready for market. Freshly harvested bunches were weighed and fruits counted. The number of hands of 'Maricongo' were counted. For yield, analysis of variance was carried out using a mixed model. Aleatory effects were planting and replicates within planting. Fixed effects were 'FHIA-21' with bunches pruned at six, five and four hands and unpruned 'Maricongo'. To compare the number of fruits per bunch and yield, two analyses were made. The first analysis included all plants whether or not the plant yielded or was unproductive. In this analysis yield was zero for unproductive plants. The second analysis included yield for plants that were productive and harvested. Means were compared by using the least significant difference at the 0.05 probability level.

Across locations, 'FHIA-21' consistently flowered later in the crop cycle and had more leaves at flowering than 'Maricongo' (Table 2). The latter observation is consistent with previous reports indicating that 'FHIA-21' flowers later than commercial false-horn clones (González-Vélez, 2014; Calvo, 2010). This result also indicates that the crop cycle for 'FHIA-21' is longer than that of 'Maricongo'. The INSL for 'FHIA-21' was 93 or higher, indicating that the available photosynthetic leaf area prior to fruit filling was high (Table 3). These observations confirm that 'FHIA-21' is highly tolerant to black Sigatoka. 'Maricongo' had an INSL from 91 to 73 at six months. However, this index went from 35 to 52 at flowering. Thus, results indicated 'Maricongo' was more susceptible to black Sigatoka than 'FHIA-21' (Table 3).

At all locations 'FHIA-21' plants showed symptoms associated with Banana Streak Virus (Table 4). Common symptoms were the necrotic streaks on the leaves, stunted plants, cigar leaf necrosis, splitting of the pseudostem, absence of bunch and abnormally shaped bunch. 'Maricongo' plants did not present symptoms of this virus. Percentage of 'FHIA-21' plants showing symptoms of the Banana Streak Virus and becoming unproductive varied from 54% at Corozal to 26% at one of the Gurabo plantings (Table 4). Even though our results confirmed 'FHIA-21' is highly tolerant to black Sigatoka, the relatively high percentage of unproductive plants associated with Banana Streak Virus reduces the chances this cultivar will become commercial under the current agricultural system for plantain production in Puerto Rico. Local cost for plantain production is high; thus, a high percentage of productive plants is necessary to recover investment and to generate adequate returns.

In this study, the number of hands per bunch of 'FHIA-21' plants was set to six, five and four through bunch pruning. Unpruned 'Maricongo' bunch had on average 6.8 hands (Table 5). ***Yield analysis counting all plants whether or not plants yielded or were unproductive*:** Under this analysis, 'FHIA-21' plants with their bunches pruned to six hands had more fruits and higher bunch weight than 'FHIA-21' plants pruned to four and five hands, and more than 'Maricongo' (Table 5). ***Yield analysis counting plants that were productive and harvested*:** Under this analysis, the higher the number of hands in 'FHIA-21' bunches, the higher the number of fruits (Table 5). 'FHIA-21' plants pruned to six and five hands did not differ in bunch weight, and bunches from both treatments weighed significantly more than those from 'FHIA-21' plants pruned to four hands, and also more than 'Maricongo'.

TABLE 2.—*Plant height and diameter, days to flower and leaves at flowering for 'FHIA-21' and 'Maricongo' planted at various locations.*

Location	Cultivar	Plants sampled no.	Height m	Diameter cm	Days to flowering	Leaves at flowering
					------------- no.	-------------
Corozal	FHIA-21	125	3.37	18.4	352	9.9
	Maricongo	51	3.60	17.6	295	8.7
Gurabo first planting	FHIA-21	141	3.20	18.0	258	13.7
	Maricongo	59	3.38	16.3	237	10.3
Gurabo second planting	FHIA-21	103	3.21	18.3	265	14.2
	Maricongo	46	3.30	16.3	252	10.9
Gurabo third planting	FHIA-21	50	3.03	16.5	256	13.2
	Maricongo	21	3.09	15.5	234	9.9
Isabela	FHIA-21	144	2.89	15.9	314	—*
	Maricongo	58	2.99	16.1	256	—
Juana Díaz	FHIA-21	91	3.53	19.5	290	—
	Maricongo	24	3.41	17.8	246	—

*—Missing results.

TABLE 3.—*Total and functional leaves and index of non-spotted leaves for 'FHIA-21' and 'Maricongo' plantains sampled at six months after planting and at flowering at various locations.*

		'FHIA-21' leaves			'Maricongo' leaves		
Sampling date	Location	Total	Functional	Index of non-spotted leaves	Total	Functional	Index of non-spotted leaves
		- - - - - - - - - no. - - - - - - - - -			- - - - - - - - - no. - - - - - - - - -		
Six months after planting	Gurabo	9.9	9.9	100	9.4	9.2	91
	Corozal	10.7	10.7	100	11.1	9.4	61
	Isabela	9.0	9.0	100	7.7	6.3	73
At flowering	Gurabo	12.2	12.2	100	10.3	10.1	51
	Corozal	9.8	9.6	93	7.6	6.1	52
	Isabela	6.7	6.7	97	8.4	7.3	35

TABLE 4.—*'FHIA-21' plants with Banana Streak Virus (BSV) before and after flowering and percentage of unproductive plants at various locations.*

	'FHIA-21' Plants			
	Planted	With BSV symptoms and dead before flowering	With BSV symptoms and with underdeveloped bunch	Unproductive
Location	- - - - - - - -	- - - - no. - - - -	- - - - - - - -	- - - % - - -
Corozal	150	16	65	54
Gurabo first planting	180	25	21	26
Gurabo second planting	150	28	21	33
Gurabo third planting	72	10	12	31
Isabela	210	29	—*	—
Juana Díaz	148	14	27	27

*—Missing results

TABLE 5.—*Average number of fruits per bunch and bunch weight for 'FHIA-21' and 'Maricongo' plants, counting dead and unproductive plants, and plants completing crop cycle.*[1]

Cultivar	Hands in the bunch	Counting dead and unproductive plants: Fruits	Counting dead and unproductive plants: Bunch Weight	Counting plants that completed the crop cycle: Fruits	Counting plants that completed the crop cycle: Bunch Weight
		--- no. ---	--- kg ---	--- no. ---	--- kg ---
FHIA-21	6	57.8 a[3]	15.8 a	72.1 a	19.6 a
FHIA-21	5	41.7 b	12.9 b	63.7 b	19.6 a
FHIA-21	4	35.1 b	12.5 b	51.8 c	18.3 b
Maricongo	6.8[2]	40.3 b	12.7 b	44.0 d	13.8 c

[1]These results are averages of plantings at Gurabo.
[2]Average number of hands for unpruned bunch.
[3]Within columns means followed by the same letter are not significantly different at $P < 0.005$.

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Research Note

MORPHOLOGICAL AND PHENOLOGICAL EVALUATION OF TEN AVOCADO CULTIVARS[1]

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Avocado *(Persea americana)* belongs to the family Lauraceae. It is native to the tropical and subtropical regions of North and South America and has spread to all tropical countries in the world (Schaffer et al., 2013; Ayala-Silva and Ledesma, 2014). The avocado originated in Central America and southern Mexico. Based on archaeological evidence found in Tehuacan, Puebla (Mexico), it is believed to have appeared approximately 12,000 years ago (Yahia, 2011). The avocado tree is an evergreen that attains heights of 20 m, has many branches and produces edible fruits.

Avocado cultivars are classified in three groups or races, known as the West Indian, Guatemalan and Mexican "races". Cultivars fall into one of two pollination types, referred to as type A and type B, the difference being the time of day (morning vs. afternoon) that the male and female flowers are capable of reproduction. Flowers of type A cultivars open in the morning as receptive females, then close in the afternoon until the following afternoon when they reopen for pollen shed. Type B avocado flowers open in the afternoon as receptive females, close overnight and reopen the following morning to shed pollen (Schaffer et al., 2013).

West Indian avocados originated in the tropical lowland areas of southern Mexico and Central America whereas Guatemalan and Mexican avocados originated in mid-altitude highlands in Guatemala and Mexico (Figure 1) (Ayala-Silva and Ledesma, 2014). The fruit of avocado is referred to as a berry, consisting of a single carpel and a single seed (Schaffer et al., 2013). The fruit may be round, pear shaped or oblong, and the skin of the fruit may vary in texture and color. The skin of the fruit may be flexible to woody, smooth to rough, and green-yellow, reddish-purple, purple, or black in color. The flesh of the fruit is greenish yellow to bright yellow and buttery when ripe in good varieties, but in poorer cultivars may be fibrous. The avocado fruit has one large seed that makes up to 10 to 25 percent of the fruit weight. Avocado fruits range from 150 g to more than 1.50 kg in weight.

Choice of cultivars must include many factors to determine the best available for commercial or home use. Soil type and location are quite variable and depend on the characteristics of rootstocks and disease resistance. Cultivars should be selected based on production and resistance to ailments (Knight, 1999) and climatic conditions; rootstocks (Ben-Ya'acov et al., 1992); and consumer requirements, such as minimum or maximum oil content and vitamins according to amended dry weight procedures (OECD, 2004). Further characteristics are size, color, peel roughness and shape, depending on

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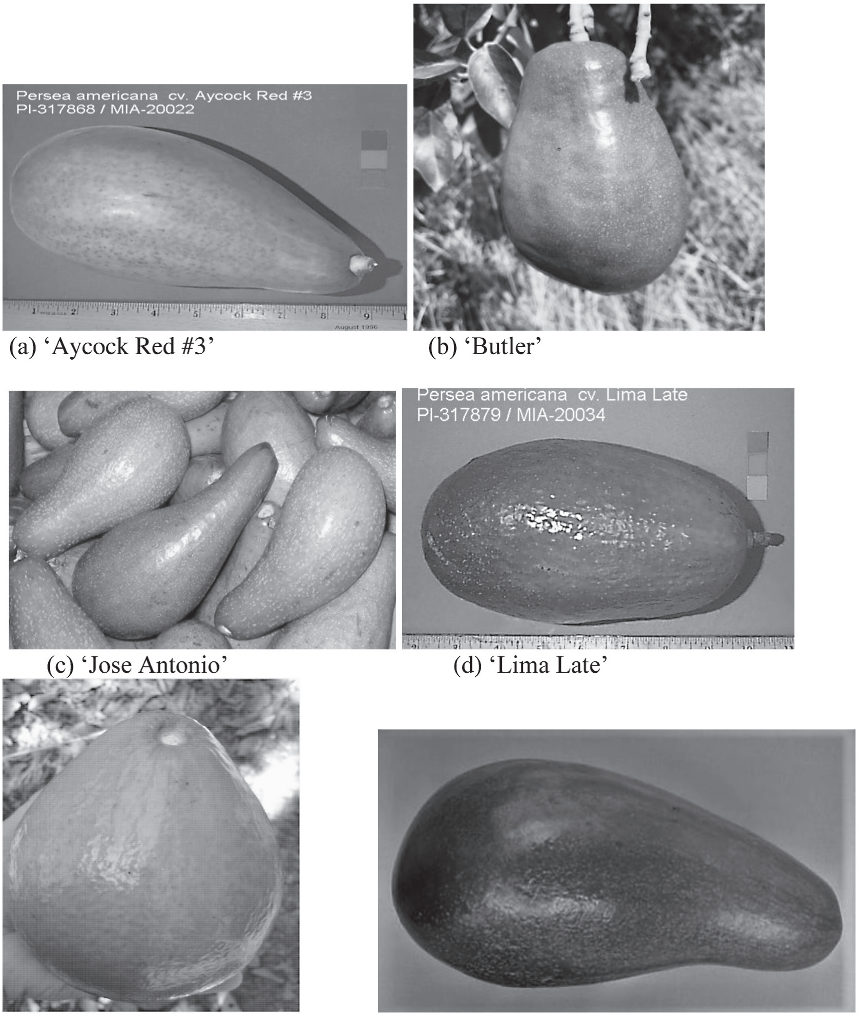
FIGURE 1. Avocado races' origin and distribution (Ayala-Silva and Ledesma, 2014).

consumer taste (Lewis et al., 1979), pulp content (Rouse and Knight, 1991) and ease of skin removal. Supplementary features could be considered when production is oriented to high pulp yield for consumption (Rouse and Knight, 1991) or for the total production of oil (Swisher, 1988).

The objective of this work was to provide agronomic and physiological information on 10 cultivars of avocado to help breeders and consumers choose cultivars based on their health (i.e., diet, high cholesterol) and to complement the agronomic data available, making information accessible in databases that would be useful to growers, consumers and researchers.

Plant materials. During the 2010-2012 avocado seasons, fifty mature fruits of each of the following avocado cultivars from trees at least 15 years old were harvested: 'Aycock Red #3' (Figure 2a), 'Belize', 'Butler' (Figure 2b), 'Donaldson','Ereguayquin #7', 'Jose Antonio' (Figure 2c), 'Lima Late' (Figure 2d), 'Marcus' (Figure 2e), 'Orizaba 3' and 'Tensen' (Figure 2f). The samples were collected from the avocado collection maintained at the National Germplasm Repository (NGR-SHRS) in Miami, Florida, whose location and characteristics have been indicated previously (Ayala-Silva et al., 2005; Ayala-Silva et al., 2013; Gordon et al., 2013). The samples were harvested and then taken to the laboratory and kept at room temperature settings until ripe. Fruits were considered ripe when the skin could be broken with a 0.8 cm width cylindrical plunger in an Instron Universal Testing Machine model 1101[6]. Ten fruits of each cultivar were measured to obtain fruit

[6]The USDA is an equal opportunity provider and employer. 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 by the U.S. Department of Agriculture or by the Agricultural Experiment Station of the University of Puerto Rico.



(a) ‘Aycock Red #3’ (b) ‘Butler’

(c) ‘Jose Antonio’ (d) ‘Lima Late’

(e) ‘Marcus’ (f) ‘Tensen’

FIGURE 2. Avocado cultivars

size, weight, color and pulp and seed yield. Ripe fruits of each cultivar were randomly selected, and analytical measurements were performed.

Analysis. A digital scale (Ohaus® Model GT8000; Florham Park, NJ) was used to measure fruit weight (whole fruit, seed and pulp). Fruit length, shape and peel characteristics including roughness, hand peeling, and color were determined. Race and flower type [A or B (Figure 3)] of the selected avocado cultivars are reported.

Color results are the average of three readings taken equidistantly at the top, middle and bottom of the fruit with a CR-400 tristimulus colorimeter (Minolta Chroma Meter CR 400, Osaka, Japan) and SpectraMatch software, set to L*, a*, b* mode using the Lab

Type A flower Type B flower

FIGURE 3. Avocado flower.

Hunter System as described earlier by Ayala-Silva and Meerow (2006); Ayala Silva et al. (2013); Gordon et al. (2013); and Ayala-Silva et al. (2016). Calibration was conducted using a white plate and these calibration factors (L*= 98.15, C*= 1.92, h°*= 93.8, a*=— 0.13, b*= 1.92).

The L*, a* and b* values obtained from each avocado fruit at the time of selection symbolize average L*, a* and b* values calculated from three distinct light beats from the colorimeter. Data was analyzed using statistical models (ANOVA and mean separation) using the Univariate procedures of PC-SAS version 9.1 (SAS Institute, Cary, N.C.).

Information on West Indian cultivars and their crosses is lacking. Thus, this may be the first time that most of these cultivars are reported in detail. Comparing data on fruit characteristics from different environments is very difficult since different factors can induce variability even in the same location and at different harvesting seasons (Salazar et al., 1971).

Most cultivars flowered from early January to May and were divided into early, middle, and late flowering groups. The flowering period of 'Lima Late' was the shortest (January to March) followed by 'Orizaba 3' and 'Marcus', which began in early January and ended in late March. While 'Aycock Red' and 'Ereguayquin #7' bloom from early January to early April. 'Lima Late' and 'Donaldson', which belong to the middle flowering group, bloom from late January to late April. The flowering period of the late flowering cultivars, which include 'Butler' and 'Jose Antonio', is from late February to mid-May. The full bloom period of the cultivars fluctuated between seven weeks and five months. Based on the flowering pattern and IPGR (1995) guidance, four cultivars revealed an A flower type, and six presented a B flower type (Table 1).

Fruit size and shape impact market value and are important physical attributes in sorting, sizing, packaging and transporting fruits (Storey et al., 1973). Seed size is very important in any fruit for consumption. Consumers prefer fruits with a small seed and large pulp content (Ayala-Silva et al., 2005).

'Jose Antonio', 'Lima Late', 'Marcus' and 'Tensen' demonstrated the highest weight, while 'Belize', 'Orizaba 3', and 'Donaldson' showed the lower weight (Table 2). Further, 'Jose Antonio' and 'Lima Late' were the cultivars with the highest pulp proportion ($p < 0.05$) in this group (Table 2); however, there was a significant difference in seed weight (Table 2) between these two cultivars. 'Jose Antonio' showed the highest weight and largest fruit length (24.10 cm), while 'Belize' showed the lowest. Their weight was superior to

TABLE 1.—*Cultivar, race, MIA/PI number, flower type and ease of skin peeling for 10 avocado cultivars from the USDA, ARS germplasm repository, Miami, FL, USA.*

Cultivar	Race[1]	MIA/PI[2] number	Flower type[3]	Skin Peeling
'Aycock Red 3'	WI	MIA 6915	B	Easy
'Belize'	WI	MIA 20023/317869	A	Easy
'Butler'	WI	MIA 35715	B	Easy
'Donalson'	WI	MIA 20024/317870	A	Semi-hard
'Ereguayquin #7'	G	MIA 34972	A	Easy
'Jose Antonio'	WI	MIA 17252/281924	B	Semi-hard
'Lima Late'	GXWI	MIA 19847	B	Easy
'Marcus'	GXW	MIA 35704	B	Semi-hard
'Orizaba 3'	G	MIA 34871/576516	A	Easy
'Tensen'	GXM	MIA 17114/234281	B	Easy

[1]WI= West Indian, G=Guatemalan, GXM= Guatemalan cross with Mexican, GXWI= Guatemalan x West Indian
[2]MIA= Miami accession number; PI=Plant Introduction number
[3]Type A or Type B flower

the values reached by cultivars from other locations, such as Venezuela (Gomez-Lopez, 2000, 2002) and Cuba. 'Belize' showed the lowest weight (Table 2). 'Tensen' and 'Lima Late' showed the largest seed content, whereas 'Donaldson' had the smallest seed (Table 2).

Following the descriptors for avocado issued by Bioversity International (IPGR, 1995), the cultivars were classified as, three obovate, two narrowly-obovate, two pyriform and three clavate shaped (Table 3). Seven cultivars had smooth texture, two were semi-rough, and one, rough. The rough texture is related to the development of extensive corky areas in the external fruit surface (Yahia, 2011) rather than the irregular surface exemplified by the 'Belize' and 'Ereguayquin #7' cultivars. 'Aycock Red', 'Tensen' and 'Orizaba 3' showed a purple peel (positive chromaticity value *a*, Table 3), which might be due to anthocyanin pigments as reported by Prabha et al. (1980); two cultivars had yellowish skin and the other cultivars were green (negative chromatic value *a*).

TABLE 2.—*Cultivars, fruit and seed weight, length and diameter, and pulp of 10 avocado cultivars at the Subtropical Horticulture Research Station at Miami, FL.*

Cultivar	Weight (g)	Length (cm)	Diameter (cm)	Pulp (g)	Seed (g)
'Aycock Red 3'	825.30 b[1]	18.80 b	9.92 b	770.40 b	55.20 f
'Belize'	610.80 e	17.67 c	9.19 b	519.20 f	91.33 c
'Butler'	747.76 c	19.30 b	8.94 b	658.00 d	90.24 c
'Donalson'	740.40 c	18.30 b	9.04 b	690.15 c	49.25 g
'Ereguayquin #7'	850.50 b	15.80 c	10.15 a	691.50 c	61.01 e
'Jose Antonio'	1,196.25 a	24.10 a	11.25 a	960.12 a	94.62 b
'Lima Late'	1,053.30 a	17.54 c	12.50 a	958.98 a	125.75 a
'Marcus'	780.55 c	16.75 c	10.85 a	715.23 b	65.23 d
'Orizaba 3'	682.21 d	11.22 d	8.657 c	630.11 e	52.10 f
'Tensen'	930.45 a	18.20 b	11.34 a	750.24 b	135.45 a

[1]Numbers within columns followed by the same letter are not significantly different ($p \leq 0.05$).

TABLE 3.—*Cultivar, shape[1], texture and color characteristics[2] of 10 avocado cultivars from the USDA, ARS germplasm repository, Miami, FL, USA.*

Cultivar	Shape	Texture	L^X	a^Y	b^Z
'Aycock Red'	Pyriform (7)	Soft	41.37 d[2]	-9.80 d	19.49 f
'Belize'	Narrowly obovate (5)	Semi-rough	37.35 e	-14.94 c	36.58 d
'Butler'	Clavate (8)	Soft	58.33 a	-10.00 d	48.71 b
'Donalson'	Clavate (8)	Soft	59.34 a	-18.99 b	52.13 a
'Ereguayquin #7'	Ovobate (6)	Soft	40.35 d	-24.96 a	41.87 c
'Jose Antonio'	Clavate (8)	Soft	54.36 b	-10.50 d	51.75 a
'Lima Late'	Ovobate (6)	Rough	42.76 c	-15.29 c	25.72 e
'Marcus'	Pyriform (7)	Soft	36.30 f	-14.86 c	40.27 c
'Orizaba 3'	Narrowly obovate (5)	Semi-rough	40.91 d	-6.95 e	12.16 g
'Tensen'	Ovobate (6)	Soft	39.92 d	-3.02 f	9.61 h

[1]Based on descriptors (IPGR, 1995)
[2]^{X}lightness/Luminosity, ^{Y}red/green chromaticity, ^{Z}yellow blue chromaticity
[3]Numbers within columns followed by the same letter are not significantly different ($p \leq 0.05$).

Most of the cultivars characterized were easy to hand peel, except 'Belize', 'Lima Late' and 'Ereguayquin #7'. 'Belize' showed a very adherent peel, and 'Lima Late' a very attached and easily torn skin. Most of the cultivars of WI origin showed an easy to peel and thin skin, yet most crossed cultivars with Guatemalan or pure Guatemalan race exhibit a tough and thick skin (Ayala Silva and Ledesma, 2014).

The highest point of fruit harvesting is the time when the greatest number of each cultivar ripen (Storey et al., 1973; Lee, 1982; Bergh et al., 1989) or meet international standards; that was three days for 'Butler'. 'Jose Antonio' and 'Marcus' ripened in three to four days, while the remaining seven ripened in four to seven days.

Selection of avocado cultivars is affected by fruit size, skin color and peel quality, weight with pulp percentages and oil content that the international market and consumers demand. For individuals with great interest in large size avocados with high pulp content, these four cultivars can be recommended: 'Jose Antonio', 'Lima Late', 'Butler' and 'Tensen'. However, if interested in the maturity period (shelf life), 'Jose Antonio' and 'Butler' should be avoided. This information should be useful in choosing among commercial cultivars, because the longer fruits take to reach their highest point of maturity, the longer their shelf life. The information provided will help individuals, researchers and growers to make the best use of these cultivars, to learn about diversity in avocados and aid stakeholders in deciding which avocado is most suitable for their needs.

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IN MEMORIAM

PAUL F. RANDEL
1937 - 2018

Wanda I. Lugo[1]*, Américo Casas-Guérnica*[2] *and Lorelei Albanese*[3]

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Paul F. Randel was born on 16 September 1937 in Long Island, New York. By the time he was 26 years old, he had completed a bachelor's and a master's degree from Rutgers University and a doctorate from Louisiana State University. His life changed in 1963 when he landed the job of researcher in Animal Nutrition in the Department of Animal Industry at the Agricultural Experiment Station of the University of Puerto Rico's Mayagüez Campus. A few years later, Randel married a young Lajeña, Crimilda Avilés Vargas, and had a daughter, Patricia Gail Randel Avilés, a veterinarian.

Excellence framed the 55 years that he dedicated to our institution. By 2013, Randel had already received a fair share of recognition. The activity "Cinco Días con Nuestra Tierra" (Five days with our land), an agricultural festival that has been organized by students of the College of Agricultural Sciences for more than forty years, was dedicated to him in 2013, as was the awards presentation of the Honor Students of the Faculty of Agriculture. In 2014, the Association of Scientists of the Agricultural Experiment Station (ACEEA, by its Spanish acronym) honored him on his long and fruitful career.

In 2015, he was named Distinguished Professor, the highest honor that the University of Puerto Rico bestows on its active professors. Randel was the second professor at the Mayagüez campus to receive the coveted title. In 1987, Dr. Juan Rivero-Quintero, a renowned zoologist, received the distinction. Rivero-Quintero was the founder of the Institute of Marine Biology, known today as the Marine Sciences Department, and the Mayagüez zoo.

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As a researcher, Randel published almost 100 articles, most of them in peer-reviewed scientific journals. His studies in animal nutrition emphasized dairy cattle but extended to the industries of poultry, goats, sheep and pigs. In the mid 60s, he began experiments using sugarcane bagasse as a source of fiber for dairy cows, which led to the establishment of a commercial venture at the Mayagüez Malecon. For eight years, the enterprise sold rations containing bagasse to farmers, Randel said in a television interview with the Mayagüez campus press upon receiving UPR's prestigious award.

Numerous students felt privileged to have had him as a teacher in Animal Science, Animal Nutrition and Dairy Cattle Management. Under his tutelage, many of them learned the formal structure of composing a thesis and conducting research in animal science with dedication, professionalism and integrity. Randel also served as both member and president of the Graduate Committee, steering a significant number of graduate students in Animal Sciences through the shoals of thesis writing.

In 1990 Randel became an accidental editor-in-chief of the journal "Archivos Latinoamericanos de Producción Animal," the official organ of the Latin American Association of Animal Production. A colleague volunteered him for the job. John Fernández Van Cleve, the Puerto Rican representative to the Latin American Association which was looking for an editor for the official publication, submitted Randel's name. Randel took three years to organize the journal, publishing its first volume in 1993. He continued to serve as editor, chalking up the 23rd volume in 2015. For almost two decades, he was also an associate editor of *The Journal of Agriculture of the University of Puerto Rico*, reviewing manuscripts on animal science. Other achievements include membership on the Committee of the United States of America for Scientific Cooperation with Vietnam, director of the Department of Animal Science of the UPR-Mayagüez Campus (2000 to 2003), interim director of the Lajas Agricultural Experiment Substation (1979 to 1981) and member of the Board of Directors of the Association of Scientists of the Agricultural Experiment Station.

Considered a "teacher of teachers" by both students and colleagues, Paul Randel was a model of professional and personal ethics. His honesty, dedication and unwavering commitment to our Institution was exemplary. He also encouraged the local agricultural industry to promote a better society. The imprint that Randel left behind will endure and will help us to continue the important academic work that he long performed with dedication.

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[1]An author's name may appear in more than one form. Although all first names are abbreviated, an author may appear with one or two initials. Last names may appear single or compound. When compound, they are hyphenated regardless of how they appear in the original. Alphabetically, names with a single initial precede two-initial ones (Badillo, Y. precedes Badillo, Y. A.); single names precede hyphenated ones (Abreu, Z., precedes Abreu-Abadía, A.). Articles under one name are organized chronologically; those in number 1 precede those in number 2 and those on page 1 precede those on page 2.

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