# Performance of sweet chili pepper (*Capsicum chinense* Jacq.) landraces in three agricultural zones of Puerto Rico[1,2]

*Linda Wessel-Beaver[3], Sonia L. Martínez-Garrastazú[4], Jose C. Rodrigues[5], Evelyn Rosa-Márquez[6], Guillermo Fornaris-Rullán[7], and Agenol González-Vélez[8]*

**J. Agric. Univ. P.R. 106(2):207-231 (2022)**

## ABSTRACT

***Capsicum chinense*** **is a small aromatic pepper native to the Amazon and widely used in the Caribbean Basin. Most types of** ***C. chinense*** **are highly pungent, but landraces in Puerto Rico generally have little or no pungency. This "sweet chili pepper" (or** ***ají dulce*****, as it is known on the Island) is an integral part of the local cuisine. Ten sweet chili pepper lines derived from non-pungent landraces were evaluated in Lajas, Juana Díaz and Corozal, Puerto Rico, in 2009. The lines represented a diversity of fruit types common on the Island. Plants in Juana Díaz grew to about twice the height of those in Lajas and Corozal. Fruit yield varied from 809 g/plant in Lajas to 1,420 g/plant in Juana Díaz. Planting density (number of plants per hectare) was greater at Corozal compared to the other two locations, resulting in a yield per hectare similar to that of Juana Díaz (10,210 kg/ha in Juana Díaz; 10,112 kg/ha in Corozal). Yield was much lower in**

[1]Manuscript submitted to Editorial Board 14 February 2022.

[2]This research was supported in part by funds from the United States Department of Agriculture, National Institute of Food and Agriculture (NIFA), Hatch Program grants PR00421 and PR00443. The authors wish to recognize Obed Román, Luisa Flores, Juan Toro, Ariel Aponte, Moisés Rodríguez and Nehyra Toro for their technical and field support.

[3]Professor Ad-Honorem, Department of Agro-environmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Mayagüez, PR. *Corresponding author. email: lindawessel.beaver@upr.edu.

[4]Associate Horticulturist (retired), Department of Agroenvironmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Agricultural Experiment Station, Lajas, PR 00667

[5]Professor, Department of Agro-environmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Agricultural Experiment Station, Río Piedras, PR 00926.

[6]Professor (retired), Department of Agro-environmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Agricultural Experiment Station, Río Piedras, PR 00926.

[7]Associate Horticulturist (retired), Department of Agro-environmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Agricultural Experiment Station, Río Piedras, PR 00926.

[8]Professor (retired), Department of Agro-environmental Sciences, College of Agricultural Sciences, University of Puerto Rico, Mayagüez Campus, Agricultural Experiment Station, Corozal, PR 00783.

**Lajas (6,400 kg/ha). Average fruit weight was greatest at Juana Díaz (12.1 g) and lowest at Corozal (10.0 g). Plant height at 11 weeks was weakly correlated (r = 0.33) with fruit yield. Plants infected by at least one of three genera of viruses, *Cucumovirus*, *Tobamovirus* and *Potyvirus*, were found at each location. Seed weight per 500 seeds averaged 2.34 g. The average fruit produced about 23 seeds. Genotype x environment (GxE) interaction (= line x location) was highly significant for height, number of fruit and fruit yield, but not for average fruit weight. Because of GxE interaction, the best performing lines varied, depending on location. The presence of GxE interaction presents challenges to a sweet chili pepper breeding program. Although it may be difficult to develop cultivars that perform equally well over diverse environments, improved cultivars with virus resistance should result in increased production. More research is needed to better understand the impact that variation in planting density has on sweet chili pepper yields.**

**Key words: ají dulce, germplasm, genotype x environment interaction, plant breeding, vegetable production, tropics, pungency**

## RESUMEN

### Comportamiento de líneas de ají dulce (*Capsicum chinense* Jacq.) en tres zonas agrícolas de Puerto Rico

***Capsicum chinense* es un pequeño pimiento aromático originario del Amazonas y muy utilizado en la Cuenca del Caribe. La mayoría de los tipos de *C. chinense* son muy picantes, pero las variedades criollas en Puerto Rico generalmente tienen poca o ninguna pungencia. Conocido como "ají dulce" en Puerto Rico, este pimiento es parte integral de la cocina local. Diez líneas de ají dulce derivadas de variedades criollas no picantes fueron evaluadas en Lajas, Juana Díaz y Corozal, Puerto Rico, en 2009. Las líneas representaron una diversidad de tipos de frutas comunes en la isla. Las plantas de Juana Díaz crecieron aproximadamente el doble que las de Lajas y Corozal. El rendimiento de frutos varió de 809 g/planta en Lajas a 1,420 g/planta en Juana Díaz. La densidad de siembra fue mayor en Corozal en comparación con las otras dos localidades, lo que resultó en un rendimiento por hectárea similar en Juana Díaz y Corozal (10,210 y 10,112 kg/ha, respectivamente). El rendimiento fue mucho menor en Lajas (6,400 kg/ha). El mayor peso promedio de la fruta se obtuvo en Juana Díaz (12.1 g) y el menor en Corozal (10.0 g). Hubo una débil correlación (r = 0.33) entre la altura de la planta a las 11 semanas y el rendimiento de frutos. Se encontraron plantas que dieron positivo a varios virus incluyendo *Cucumovirus*, *Tobamovirus* y *Potyvirus*. Las líneas obtuvieron un peso medio de semilla de 2.34 g por 500 semillas. Cada fruta produjo un promedio de aproximadamente 23 semillas. La interacción genotipo x ambiente (GxE) (= línea x localidad) fue altamente significativa para altura, número de frutos y rendimiento, pero no para el peso promedio de la fruta. Las líneas con mejor comportamiento variaron entre localidades debido a la interacción GxE. La presencia de la interacción GxE presenta desafíos para un programa de mejoramiento de ají dulce. Desarrollar cultivares que funcionen igualmente bien en diversos ambientes puede ser difícil; sin embargo, cultivares mejorados con resistencia a virus deberían resultar en una mayor producción. Se necesita más investigación para determinar qué efecto tiene la densidad de siembra en la producción de ají dulce.**

**Palabras clave: ají dulce, germoplasma, interacción genotipo x ambiente, fitomejoramiento, producción vegetal, trópicos, pungencia**

## INTRODUCTION

Among the five domesticated species of *Capsicum*, two are important to the agriculture and cuisine of Puerto Rico: *C. annuum* L. and *C. chinense* Jacq. In Puerto Rico, the most popular cultivars of *C. annuum* are cubanelle types (elongated and light green), known locally as *pimiento de cocinar* ("cooking pepper"), and to a lesser extent bell types (blocky with thick walls), known as *pimiento morrón.* Commercial cultivars are available to growers of cubanelle and bell peppers in Puerto Rico. By contrast, plantings of the small, red *C. chinense*, locally known as *ají dulce* (literally "sweet chili pepper"), consist mostly of landraces. As the local name implies, *C. chinense* grown in Puerto Rico is mild and minimally pungent. González et al. (1970) described the fruit (mistakenly identified as *C. frutescens*) as ". . . mildly pungent and hav[ing] a very rich aroma." In Puerto Rico, *ají dulce* is used as an important condiment in *sofrito*, a mixture of chopped onion, garlic, culantro (recao), coriander, and pepper (usually a combination of sweet chili pepper and cooking pepper) used to flavor several local dishes, especially the sauce added to beans (*Phaseolus vulgaris* L.).

The common names used for the many types of *Capsicum* species can be confusing because the same or similar names can be used for more than one species. In English, pepper, chili, chile, and chilli are words that have been used to refer to fruits of the various species of *Capsicum* (Bosland, 1996). The use of the word "pepper" in English to describe *Capsicum* fruit derives from the fact that Christopher Columbus confused the small, spicy red fruits he encountered in the Caribbean (likely *C. chinense*) with black pepper, *Piper nigrum* L. [Anghiera, P.M. (1493), cited in Bosland (1996)]. The use of the term "chili" or "chile" to describe pungent peppers derives from Nahuatl, the language of the Aztecs (Bosland, 1996). The Spanish name *ají* originates from *axi*, the word used by indigenous people of the Caribbean. In Spanish the word *ají* is generally associated with pungent pepper fruits, which are often (but not always) small. In U.S. English, the terms "chili" and "chili pepper" are often associated with small pungent peppers. The first author of this paper suggests the term "sweet chili pepper" as an appropriate English language name for the types of mild *C. chinense* grown in Puerto Rico, and we will use that term here. This name recognizes the fact that in English "chili" refers to pungent peppers (more or less the Spanish equivalent of *ají*), and at the same time acknowledges that certain types of *C. chinense* have a uniquely mild pungency (they are "sweet" and distinctly different from highly pungent types of *C. chinense* landraces). It is interesting to note that, except for Mexico, the Spanish-speaking Caribbean generally prefers non-pungent or mildly pungent *C. chinense*. In Venezuela there is a strong preference for non-pungent *C. chinense* and the term *ají dulce* is also used (Ohep-Gruny, 1985; Quevedo and Laurentin, 2020). In the Dominican Republic and Cuba, the terms *ají gustoso* ("flavorful chili pepper") and *ají cachucha* ("cap chili pepper", in reference to its cap-like shape) are used for non-pungent types. The term *cachucha* is also sometimes used in Puerto Rico. By contrast, the *C. chinense* varieties widely used in Mexico ("habanero" types) and in Jamaica and the islands of the Lesser Antilles ('Scotch Bonnet' and similar types) are much more pungent, often extremely so.

Orengo-Santiago et al. (1999) suggested that sweet chili pepper landraces in Puerto Rico derive from a cross between Cubanelle peppers (*C. annuum*) and an unknown pungent type of pepper; however, this is very unlikely. We propose that the non-pungent or mildly pungent landraces found in Puerto Rico and other places in the Caribbean are the result of farmers selecting for mild flavor variants among the generally pungent types of *C. chinense* found in the region. According to Antonious et al. (2009), capsaicin and dihydrocapsaicin are the principal capsaicinoids causing pungency in peppers. They evaluated 63 accessions of *C. chinense* from the USDA germplasm collection and found that the Puerto Rican accessions had the lowest levels of total capsaicinoids.

Despite its importance in local cuisine, relatively little research has been carried out on this crop in Puerto Rico. In a review of research published in *The Journal of Agriculture of the University of Puerto Rico* (JAUPR) we were able to find only three studies, González et al. (1970), Orengo et al. (1991) and Orengo-Santiago and Lui (1994), that dealt specifically with what we believe was *C. chinense*, sweet chili pepper. All three papers identify the species being studied as *C. frutescens*, but in each case the crop was apparently *C. chinense* since the Spanish language abstracts refer to "*ají dulce*". González et al. (1970) looked at methods of freeze-drying and used the term "sweet pepper". The other two studies (Orengo et al., 1991; Orengo-Santiago and Lui, 1994) dealt with weed control and refer to the crop as "sweet cherry pepper." Sweet chili pepper is briefly mentioned in the JAUPR publication of Ruiz-Giraldo and Rodríguez (1992) as being mildly susceptible to powdery mildew [*Leveillula taurica* (Lev.) Arn.], although *C. annuum* was the primary focus of their study. The article was written in Spanish and uses the term "*ají dulce*", thus making it clear that the reference was to *C. chinense.* All other research articles in the JAUPR concern *C. annuum,* along with a few references to *C. frutescens* (in those cases the cultivars mentioned are known to be *C. frutescens*). Interestingly, Frank Martin, a keen observer of vegetable production in Puerto Rico and the tropics who wrote extensively on the topic during the 1970s while working for the U.S. Department of Agriculture, does not even mention *C. chinense* in the pepper section of his series on vegetables in the tropics (Martin et al., 1979). The widely used production practices guide for Puerto Rico [*Conjunto Tecnológico para la Producción de Ají Dulce* (Orengo-Santiago et al., 1999)] indicates that sweet chili pepper is variously identified as *C. annuum* or *C. frutescens,* but then correctly suggests that the proper taxonomic classification is *C. chinense.*

The distribution of *C. chinense* in the Western Hemisphere ranges from the Caribbean through northern South America, the Amazon Basin and to Peru and Bolivia (Pickersgill, 1971). Several studies support the hypothesis of an Amazon origin for *C. chinense*. Studies of RAPD markers (Moses and Umaharan, 2012), microsatellites (Moses et al., 2014) and morphological characteristics (Banchi et al., 2020) found the highest degree of genetic diversity in the Amazon. Cytogenetic studies support an Amazon origin as well and suggest a close genetic association between *C. annuum, C. frutescens* ("Tabasco" types) and *C. chinense* (Moscone et al., 2007). No other country seems to have so many different common names for *C. chinense* as Brazil, undoubtedly a consequence of the great degree of genetic variation in that country (Baba et al., 2016; Fonseca et al., 2008). Baral and Bosland (2004) used molecular and morphological marker studies as well as compatibility tests to conclude that *C. frutescens* and *C. chinense* are separate species. The morphology of Puerto Rican sweet chili pepper landraces agrees with the description of *C. capsicum* of Baral and Bosland (2004).

The Agricultural Experiment Station of the University of Puerto Rico, Mayagüez Campus, initiated a sweet chili pepper breeding program in 2007. A challenge to this program was the lack of published data concerning the horticultural performance and characterization of landraces of this crop on the island. Thus, the purpose of our field study was to document the development and production of sweet chili pepper landrace-derived lines grown in three distinct environments in Puerto Rico, providing baseline data that can be used as a reference for future studies. In addition, the above introduction provides a literature review of sweet chili pepper with emphasis on the crop's history and use in Puerto Rico. Together, the information we present will aid both current and future vegetable researchers in better understanding this unique pepper.

## MATERIALS AND METHODS

Ten sweet chili pepper breeding lines were evaluated at three locations (Lajas, Juana Díaz and Corozal) in Puerto Rico. The lines originated from landraces collected from around the island by agronomist E. Orengo-Santiago in the 1990s. Seed from this collection was grown in Lajas in 2007 and single plant selections were self-pollinated one ($S_1$) or two ($S_2$) generations to obtain the lines used in the study (Table 1). Selection was based on good plant vigor, large fruit size, and overall productiveness. The lines were representative of the diversity of sweet chili pepper morphotypes from Puerto Rico.

Each testing location has distinct soils [from the orders Vertisol (series Fraternidad), Mollisol (series San Antón) and Oxisol (series Corozal), at Lajas, Juana Díaz and Corozal, respectively]. Two locations (Lajas and Juana Díaz) are at near sea level and close to the main vegetable growing areas, while the third location is in the central mountainous region of Puerto Rico (Corozal at 195 m above sea level).

Lines were seeded in a greenhouse in Mayagüez on 10 December 2008 (Lajas and Juana Díaz) and 16 December 2008 (Corozal) in a commercial planting mix (ProMix®; Premier Tech Horticulture, Quakertown, Pennsylvania)[9]. Seedlings were watered with a weak solution of 20-20-20 (N-P-K) every 3 to 4 d. Seedlings were kept in a greenhouse until transplanted to 7 cm diameter plastic pots in mid-January 2009 and moved outside. Eight- to nine-week-old seedlings were transplanted to the field and arranged in a randomized complete block de-

TABLE 1.—*Experimental number and generations of self-pollination of 10 lines of sweet chili pepper (*Capsicum chinense*) derived from landraces collected in Puerto Rico and evaluated in three locations during 2009.*

| Line | Experimental number | Generations of self-pollination[1] |
|---|---|---|
| 1 | E0801-4-17 | $S_2$ |
| 2 | E0801-7-11 | $S_2$ |
| 3 | E0801-7-15 | $S_2$ |
| 4 | E0801-8-14 | $S_2$ |
| 5 | E0801-8-20 | $S_2$ |
| 6 | E0801-23-10 | $S_2$ |
| 7 | E0801-B-9-1 | $S_1$ |
| 8 | E0801-B-9-2 | $S_1$ |
| 9 | E0801-B-2-3 | $S_1$ |
| 10 | E0801-B-2-2 | $S_1$ |

[1]Subscript refers to the number of generations of controlled (manual) self-pollination following the initial screening of landraces before this study.

[9]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.

sign with three replications at each location. Seedlings were planted on raised beds [1.83 m (Lajas and Juana Díaz) or 1.52 m (Corozal) center-to-center] with drip irrigation (perforations 30.5 cm apart) and silvered-coated plastic mulch, except in Corozal where no plastic mulch was used. Plots consisted of a single row of nine plants with plants spaced 0.76 m apart within rows. Dates of greenhouse planting, field operations and data collections are shown in Table 2. Plant height was measured on four occasions. Production data was collected as fruit matured; the number of harvests varied by location. Fruits were harvested from the mature green to red stage. All nine plants in a plot were included in the collection of plant height and production (weight and number of fruit) data. Average fruit weight was determined by dividing total fruit weight by total number of fruits. Samples of fruit from the first harvest in Lajas and Juana Díaz were photographed with a reference centimeter ruler (Figure 1). Morphological characteristics of each line were described (Table 3) using *Capsicum* sp. descriptors of the International Plant Germplasm Research Institute (1995). Plots were regularly observed for the presence of diseases and insects. Plants with foliar disease symptoms were sampled to identify the pathogen. Plants showing symptoms of virus (leaf curl, stunting, chlorosis, mottling) were sampled and tested with commercial enzyme-linked immunosorbent assay (ELISA) kits or immunostrips (Agdia; Elkhart, Indiana) for viruses that commonly infect peppers. To study sweet chili pepper seed production, seed was extracted from bulk samples of fully mature fruit harvested in the Lajas plots. Bulks of each line contained at least 40 random fruits. The sampled fruits and seed they produced were weighed to determine seed production (grams of seed per kilogram of fruit). Once the seed was dried, a sample of 500 seeds was weighed.

Plant height was analyzed in a combined analysis of variance over locations. Within locations, lines were treated as whole plots and weeks after planting as subplots (“split plot in time”). Yield data were analyzed as a combined analysis of variance over locations. Locations, lines, and weeks after planting were considered fixed effects. Means were compared using Fisher’s least significant difference at the 0.05 probability level. Pearson´s correlations between variables were determined using individual plot data. Spearman rank correlations between locations were calculated using line means. All analyses and figures were generated with InfoStat (Di Rienzo et al., 2019).

## RESULTS

*Phenotypic diversity.* The lines produced diverse fruit types (Table 3, Figure 1). Two of the lines (9 and 10) had very noticeable purple

TABLE 2.—*Summary of dates of seeding, transplanting and data collection in an evaluation of ten sweet chili pepper (*Capsicum chinense*) lines at three locations in Puerto Rico from 10 December 2008 to 26 August 2009.*

| | Lajas | | Juana Díaz | | Corozal | |
|---|---|---|---|---|---|---|
| Operation | Date | DAT[1] | Date | DAT | Date | DAT |
| Seeding in greenhouse | 10 December | | 10 December | | 16 December | |
| Transplanting to field | 28 January (49 DAP[2]) | | 9 February (61 DAP) | | 23 February (69 DAP) | |
| Plant height measurements | | | | | | |
| 1 | 6 March | 37 | 18 March | 37 | 27 March | 32 |
| 2 | 26 March | 57 | 7 April | 57 | 20 April | 56 |
| 3 | 16 April | 78 | 22 April | 77 | 121 May | 77 |
| 4 | 17 August | 201 | 19 August | 191 | 26 August | 184 |
| Harvests | | | | | | |
| 1 | 23 April | 85 | 30 April | 80 | 11 May | 77 |
| 2 | 5 May | 97 | 18 May | 98 | 5 June | 102 |
| 3 | 29 May | 121 | 16 July | 157 | 19 June | 116 |
| 4 | 19 June | 142 | 12 August | 184 | 26 June | 123 |
| 5 | 3 July | 156 | | | 2 July | 129 |
| 6 | 14 July | 167 | | | 10 July | 137 |
| 7 | 7 August | 191 | | | 16 July | 143 |
| 8 | | | | | 23 July | 150 |
| 9 | | | | | 31 July | 158 |

[1]DAT = days after transplanting, [2]DAP = days after planting


FIGURE 1. Photographs of 10 sweet chili pepper (*Capsicum chinense*) lines derived from landraces and evaluated in 2009 in Puerto Rico. The line number is followed by its experimental designation. Each black or white square corresponds to one centimeter.

TABLE 3.—*Phenotypic descriptions of ten landrace-derived lines of sweet chili pepper (*Capsicum chinense*) evaluated in Puerto Rico in 2009. Descriptions are based on* Capsicum *descriptors from the International Plant Germplasm Research Institute (1995).*

| | | Fruit color[1] | | Fruit shape | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Line | Anthocyanin coloring | Just before maturity | At maturity | Whole fruit | At blossom end | At pedicel end | Length to diameter ratio[2] | Lobing | Comments |
| 1 | Absent | Lt. green | Red | Triangular | Sunken | Cordate | >1 | Strong | |
| 2 | Absent | Lt. green | Red | Campanulate, some triangular | Pointed, some blunt | Truncate | >1 | None | |
| 3 | Absent | Lt. green | Red | Campanulate, some triangular | Pointed, some blunt | Truncate | 1 | None | |
| 4 | Slight on immature fruit | Some purple to Lt. green | Red | Campanulate, some triangular | Pointed, some blunt | Truncate | >1 | None | |
| 5 | Absent | Lt. green | Red | Campanulate, some triangular | Pointed, some blunt | Truncate | >1 | None | |
| 6 | Absent | Dk. green | Dk. red | Campanulate | Blunt to sunken | Cordate | <1 | Intermediate | Cap or bonnet shape |
| 7 | Absent | Lt. green | Red | Triangular | Sunken | Truncate or cordate | 1 | Strong | |
| 8 | Absent | Lt. green | Red | Triangular | Sunken | Truncate | Variable | Strong | |
| 9 | Purple stripes on stems | Purple to Lt. green | Red | Blocky | Sunken | Cordate | <1 | Intermediate | "Arroyo" type (Orengo-Santiago et al., 1999) |
| 10 | Purple stripes on stems | Purple to Lt. green | Red | Blocky | Sunken | Cordate | <1 | Intermediate | "Arroyo" type (Orengo-Santiago et al., 1999) |

[1]Lt. = light; Dk. = dark.
[2] >1 = length greater than width (elongated); 1 = approximately same length and width (round); <1 = length smaller than width (flatten).

coloring on the stems and immature fruit due to the presence of anthocyanins. The purple stem color was present from the seedling stage. The coloring of the fruit of line 6 was quite distinct: very dark green at the immature stage and dark red or scarlet at the mature stage. Line 6 also had a very distinct cap or bonnet shape. Lines 1, 7, and 8 had a triangular shape (wide near the pedicel end, then narrowing) with strong lobing. Lines 2, 3, 4, and 5 had a campanulate shape (bell shaped; narrow at the pedicel end, widening, then narrowing at blossom end) with no lobing. Line 6 also had a campanulate shape but with lobing. Lines 9 and 10 were of the "arroyo" type described by Orengo-Santiago et al. (1999). The International Plant Genetics Resources Institute (1995) describes their shape as "blocky" because they maintain the same width on the top, middle and bottom of the fruit.

*Flowering and plant height.* The rate at which height increased over time varied by location. At five weeks post-transplant, average plant heights at Juana Díaz (29.9 cm) and Lajas (28.0 cm) were not different. Plant height at Corozal (10.1 cm) was about a third of the plant height of the other two locations (Figure 2). At five weeks post-trans-

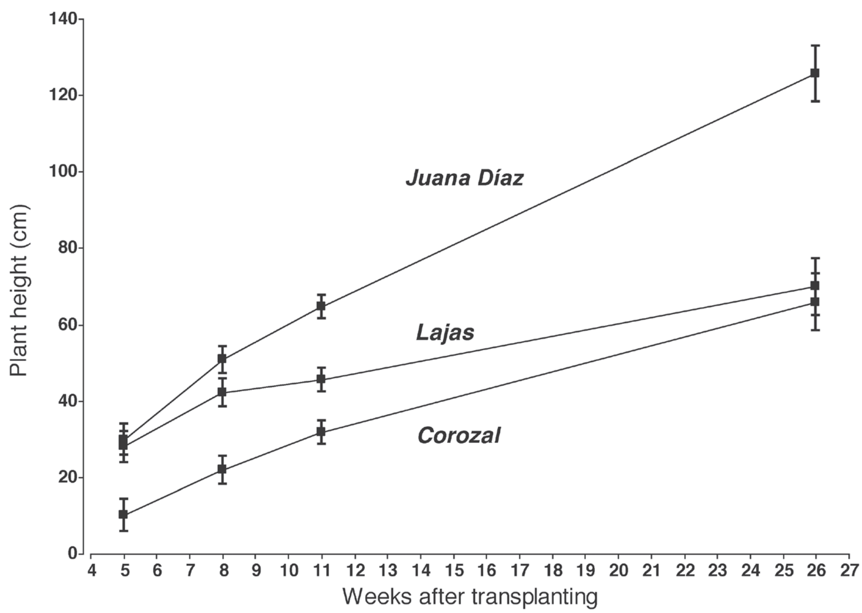


FIGURE 2. Plant height averaged over 10 lines of sweet chili pepper (*Capsicum chinense*) evaluated at 5, 8, 11 and 26 to 28 weeks after transplanting to three locations (Corozal, Juana Díaz and Lajas) in Puerto Rico during 2009. Within each date, vertical bars correspond to ±Fisher´s least significant difference (0.05 probability level) for comparisons between locations.

plant, several of the lines were beginning to flower (data not shown). Eight weeks after transplanting, all genotypes were flowering and plant height was greatest at Juana Díaz (50.8 cm), followed by Lajas (42.2 cm) and Corozal (21.9 cm). At each subsequent date of measurement, the difference between plant height at Juana Díaz and Lajas became greater than on the previous measurement date. On the final height measurement date at 26 to 28 weeks, plants at Lajas averaged just over half the height (69.9 cm) of plants at Juana Díaz (125.6 cm) and only slightly greater in height than those at Corozal (65.9 cm).

*Fruit production.* The first harvest occurred 11 to 12 weeks after transplanting. Most genotypes had sufficient fruit production to justify harvest at that time. The number of fruits per plant was about 40% greater in Juana Díaz and Corozal than in Lajas (Table 4). Plots in Juana Díaz produced the highest fruit yield on a per-plant basis, but because plants were spaced closer in Corozal (greater planting den-

TABLE 4.—*Mean number of fruits and fruit yield (weight) on a per-plant and per-hectare basis, and average fruit weight, in 10 sweet chili pepper (*Capsicum chinense*) lines evaluated at three locations in Puerto Rico during 2009.*

| | Per plant | | Per hectare[1] | | Average fruit weight |
|---|---|---|---|---|---|
| Effect | Number of fruits | Fruit yield (g) | Number of fruits | Fruit yield (kg/ha) | (g) |
| Location | | | | | |
| Lajas | 80 b[2] | 890 c | 576,024 c | 6,400 b | 11.2 b |
| Juana Díaz | 123 a | 1,420 a | 881,987 b | 10,210 a | 12.1 a |
| Corozal | 121 a | 1,168 b | 1,050,946 a | 10,112 a | 10.0 c |
| F-LSD[2] | 16.6 | 208.8 | 166,825.5 | 1,590.7 | 0.69 |
| *Line* | | | | | |
| 1 | 64 c | 631 c | 517,472 c | 5,113 c | 10.4 d |
| 2 | 131 a | 1,272 ab | 1,023,890 a | 9,853 ab | 9.9 d |
| 3 | 108 abc | 1,088 abc | 823,588 abc | 8,270 abc | 10.2 d |
| 4 | 132 a | 1,279 ab | 1,010,574 a | 9,763 ab | 9.7 de |
| 5 | 137 a | 1,343 ab | 1,069,892 a | 10,355 ab | 9.8 de |
| 6 | 114 ab | 859 bc | 883,050 abc | 6,601 bc | 7.8 e |
| 7 | 93 abc | 1,121 abc | 730,592 abc | 8,773 abc | 12.6 bc |
| 8 | 124 ab | 1,362 a | 952,787 ab | 10,404 a | 11.0 cd |
| 9 | 101 abc | 1,453 a | 771,690 abc | 11,027 a | 14.4 ab |
| 10 | 77 bc | 1,187 ab | 579,655 bc | 8,912 ab | 15.2 a |
| F-LSD[3] | 50.0 | 495.4 | 382,906 | 3,795 | 2.04 |
| C.V. | 29.8 | 27.5 | 29.4 | 27.4 | 11.9 |

[1]Data was collected on a per-plot basis. Means on a per-hectare basis have been adjusted to reflect differences in planting densities among the three locations.

[2]Within a column, means followed by the same letter are not significantly different ($P>0.05$).

[3]F-LSD = Fisher's least significant difference at the 0.05 probability level.

sity), that location produced yields on a per-hectare basis equal to that in Juana Díaz. Average fruit weight was greatest at Juana Díaz and the smallest in Corozal.

Harvests were carried out over a 106-d-, 104-d- and 81-d-period at Lajas, Juana Díaz and Corozal, respectively. At all three locations, the first harvest occurred 11 to 12 weeks after transplanting. Each location had a different harvest pattern. After a small initial harvest at Corozal, the remaining eight harvests followed a wave-like pattern of higher, then lower, then higher number of fruit and fruit yield (Figures 3 and 4). In Lajas, number of fruit and yield started low, increased in the second harvest, and then tapered off for the remaining five harvests. Only half the number of harvests was carried out in Juana Díaz compared to the other locations. Fruit production was much diminished in the third harvest, which was also much delayed due to lack of fruit. The fourth and final harvest was much greater than the previous three harvests combined.

In contrast to number of fruit and fruit yield, average fruit weight over the various harvests followed a broadly similar pattern in all three environments: the average fruit weight was initially high (about 17 g in Corozal and Juana Díaz, about 13 g in Lajas), then declined to 40% to 50% of the original weight by the final harvest (Figure 5).

*Correlations among variables.* Strong positive correlations were observed between plant heights measured at different dates although this correlation diminished over time (Table 5). Plants that were taller at 11 weeks post-transplant and beyond showed a slight tendency to produce higher yields and number of fruits. However, even the highest significant correlation (r = 0.33) was quite low, indicating that shorter plants can have high yields and taller plants can have low yields. Average fruit weight was generally not correlated with plant height, and only very weakly correlated with fruit number and yield.

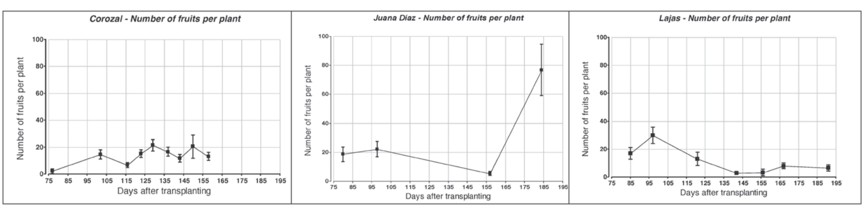


FIGURE 3. Number of fruits per plant at each harvest date of sweet chili pepper (*Capsicum chinense*) planted in Corozal, Juana Díaz and Lajas, Puerto Rico during 2009. Points are averages of 30 plots (three replications of 10 genotypes). Vertical lines extending above and below a mean correspond to 95% confidence limits.

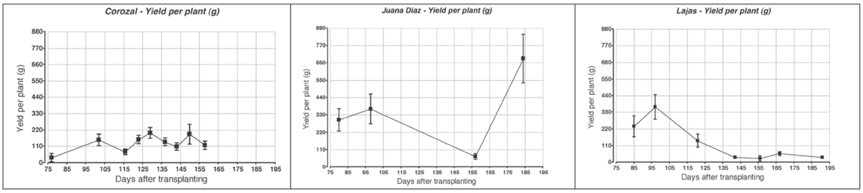


FIGURE 4. Fruit yield per plant at each harvest date of sweet chili pepper (*Capsicum chinense*) planted at Corozal, Juana Díaz and Lajas, Puerto Rico, during 2009. Points are averages of 30 plots (three replications of 10 genotypes). Vertical lines extending above and below a mean correspond to 95% confidence limits.

*Genotype x environment interaction.* Genotype x environment interaction (GxE) (corresponding to line x location interaction in this study) was highly significant for all variables except fruit weight (Table 6). Among the variable where GxE was significant, the best and worst performing lines at one location seldom corresponded to the best and worst performing lines at the other two locations (Table 7). Except for plant height and fruit weight, Spearman rank correlations among locations were not significant (data not shown). For plant height the rank correlation between Corozal and Juana Díaz was r = 0.66 ($p$ = 0.047); rank correlations between Lajas and these locations were not significant. There was no GxE interaction for average fruit weight. Lines 9 and 10 had the heaviest fruit, followed by line 7. Line 6 had very small, lightweight fruit. Rank correlations among locations for fruit weight ranged from r = 0.75 ($p$ = 0.0253) to r = 0.89 ($p$ = 0.0075).

*Disease and insect incidence.* We observed chlorosis followed by leaf drop in several plants in Lajas. *Rhizoctonia*, *Fusarium* and *Choanephora* sp. were the pathogen species identified and associated with stem and foliar symptoms. We regularly observed pepper weevil (*Anthonomous eugenii* Cano) damage at all three locations. Damage included early fruit dehiscence (fruit drop) and harvested fruit that contained larva. Seed set, especially in line 6, appeared to be reduced

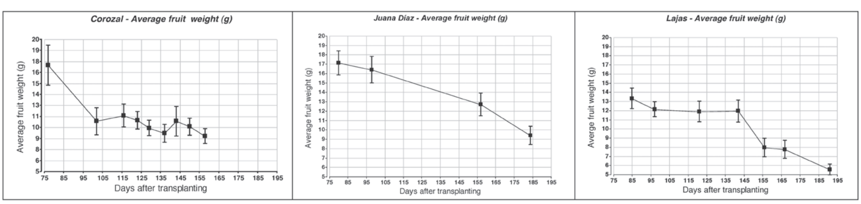


FIGURE 5. Average fruit weight at each harvest date of sweet chili pepper (*Capsicum chinense*) planted in Corozal, Juana Díaz and Lajas, Puerto Rico, during 2009. Points are averages of 30 plots (three replications of 10 genotypes). Vertical lines extending above and below a mean correspond to 95% confidence limits.

TABLE 5.—*Pearson's correlations (p-value in parenthesis) between measures of plant height (at indicated number of weeks after transplanting), number of fruits per plant, fruit yield and average fruit weight. Correlations were calculated using plot averages for 10 sweet chili pepper (*Capsicum chinense*) breeding lines at three locations (Lajas, Juana Díaz and Corozal) in Puerto Rico in 2009.*

| | Plant height 5 w | Plant height 8 w | Plant height 11 w | Plant height 26 to 28 w | Fruit (no./plant) | Yield (wt./plant) |
|---|---|---|---|---|---|---|
| Plant height at 5 w | — | | | | | |
| Plant height at 8 w | 0.94 (<0.01) | — | | | | |
| Plant height at 11 w | 0.79 (<0.01) | 0.91 (<0.01) | — | | | |
| Plant height at 26 to 28 w | 0.53 (<0.01) | 0.69 (<0.01) | 0.88 (<0.01) | — | | |
| Fruit (no./plant) | -0.08 (0.43) | 0.06 (0.59) | 0.24 (0.02) | 0.28 (0.01) | — | |
| Yield (wt./plant) | 0.08 (0.48) | 0.20 (0.06) | 0.33 (<0.01) | 0.36 (<0.01) | 0.85 (<0.01) | — |
| Average fruit wt. | 0.22 (0.03) | 0.19 (0.08) | 0.09 (0.42) | 0.12 (0.26) | -0.33 (<0.01) | 0.21 (0.04) |

TABLE 6.—*F-test probability values for sources of variation in the combined analysis of variance of 10 landraces of sweet chili pepper (*Capsicum chinense*) planted in three locations in Puerto Rico.*

| | Probability value (F-test) | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Per plant | | Per hectare | | |
| Source of variation | Degrees of freedom | Plant height | Number of fruits | Fruit wt. (yield) | Number of fruits | Fruit wt. (yield) | Average fruit wt. |
| Location | 2 | <0.0001 | 0.0012 | 0.0007 | 0.0004 | 0.0005 | 0.0011 |
| Blocks/Location | 6 | — | — | — | — | — | — |
| Line | 9 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Line x Location | 18 | 0.0002 | 0.0022 | 0.0008 | 0.0020 | 0.0012 | 0.2065 |
| Error | 54 | — | — | — | — | — | — |

TABLE 7.—*Best (ranked 1*[st] *and 2*[nd]*) and worst (ranked 9*[th] *and 10*[th]*) performing lines (in parentheses) among 10 sweet chili pepper (*Capsicum chinense*) lines evaluated in Corozal, Juana Díaz, and Lajas, Puerto Rico, in 2009.*

| | | | | Per plant | | | | Per hectare[1] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Rank | Plant height (cm) | (Line) | No. of fruits | (Line) | Fruit yield (g) | (Line) | No. of fruits | (Line) | Fruit yield (kg) | (Line) | Fruit wt. (g) | (Line) |
| *Best lines* | | | | | | | | | | | | | |
| Corozal | 1st | 83.8 | (1) | 170.3 | (5) | 1,463 | (7) | 1,474,463 | (5) | 12,664 | (7) | 13.3 | (9) |
| | 2nd | 76.3 | (5) | 166.8 | (2) | 1,449 | (2) | 1,443,588 | (2) | 12,539 | (2) | 13.1 | (10) |
| Juana Díaz | 1st | 143.4 | (6) | 181.3 | (4) | 1,943 | (5) | 1,303,567 | (4) | 13,969 | (5) | 18.1 | (10) |
| | 2nd | 132.4 | (5) | 174.4 | (5) | 1,773 | (4) | 1,253,955 | (5) | 12,462 | (4) | 14.7 | (9) |
| Lajas | 1st | 77.5 | (8) | 119.9 | (8) | 1,553 | (9) | 862,855 | (8) | 11,169 | (9) | 15.2 | (9) |
| | 2nd | 74.5 | (9) | 116.7 | (6) | 1,322 | (8) | 839,086 | (6) | 9,412 | (8) | 14.4 | (10) |
| *Worst lines* | | | | | | | | | | | | | |
| Corozal | 9th | 50.9 | (9) | 88.8 | (9) | 876 | (6) | 768,958 | (9) | 7,579 | (6) | 8.4 | (5) |
| | 10th | 45.3 | (10) | 58.9 | (10) | 769 | (10) | 509,695 | (10) | 6,658 | (10) | 6.8 | (6) |
| Juana Díaz | 9th | 114.8 | (9) | 92.8 | (7) | 823 | (6) | 667,242 | (7) | 5,919 | (6) | 9.5 | (4) |
| | 10th | 112.5 | (10) | 50.4 | (1) | 519 | (1) | 362,382 | (1) | 3,735 | (1) | 8.9 | (6) |
| Lajas | 9th | 65.8 | (10) | 54.2 | (7) | 665 | (5) | 481,258 | (5) | 4,710 | (5) | 9.8 | (5) |
| | 10th | 64.9 | (5) | 19.7 | (1) | 202 | (1) | 389,464 | (7) | 1,450 | (1) | 7.7 | (6) |
| LSD(0.05)[2] | | 11.71 | | 52.65 | | 521.6 | | 403,023 | | 3,993 | | 2.15 | |

[1]Data was collected on a per-plot basis. Means on a per-hectare basis have been adjusted to reflect differences in planting densities among the three locations.
[2]Fisher's least significant different at the 0.05 probability level.

due to damage by the pepper weevil. Virus-infected plants were found at all locations (Table 8). Typical virus symptoms observed included cupped, chlorotic, mottled and deformed leaves as well as plant stunting. *Tobacco mosaic virus* (TMV), *Tomato etch virus* (TEV) and *Potato virus Y* (PVY) were each found in plants at one or more locations. *Cucumber mosaic virus* (CMV) was present at all three locations.

*Seed production.* There were differences among lines for each of the five seed-related variables (Table 9). Lines 7 and 8 were consistently among the poorest performing in seed weight and seed yield per kilogram of fruit, per plant and per fruit. The four variables related to seed yield (per kilogram of fruit, per plant and per fruit) and number of seeds per fruit were strongly correlated (r = 0.95 to 0.99) among themselves. However, the correlation between these variables and 500-seed weight was weaker (r = <0.50).

## DISCUSSION

*Phenotypical variability.* The publication by Orengo-Santiago et al. (1999) includes photographs of four types of sweet chili pepper: flattened (*chato*), round (*redondo*), star-like (*arroyo*) and trumpet-like (*trompo*). The *Capsicum* descriptors of IPGRI, the International Plant Genetics Resources Institute (1995), define fruit shape in a much more complex way by considering overall shape (elongate, almost round, triangular, campanulate, or blocky), followed by fruit shape at both the

TABLE 8.—*Results of virus testing on Capsicum chinense samples collected from Lajas, Juana Díaz and Corozal, Puerto Rico, in 2007 and 2008.*

| Virus | Lajas | Juana Díaz | Corozal |
|---|---|---|---|
| Testing conducted with immunostrips | | | |
| *Cucumber mosaic virus* (CMV) | + | No test | No test |
| *Tobacco mosaic virus* (TMV) | + | No test | No test |
| *Impatiens necrotic spot virus* (INSV) | — | No test | No test |
| *Tomato spotted wilt virus* (TSWV) | — | No test | No test |
| *Potato virus Y* (PVY) | — | No test | No test |
| Testing conducted with ELISA | | | |
| CMV | No test | + | + |
| TSWV | No test | — | — |
| PVY | No test | + | + |
| *Pepper mottle virus* (PepMoV) | No test | — | — |
| *Tobacco etch virus* (TEV) | No test | — | + |
| Potyvirus (general test) | No test | — | + |

+ at least one sample was positive for indicated virus.
- all samples were negative for indicated virus.

TABLE 9.—*Weight of 500 seeds, seed yield per kilogram of fruit, per plant, and per individual fruit, and number of seeds per fruit in nine lines of sweet chili pepper,* Capsicum chinense*, produced in Lajas, Puerto Rico, in 2009.*

| Line | 500 seed weight (g) | Seed yield per kilogram of fruit (g) | Seed yield per plant (g)[1] | Seed yield per fruit (g)[2] | Number of seeds per fruit[3] |
|---|---|---|---|---|---|
| 2 | 2.36 a[4] | 11.5 abc | 7.3 bc | 0.113 ab | 23.94 ab |
| 3 | 2.29 ab | 18.2 ab | 23.1 ab | 0.177 a | 38.65 a |
| 4 | 2.35 a | 9.9 abc | 10.8 abc | 0.100 ab | 21.28 ab |
| 5 | 2.54 a | 11.0 abc | 14.1 abc | 0.107 ab | 21.06 ab |
| 6 | 2.42 a | 20.5 a | 27.5 a | 0.201 a | 41.53 a |
| 7 | 2.00 b | 4.2 c | 3.6 c | 0.032 b | 8.00 b |
| 8 | 2.23 ab | 1.7 c | 1.9 c | 0.020 b | 4.48 b |
| 9 | 2.49 a | 9.6 abc | 13.1 abc | 0.105 ab | 21.08 ab |
| 10 | 2.38 a | 8.0 bc | 11.6 abc | 0.115 ab | 24.16 ab |
| Mean ± SD | 2.34 ± 0.16 | 10.51 ± 5.97 | 12.55 ± 8.40 | 0.108 ± 0.058 | 22.69 ± 12.08 |

[1]Estimated using fruit yield per plant from Table 4.
[2]Estimated using fruit number per plant from Table 4.
[3]Estimated using weight of 500 seeds and seed yield per fruit.
[4]Twice the SD was used as the basis for comparisons among lines. Within a column, values followed by the same letter are considered not different. The probability of error cannot be determined for comparisons since a single sample of approximately 40 fruits was taken from each line.

pedicel and blossom end, and finally defining the degree of corrugation (lobing). Those descriptors were used to describe our 10 lines (Table 3). At the time of publication of Orengo-Santiago et al. (1999), the flattened (*chato*) type was the most common in Puerto Rico. Line 6 was similar to the *chato* type. IPGRI considers that shape to be campanulate (bell-like) since fruit width increases and then diminishes from the top to the bottom of the fruit. Lines 9 and 10 had the star-like (*arroyo*) shape of Orengo-Santiago (1999), considered “blocky” according to IPRGI (fruit width remaining the same from top to bottom). Their shape evokes that of a tiny lobed pumpkin. Lines 9 and 10, and other untested lines with the *arroyo* shape not included in this study, consistently had much thicker fruit walls than other lines. Lines 9 and 10 were also notable for the presence of anthocyanins, a purple pigment, in the stems and fruits. Lines 1, 7, and 8 were triangular, with fruit wider at the pedicel end, then narrowing at the blossom end. These correspond to the trumpet-like (*trompo*) shape of Orengo-Santiago et al. (1999). Orengo-Santiago et al. (1999) does not mention a bell-like type of sweet chili pepper like we observed in lines 2, 3, 4, and 5. While bell-shaped fruit was predominant in these lines, as much as a quarter of the fruit produced had an almost round shape. A mix of shapes was often observed on the same plant.

*Plant height.* Plant height, measured about 11 weeks post-transplanting, had a high correlation with height observed at other dates, as well as significant, although low correlations with yield and number of fruits (Table 5). Therefore, an early measurement of plant height (around 11 weeks post-transplant) is as informative as later plant height measurements when evaluating sweet chili pepper in a breeding program, especially when selection is carried out before yield data is obtained. Large fruit size is a desirable characteristic that can be observed from the first harvests. While plants with larger fruit have a slight tendency to produce fewer fruits per plant (r = -0.33), they also tend to produce somewhat greater yield/plant (r = 0.21). Early selection for fruit size in a breeding program may improve yield.

*Fruit production.* Orengo-Santiago et al. (1999) indicated that typical sweet chili pepper yields in Puerto Rico are from 8,405 to 11,207 kg/ha (75 to 100 cwt/acre). Some of the individual lines tested in our study had considerably higher yields, up to almost 14,000 kg/ha (Table 7). Release of those lines could improve sweet chili pepper production in Puerto Rico. Planting density appears to have an important impact on sweet chili pepper yields on a land-area basis. Orengo-Santiago et al. (1999) recommended planting sweet chili pepper at a density of about 17,290 plants per hectare (7,000 plants per acre). Planting densities for *C. chinense* vary immensely around the Caribbean: 7,143 to 35,000 plants per hectare for sweet chili pepper in Venezuela (Hernández, no year; Ohep-Gruny, 1985), 7,410 to 12,350 plants per hectare for hot peppers in Jamaica (McGlashan, no year), 4,940 to 9,570 plants per hectare for hot peppers in the southern Caribbean (Adams et al., 2001; Sinha and Petersen, 2011), and 16,667 to 27,778 plants per hectare for habanero peppers in the Yucatán Peninsula of Mexico (Aviles-Baeza, 2021; Latournerie-Moreno et al., 2015). Our study used 7,194 plants per hectare in Lajas and Juana Díaz and 8,657 plants per hectare in Corozal. Although Orengo-Santiago et al. (1999) recommended a double row of plants on a single bank when using 1.83 m between-row spacing, our previous experience led us to use a single row at all locations. Therefore, our planting density was on the low end of the range of typical planting densities for *C. chinense.*

On a per-plant basis, there was no difference between Juana Díaz and Corozal in number of fruits per plant (Table 4). However, considering the greater planting density in Corozal, that location produced a significantly greater number of fruits on a per-hectare basis compared to Juana Díaz. Nonetheless, Juana Díaz had a higher yield than Corozal on a per-plant basis, but there was no difference between those locations for yield per hectare. The greater planting density at Corozal may have been the reason for the smaller average fruit weight at that location compared to the other two locations. Yield per plant in *C. chinense* has been demonstrated to be influenced by planting density, which in turn is influenced by the planting configuration (within- and between-row distance). Estimates of yield per plant vary greatly from 404 g/plant (O'Keefe and Palada, 2002) on St. Croix, USVI, to 2,200 g/plant (Ohep-Gruny, 1985) in Venezuela. In a Delaware, USA, greenhouse study of 'Scotch Bonnet' in containers, Bartz (2017) observed yields of up to 9,589 g/plant.

O'Keefe and Palada (2002) varied within-row planting distance of hot peppers from 0.41 to 0.61 m and observed higher yields with greater plant spacing. Adams et al. (2001) noted that hot peppers in Barbados grew taller and wider, had more branches and produced more fruit when given more space. They tested planting densities from 5,744 to 40,000 plants per hectare and observed increases in yield up to a density of 30,000 plants per hectare. Increasing density beyond 30,000 plants per hectare resulted in a decrease in yield per plant and average fruit weight, although the effect on fruit weight was small. Sinha and Petersen (2011) indicated that yields of hot pepper up to 45,000 kg/ha might be possible.

Plants from most lines in our study developed to the extent that no gaps existed between plants within rows, but sufficient space was available between rows to allow easy harvest. The planting density used in the study was adequate, but further research into planting density and configurations is needed. Fewer plants would reduce the cost of seed, production of transplants and transplanting.

Fruit size (as measured by average fruit weight) affects the relationship between number of fruits and fruit yield per plant or per hectare. Average fruit weight among lines in our study was highly variable, from 7.7 g in line 6 in Lajas to 18.1 g in line 10 in Juana Díaz (Table 7). Jarret and Berke (2008) evaluated 330 accessions of *C. chinense* from the germplasm collection of the USDA. Fruit size ranged from 0.18 g to 22.7 g with a mean of 6.31 g. Bharath et al. (2013) studied 264 Caribbean and Latin American accessions of *C. chinense* and observed a range of fruit weights from 0.2 g to 14.5 g, with a mean of 5.68 g. In a sweet chili pepper breeding program, lines with an average fruit weight >10 g would be the most desirable.

*GxE interaction*. We observed strong GxE interaction in our study, except for average fruit weight (Table 6). Latournerie-Moreno et al. (2015), studying habanero-type *C. chinense* in the Yucatán of Mexico, also observed very strong GxE except for fruit weight. GxE interaction is due to one or both of the following: (1) rankings of genotypes vary among environments and (2) the magnitude of differences among genotypes within an environment varies from one environment to the next. In our study, the general lack of significant rank correlations among locations indicate that the GxE interaction was primarily due to differences in the ranking of lines at each location and not simply due to the magnitude of differences among lines at each location. This type of GxE interaction is challenging since a line might perform among the best at one location, but among the worst at another. Except for fruit size [where the line x location interaction was not significant (Table 6)], the best two lines at one location were seldom among the best two lines at other locations (Table 7). Line 5 was particularly unstable: it appeared among both the best and worst lines for several traits, depending on the location. Line 10 was among the two lines with the heaviest fruits at all locations, but consistently had poor yields. Both lines could reasonably be eliminated from future evaluation.

*Disease and arthopod pests:* The three fungal species isolated from sweet chili pepper plants, *Rhizoctonia*, *Fusarium* and *Choanephora*, are all known to infect *Capsicum* sp. Rhizoctonia root rot has been present in sweet chili pepper fields on the island for many decades. Alvarez-García (1946) concluded that *Rhizoctonia solani* was the principal pathogen causing severe losses in Puerto Rico due to damping off or collar rot in seedlings of *ají dulce* (wrongly identified as *C. frutescens*). He also commented that, in his experience, *Phomopsis*, *Phytophthora* and *Pythium* were also occasionally causing similar symptoms. In our study, damping off in greenhouse seedlings was a problem. In the 1980s, powdery mildew (*Leveillula taurica* (Lev.) Arn.) became a problem in pepper production, including *ají dulce,* in Puerto Rico, particularly in young plants during the dry, cool months of January to April (Ruiz-Giraldo and Rodríguez, 1992). However, we did not observe this disease in our study.

Pepper weevil, *Anthonomous eugenii* Cano (Coleoptera: Curculionidae), was first observed in peppers in Puerto Rico in 1982 (Abreu and Cruz, 1985). Pepper weevil was present at all three locations and caused considerable fruit drop, decreasing yields.

Across the three locations, we encountered plants that tested positive for CMV, *Cucumovirus*, TMV, a *Tobamovirus*, and two closely related *Potyvirus*, PVY and TEV (Table 8). Viral diseases have been documented in Puerto Rico for nearly a century. In a survey conducted in 1927, Cook (1929) reported a pepper mosaic virus affecting peppers in Puerto Rico. Roque and Adsuar (1941) studied in greater depth what was possibly the same virus reported by Cook in 1929. They named the virus *Puerto Rico pepper mosaic virus* (PRPMV) and determined it was the most critical limitation on pepper production on the island. Their work focused on bell peppers (*C. annuum*) which they mistakenly identified as *C. frutescens.* Roque and Adsuar (1941) noted that by the early 1940s, CMV and TMV were widespread in pepper fields in Puerto Rico. Pérez and Adsuar (1955) established that there was an antigenic relationship between PRPMV and a strain of PVY. In the 1960s Adsuar (1964) noted that PRPMV was still the most limiting factor in sweet chili pepper production on the island. He recognized *Solanum nigrum* L. (black nightshade) as a symptomless host of the virus and recommended that it be eliminated from areas near plantings of sweet chili pepper. *Capsicum annuum* grown on the island was also affected by PRPMV but resistant varieties were developed, 'PR Wonder' bell pepper being one example. Adsuar et al. (1971) commented that, at the time of their work, a new type of virus was attacking peppers resistant to PRPMV. They named this new disease "virus producing local necrotic lesions on tobacco" or VPLLT. The new disease produced localized necrotic lesions on tobacco, *Nicotiana glutinosa* and *Datura stramonium*, different from lesions produced by PRPMV. It was also serologically unrelated to PRPMV. At the time (early 1970s), Adsuar et al. (1971) also commented that PRPMV, TMV and TEV were known to affect peppers in Puerto Rico. Pérez et al. (1974) surveyed symptomatic pepper plants at 57 locations around the island during 1971-72 and found that 82% of the samples were infected with PRPMV. TEV and TMV were also present but much less common. Arroyo-Negrón (1981) observed TEV and PVX in fields of cooking pepper in the municipalities of Santa Isabel and Isabela, respectively, in the late 1980s. PVX is closely related to PVY. In surveys conducted between 1980 and 1990 on the south coast, Escudero (1996) found pepper samples positive for PVY, TEV and TMV.

Viruses have limited *C. chinense* production in other parts of the Caribbean. In Jamaica, yields of 'Scotch Bonnet' hot pepper diminished over time due to the presence of viruses (Evans and Keil, 2009). Fields surveyed in Jamaica in 2008 and 2009 were infected with CMV, TEV, PVY, *Potato virus x* (PVX), and *Pepper mild mottle virus*. Vectors such as the aphids *Myzus persicae* and *Aphis gossypiae*, whiteflies (*Bemisia argentifolii*), and broad mite (*Polyphagotarsonemus latus*) were present in the fields. These same vectors are present in fields in Puerto Rico. Myers et al. (1998) observed up to a 50% reduction in yield in hot peppers infected with TEV. Control of insect vectors is not an effective means of controlling pepper viruses. There are no virus resistant cultivars of *C. chinense*. Currently, good sanitation practices and the use of virus-free seed are the best methods of reducing the effect of viruses.

*Seed production.* Seed characteristics of *C. chinense* have been little studied. Quevedo and Laurentin (2020) measured seed yield in three Venezuelan cultivars of sweet chili pepper and observed that all had >50 seeds per fruit. By contrast, all lines in our study had, on average, fewer than 50 seeds per fruit. The IPGRI (International Plant Genetics Resources Institute, 1995) classifies seed yield in *Capsicum* sp. into three categories: <20 seeds per fruit, 20 to 50 seeds per fruit, and >50 seeds per fruit. With the exceptions of lines 7 and 8, the lines in our study fall into the intermediate category. Fruit from lines 7 and 8 often had few or no fully formed seeds. An ideal sweet chili pepper cultivar should have good production of high-quality seed.

## CONCLUSIONS

In summary, sweet chili pepper plants grown at Juana Díaz grew considerably larger than those planted at the other two locations. These plants produced high yields of large-size fruits. Plants at Lajas also produced large fruits, but yield was considerably less than that of Juana Díaz. Plants in Corozal produced the smallest fruit but yield per hectare was not much different from that of Juana Díaz. The higher planting density at Corozal likely contributed to the high yields at that location. Over approximately six months, a grower in Puerto Rico can expect to produce between 6,500 to 10,000 kg/ha of sweet chili pepper assuming around 7,500 plants per hectare, a typical planting density used in Puerto Rico. Greater planting densities may result in better yields. The presence of a high degree of GxE interaction for fruit production made it impossible to identify a line that consistently performed well in all locations. This will present a challenge in a breeding program for sweet chili pepper. The presence of diseases, especially viral diseases, may be limiting sweet chili pepper production. Virus resistance would be an important goal for a breeding program. Practices such as using improved cultivars, higher planting densities, and better cultural methods may result in higher yields of sweet chili pepper.

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