

Early yield of five cacao families at three locations in Puerto Rico^{1,2}

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ABSTRACT

Five families of *Theobroma cacao* L. between three and eleven years of age were evaluated for yield at Gurabo, Corozal and Yabucoa. Parents involved in the combination of the families were such well-known clones as 'Pound-7', 'Scavina (SCA)-6', 'Scavina-12', and IMC, EET and UF selections which have been widely used to produce controlled-pollinated seed in Central America and elsewhere. Eight months after transplant, the temporary shade provided by plantains was removed, and the trees were grown under full sunlight and intensive management. Between 1986 and 1993 individual tree yield data were obtained. In September 1989, hurricane Hugo destroyed the Yabucoa experiment but the evaluation continued at Gurabo and Corozal until December 1993. At the termination of the first four-year evaluation period (1986 to 1989), families EET-400 × SCA-12 and SCA-6 × EET-62 were significantly superior yielders at Gurabo with an average total production of 5,538 kg/ha of dry beans. None of the families maintained superiority at Corozal and Yabucoa. The average total yield for all families was 5,950 and 5,225 kg/ha at Corozal and Yabucoa, respectively. The individual tree yield data showed that regardless of location only 2 or 3% of the trees within a family were high yielders and accounted for more than 60% of the total family production. At the termination of the eight-year evaluation period (1986-1993), families EET-400 × SCA-12 and SCA-6 × EET-62 maintained their superior yielding ability at Gurabo, with an average total production of 14,368 kg/ha. All families performed similarly at Corozal with an average total production of 14,930 kg/ha.

Keywords: cacao, genotype, location, *Theobroma cacao*.

RESUMEN

Rendimiento temprano de cinco familias de cacao en tres localidades de Puerto Rico

Se evaluó el rendimiento de cinco familias de *Theobroma cacao*, L., de entre tres y once años de edad, en Gurabo, Corozal y Yabucoa. Los padres representados en estas familias fueron los clones 'Pound-7', 'Scavina-6',

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'Scavina-12' y las selecciones IMC, EET y UF, todos extensamente utilizados en la producción de semilla bi-clonal en Centro América y otros lugares. A partir de ocho meses después del trasplante se removió la sombra temporal de plátanos y los árboles crecieron a pleno sol con manejo intensivo en parcelas replicadas. Entre el 1986 y 1993 se recopilieron datos del número de mazorcas y del peso seco de las almendras por árbol. En septiembre de 1989, el huracán Hugo destruyó el experimento de Yabucoa pero la evaluación continuó en Gurabo y Corozal hasta diciembre de 1993. A la terminación de los primeros cuatro años de evaluación (1986-1989) las familias EET-400 × SCA-12 y SCA-6 × EET-62 tuvieron una producción significativamente mayor en Gurabo, con un rendimiento total por familia de 5,538 kg/ha de almendras secas. Ninguna de las familias mantuvo superioridad en las localidades de Corozal y Yabucoa. El rendimiento medio para todas las familias fue de 5,950 y 5,225 kg/ha en Corozal y Yabucoa, respectivamente. Los datos de rendimiento recopilados por árbol demostraron que irrespectivo de la localidad, solamente el 2 o 3% de los árboles en cada familia eran altos productores y fueron responsables del 80% o más del rendimiento total de las familias. A la terminación del período de evaluación de ocho años (1986-1993) las familias EET-400 × SCA-12 y SCA-6 × EET-62 mantuvieron su alto potencial de producción en Gurabo con un rendimiento total por familia de 14,368 kg/ha. Todas las familias se comportaron más o menos igual en Corozal, con un rendimiento medio de 14,930 kg/ha.

INTRODUCTION

Puerto Rico does not produce cacao on a commercial scale but possesses the soils and climate, and the availability of local and export markets that justify the agronomic evaluation of the crop. There are about 240,000 hectares of upland Ultisols and Oxisols, and 10,000 hectares of Inceptisols in the east-central humid valleys (Vicente-Chandler, 1985) either idle or underutilized that may be used for cacao production.

Local consumption of semi-processed cacao and confectionery chocolate is about 15,450 metric tons per annum with a value of \$34 million (PR Planning Board, 1988). In addition, Puerto Rico has unlimited access to the U.S. market that yearly imports about 1.7 million metric tons of dry beans (U.S. Department of Agriculture, 1993).

Local cacao cultivation began in 1636; however, adverse weather conditions and the appearance of a disease of unknown etiology prevented further development of the crop (Bermejo-Garcia, 1970). Limited cacao research was conducted by the Federal Experiment Station in Mayagüez between 1903 and 1940. These activities were confined to the introduction and selection of superior clones, basic fermentation and drying studies, black pod disease rating, and the recording of individual tree yield data (U.S. Department of Agriculture, 1903-1940). Later research was expanded to include the establishment of the cacao germplasm collection (Fisher et al., 1967). Concurrently with these activities, a second attempt was made to establish commer-

cial orchards, but the newly established plantations succumbed to pests.

The availability of controlled-pollinated seed during the late 1970s provided another incentive to investigate the possibility of growing cacao on a commercial scale in Puerto Rico. In addition to being the easiest and cheapest form of planting material, controlled-pollinated seed combine pest and disease resistance from distant parental clones (Enríquez y Soria, 1984; Enríquez y Paredes, 1985), and have the capacity to yield three to four times more than ordinary open-pollinated seed (Esquivel y Soria, 1967). This paper reports on the yield performance of five cacao families grown at three locations in Puerto Rico.

MATERIALS AND METHODS

Three experiments were established 12 August 1982 through 31 December 1993. Four-month-old seedlings of families UF-668 × Pound-7, IMC-67 × UF-613, EET-400 × SCA-12, SCA-6 × EET-62 and IMC-67 × SCA-12 were planted at Corozal and Gurabo substations and on a private farm in the municipality of Yabucoa. The controlled-pollinated seed was introduced from the CATIE (Costa Rica) Cacao Improvement Program. The resultant seedlings were expected to contain superior combining ability for higher yield and resistance to pests and diseases.

Five treatments (families) were arranged in a randomized complete block design with six replications at Yabucoa and eight replications at Corozal and Gurabo. Each plot contained twelve experimental trees, spaced 3.05 by 3.05 m, about 1,075 trees per hectare.

The Corozal substation is located in the north-central upland region at an elevation of about 200 m. Throughout the experiment, the mean annual rainfall was 1,840 mm, with pan evaporation of 1,410 mm. Average annual minimum and maximum temperatures were 19.2 and 30.0°C, respectively. The soil, a Corozal clay, an Ultisol (clayey, mixed, isohyperthermic Aquic Haplohumults), contained 2 mg/kg of "available" P (Bray method 2), and had an exchangeable cation capacity of 10.9 cmol (+)/kg of soil. Before planting, the soil was plowed to a 25-cm depth and limestone was incorporated at the rate of 5.6 t/ha to raise the pH to about 5.3. Yearly broadcast liming applications were made at the rate of 3.4 t/ha after the trees began full production.

The Gurabo substation is located in the east-central interior valley at an elevation of 50 m. During the course of the experiment the mean annual rainfall was 1,700 mm and pan evaporation 1,678 mm. Average annual minimum and maximum temperatures were 20.2 and 31.6°C, respectively. The soil, a Mabí clay, an Inceptisol (fine, montmorillonitic,

isohyperthermic Vertic Eutropepts), pH 6.5, contained 5 mg/kg of P, and had an exchangeable cation capacity of 33.5 cmol (+)/kg of soil.

The Yabucoa experiment was established in the Playita suburb at about sea level. Throughout the experiment, mean annual rainfall was 2,274 mm and pan evaporation 1,796 mm. Average annual minimum and maximum temperatures were 21.4 and 30.2°C, respectively. The soil is a Talante sandy clay loam, an Entisol (coarse-loamy over sandy or sandy-skeletal, mixed, acid, isohyperthermic Aeric Tropic Fluvaquents). The soil, pH 4.6, contained 40 mg/kg of P, and had a low exchangeable cation capacity of only 3.8 cmol(+)/kg of soil. At all sites, evaporation exceeded rainfall during the months of January, February, March, June and July.

The four-month-old seedlings were field transplanted under the partial shade of six-month-old plantains, spaced at 3.05 by 3.05 m. The plantains were removed after the first-crop harvest, about 14 months after planting.

During the first two and a half years, each tree received a total of 2.1 kg of a 10-5-20-3 (N, P₂O₅, K₂O, MgO) fertilizer supplemented with a minor element mixture at the rate of 25.4 kg/t of fertilizer. Once the trees began full production in 1986, the fertilizer rate was increased to 1.8 kg/year until 1989. Thereafter the rate was increased to 2.7 kg/tree/year. The total amount was divided into equal applications at three-month intervals.

Every four months the tree trunk was drenched with a solution of Oxamyl (Vidate-L)⁴ at the rate of 10 ml/3.8 L of water to control *Phyllophaga* sp., so far the most tenacious cacao insect in Puerto Rico. This control measure was supplemented with applications of Aldicarb (Temik 10-G) at the rate of 28 g/tree every six months.

Weed growth was suppressed with a rotary mower and spot applications of either paraquat (Gramoxone) or glyphosate (Round-up), both at the rate of 1% v/v. The trees were pruned to control vertical growth and to facilitate cultural practices.

Between 1986 and 1989, ripened pods were harvested from 1,320 trees. In September 1989, hurricane Hugo severely damaged the Yabucoa experiment, which was terminated three months later. The harvest from 960 trees continued at the Gurabo and Corozal experiments until December 1993. Therefore, data are presented for four years (1986-1989) at three locations, and for an additional four years at only two locations. The pods were opened and the wet beans extracted, fermented,

⁴Trade names in this publication are used only to provide specific information. Mention of a trade name does not constitute a warranty of materials by the USDA/ARS or the AES/UPR, nor is this mention a statement of preference over other materials.

TABLE 1.—*Total yield of five cacao families grown under full sunlight at three locations in Puerto Rico during a four-year evaluation period, 1986-1989.*

Family	Location and bean dry weight		
	Gurabo	Corozal	Yabucoa
	----- kg/ha -----		
EET-400 × SCA-12	5,770.4 a ¹	6,427.0 a	5,103.6 a
SCA-6 × EET-62	5,306.6 a	5,959.3 a	4,965.7 a
UF-668 × Pound-7	5,140.2 ab	6,151.2 a	5,537.6 a
IMC-67 × SCA-12	4,015.3 bc	5,574.4 a	5,291.0 a
IMC-67 × UF-613	3,682.6 c	5,638.3 a	5,227.7 a

¹Means within a column followed by the same letter do not differ significantly at the 0.05 probability level.

and sundried to about 7% moisture content. Since number of pods and bean dry weight are the most important traits that determine yield in cacao (Soria, 1966), data on both attributes were collected. The pod index (number of pods needed to produce 1 kg of dry beans) was determined, and both bean dry weight and pod index were submitted to an analysis of variance. Treatment means were compared by using Duncan's test of significance.

RESULTS AND DISCUSSION

The first meaningful cacao production was obtained in 1986, when the trees were about three and a half years old from seed. At this age, about 97% of the trees were in production at all locations.

TABLE 2.—*Mean pod index values obtained in five cacao families grown under full sunlight at three locations in Puerto Rico during a four-year evaluation period, 1986-1989.*

Family	Location		
	Gurabo	Corozal	Yabucoa
IMC-67 × SCA-12	72.1 a ¹	71.6 a	73.2 a
IMC-67 × UF-613	65.5 ab	66.2 ab	67.0 a
UF-668 × Pound-7	60.8 bc	62.2 bc	59.8 b
EET-400 × SCA-12	54.6 c	56.5 c	55.9 b
SCA-6 × EET-62	37.4 d	39.7 d	37.5 c

¹Means within a column followed by the same letter do not differ significantly at the 0.05 probability level.

There was no significant interaction between families and locations for bean dry weight and pod index (data not shown). However, the comparison among families within locations demonstrated that at the termination of the first four-year evaluation period, families EET-400 \times SCA-12 and SCA-6 \times EET-62 were significantly superior yielders at Gurabo, with an average total production of 5,538 kg/ha of dry beans (Table 1). There was no significant difference among families at Corozal and Yabucoa. The average total yield for all families was 5,940 kg/ha at Corozal and 5,225 kg/ha at Yabucoa.

Families EET-400 \times SCA-12 and SCA-6 \times EET-62, the highest yielders at Gurabo, also had a significantly lower pod index at all locations (Table 2). Likewise, the families that had the greatest pod index, IMC-

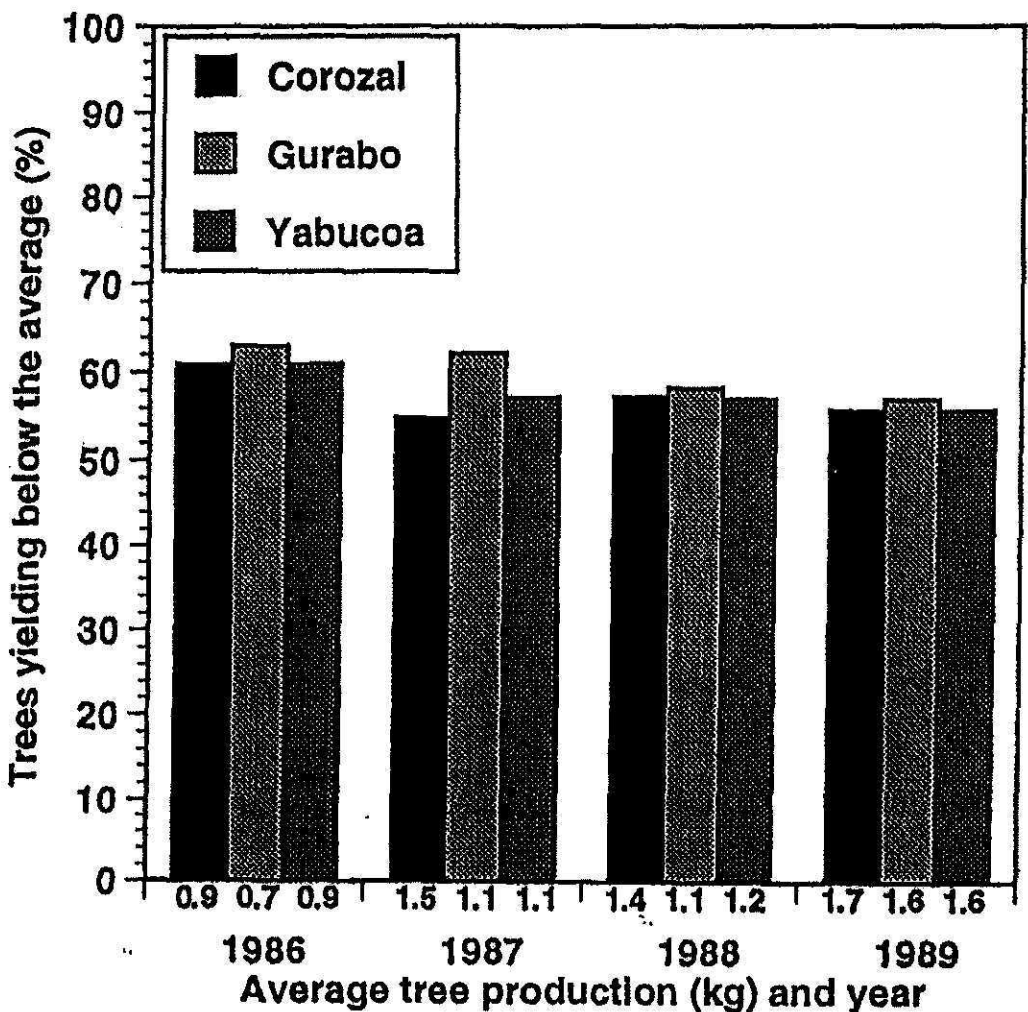


FIGURE 1. Percentage of low yielding trees recorded in five cacao families at three locations in Puerto Rico during a four-year evaluation period, 1986-1989.

67 × SCA-12 and IMC-67 × UF-613, also yielded significantly less at Gurabo. Since pod index is an indirect measurement of pod size (Soria, 1966), the largest individual pods were produced in the high yielding families. This finding may indicate that pod index rather than the number of pods is a more reliable criterion to determine yield in cacao. However, the significantly lower pod index detected in families EET-400 × SCA-12 and SCA-6 × EET-62 at Corozal and Yabucoa did not result in a significant increase in yield at these locations (Table 1).

The individual tree yield data obtained during the first four years of evaluation demonstrated that differences among trees within families were greater at all locations and fairly consistent from year to year (data not shown). In general, only 2 or 3% of high yielding trees within a family consistently accounted for more than 60% of the total family yield. This led to the selection of high yielding trees and the establishment of a clone-grafted evaluation experiment that is currently in progress. During the first full-production year (1986), about 61.7% of all trees at all locations yielded below the average (Figure 1). At the termination of the fourth full-production year (1989), about 56.2% of all trees in the five families and three locations continued yielding below the average of 1.6 kg of dry beans per tree. These results demonstrated that the high yielding ability attributed to controlled-pollinated seed in cacao is confined to only a few superior trees. Other investigators (Batista, 1981; Esquivel and Soria, 1967) have reported that in cacao families, only 8 to 14% of the population is composed of high yielding trees.

At the termination of the eight-year evaluation period, families EET-400 × SCA-12 and SCA-6 × EET-62 maintained their superior yielding ability at Gurabo, with an average total production of 14,368 kg/ha of dry beans (Table 3). This yield was significantly higher, about

TABLE 3.—*Total yield of five cacao families grown under full sunlight at two locations in Puerto Rico during an eight-year evaluation period, 1986-1993.*

Family	Location and bean dry weight	
	Gurabo	Corozal
	----- kg/ha -----	
SCA-6 × EET-62	14,375.4 a ¹	15,304.6 a
EET-400 × SCA-12	14,361.1 a	16,767.7 a
UF-668 × Pound-7	11,881.9 ab	15,124.5 a
IMC-67 × SCA-12	9,541.5 b	13,760.8 a
IMC-67 × UF-613	9,457.3 b	13,690.9 a

¹Means within a column followed by the same letter do not differ significantly at 0.05 probability level.

TABLE 4.—*Mean pod index values obtained in five cacao families grown under full sunlight at two locations in Puerto Rico during an eight-year evaluation period, 1986-1993.*

Family	Location	
	Gurabo	Corozal
IMC-67 × SCA-12	48.1 a ¹	52.7 a
IMC-67 × UF-613	46.2 ab	49.0 b
UF-668 × Pound-7	44.6 bc	48.0 bc
EET-400 × SCA-12	42.9 c	45.1 c
SCA-6 × EET-62	29.5 d	32.2 d

¹Means within a column followed by the same letter do not differ significantly at 0.05 probability level.

34% higher, than the production obtained from families IMC-67 × SCA-12 and IMC-67 × UF-613. All families performed similarly with an average total production of 14,930 kg/ha at Corozal (Table 3).

Throughout the duration of the experiments, families EET-400 × SCA-12 and SCA-6 × EET-62 also maintained a significantly lower pod index at Gurabo and Corozal (Table 4). However, only at Gurabo lower pod index resulted in a significant increase in yield (Table 3). At the termination of the last four-year evaluation period (1990-1993), all families at Gurabo and Corozal averaged about 60% more dry bean production and 25% reduction in pod index than in the first four years (1986-1989).

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