Trinidad selected hybrids: An investigation of the phenotypic and agro-economic traits of 20 selected cacao cultivars

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A recurrent breeding programme was very successfully conducted over a period of 60 years by the Ministry of Food Production, Land and Marine Affairs (MFPLMA) Trinidad and Tobago, and has resulted in the production of the Trinidad Selected Hybrid (TSH) varieties. The aims were to obtain Ceratocystis wilt (CR) and Witches' Broom (WB) resistance, large bean size and low pod index (PI) while maintaining the traditional fine or flavour bean quality. The parental types used were ICS 1 (for large bean size), SCA 6 (for Witches Broom (WB) resistance), POUND 18 (strong vigour, CR) and IMC 67 (CR, high yielding). Other types used, to a lesser extent, were ICS 95 and POUND 7. The objectives of this study were to facilitate the identification of 20 selected TSH varieties in the field and to examine the phenotypic diversity among them. In addition, evaluation of their commercial and breeding value, in terms of yield potential, compared to the parental types was undertaken.

Morphological characterization of the TSH varieties was based on 23 fruit and 12 flower traits. Traits observed for the 5 parents included 9 based on fruits and 7 on flowers. The coefficient of variation of the quantitative flower and fruit traits of the TSH varieties ranged from 6.9% to 11.5% and 5.4 % to 16.6%, respectively. The characteristics of economic interest, *viz.* bean number, cotyledon weight and Pod Index (PI) ranged from 42.2 ± 2.42 to 61.4 ± 2.89; 0.74g ± 0.02 to 1.49g ± 0.06 and 12.0 ± 0.67 to 26.1 ± 0.7, respectively. The varieties with the best yield potential were TSH 730, 1095, 1102, 1104, and 1362. TSH 1102 was outstanding with the largest number of beans and ovules. A large improvement in bean traits and PI has been observed in the TSH progeny.

Principal Components Analysis revealed a clear separation of the parental types from the progeny that was also found using Cluster Analysis. Wet bean weight, PI, pod width, number of beans and cotyledon weight contributed significantly to the separation of the varieties in the first plane of the Principal Component plot.

Keywords: Cacao, *Theobroma cacao*, Trinidad selected hybrids, phenotypic traits, principal component analysis, cluster analysis

The indigenous variety of cacao in Trinidad and Tobago is Trinitario – a *hybrid of Criollo and Forastero* (Cheesman 1944). Criollo and Trinitario beans are collectively known as "fine or flavour" cocoa, which has a high demand among manufacturers of fine chocolates and commands premium prices on the world market. The reputation of Trinidad and Tobago as a producer of 100% fine or flavour is well known (ICCO 2006) with its premium Trinitario origin beans widely sought by niche chocolate producers. The flavour attributes of these beans are linked to genetic factors, which are expressed in the Trinidad Selected Hybrids (TSH) now widely grown on commercial estates in Trinidad and Tobago (Abdul-Karimu et al. 2003).

The breeding programme that produced the TSH cacao varieties is considered one of the most successful in the world. It involved uninterrupted cycles of hybridization and recurrent selections conducted over 60 years (Kennedy et al. 1987), and still continue today. Initial goals were aimed at Ceratocystis (CR) and Witches' Broom (WB) disease resistance, large bean size, early bearing, low pod index (PI) and maintenance of the traditional fine or flavour status of Trinidad

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and Tobago cocoa. Low PI values are associated with high yield potential.

For breeding purposes, a PI of less than 15 is very desirable (Pound 1932).

The late W. E. Freeman spent over 30 years (1949 – 1984) of this period guiding the breeding programme of the Ministry of Food Production, Trinidad and Tobago by developing further on the foundation established by Dr. F.J. Pound, who collected the famous Imperial College Selections in Trinidad and Tobago in 1931-1935 (Johnson et al. 2004; 2009) and Upper Amazon populations from Peru and Ecuador between 1937-1942. The latter were established at Marper Farm, East Trinidad in 1938.

The parental types used in the TSH breeding programme were ICS 1 (selected for large bean size and low PI), SCA 6 (WB resistance), POUND 18 (low PI, precocious, vigorous and with CR resistance), IMC 67 (CR resistance, low PI, large number of beans per pod). Other types used were ICS 95 (very adaptable and high yielding), POUND 7 and some PA clones.

The large number of progenies and candidate clones being screened in the TSH breeding programme necessitated the use of a unique nomenclature system. Each Trinidad clone bore certain letters as a prefix (TS-Trinidad Selections, TSA-Trinidad Selected Amazon and TSH) followed by a number, which runs consecutively from 500 upwards. In this breeding programme, the following groups of accessions were selected: Twenty-three TS accessions from the existing Trinitario cacao population or from new populations made by crossing two clones of the TS group; 227 TSA accessions from populations which are entirely Amazon in their parentage and 615 TSH accessions from populations, which are a mixture of Amazon and Trinitario and inclusive of open-pollinated populations from both TSA and TSH clones. All introductions (upper Amazon cultivars and ICS collections) were referred to by their original name (Shripat 1993).

Commercial TSH clones were filtered out of this programme at strategic periods and gave rise to the TSH series of early selections (TSH 728, 730, 919, 973, 1076 and 1095), later selections (TSH 1102, 1104 1188 and 1220) and newer selections (TSH 1313,1315, 1330, 1344, 1347, 1350, 1352, 1362, 1364 and 1380). The current TSH clones have potential yield of well over 2 tonnes per ha and are quite versatile as commercial candidates (Mooleedhar and Lauckner 1990; Shripat and Bekele 1996 and Maharaj et al. 2005).

W.E Freeman conducted several multi-location trials for the evaluation and assessment of the TSHs, which produced significant field agronomic data for the utilization of these varieties. Most of this work has remained unpublished. To date, several of these varieties form the basis of commercial production, and continuous breeding efforts to improve these types are being undertaken. There is, however, no formal study or documentation to guide the use of these varieties for future breeding and full commercial exploitation.

Morphological characterisation studies are well known in their applicability to derive economic and breeding gains from germplasm collections and families of related accessions (Bekele et al. 2006; Brown et al. 1989; Hawkes 1983; Iwaro et al. 2003) The current study attempts to investigate the phenotypic diversity and economic value of 20 selected TSH clones, of which nine are commercial, using morphological cacao descriptors (Anon. 1981).

The objectives of this study are:

1. To facilitate identification of existing and future commercial clonal TSH cultivars in the field;
2. To examine the phenotypic diversity among these types;
3. To evaluate the commercial value in terms of yield potential of these types;
4. To assess the relative improvement of these selected progenies as compared to the parental types and to identify candidate types for use in further breeding work in particular for yield potential.

Table 1: List of descriptors (35) used for morphological characterization - their states and sample sizes (n)

Flower descriptors (12)
Flower, sepal colour (anthocyanin intensity on ligule) Where 0=absent, 3=slight, 5=intermediate, 7=intense [n=10].
Flower, sepal length (mm) [n=10].
Flower, sepal width (mm) [n=10].
Flower, ligule colour (anthocyanin intensity on ligule) Where 0=absent, 3=slight, 5=intermediate, 7=intense [n=10].
Flower, ligule width (mm) [n=10].
Flower, filament colour Where 0=absent, 3=slight, 5=intermediate, 7=intense [n=10].
Flower, staminode length (mm) [n=10].
Flower, style length (mm) [n=10].
Flower, ovary pigmentation (apex and base) Where 0=absent, 3=slight, 5=intermediate, 7=intense [n=10].
Flower, ovule number [n=10].
Flower, pedicel (anthocyanin intensity in column) Where 1=green, 2=reddish, 3=red [n=10].
Flower, pedicel length [n=10].
Fruit characters (23)
Fruit, shape Where 1=oblong and narrow, 2=elliptic, 3=obovate, 4=oblate, 5=other [n=10].
Fruit, basal constriction Where 0=absent, 1=slight, 2=intermediate, 3=strong [n=10].
Fruit, apex form Where 1=attenuate, 2=acute, 3=obtuse, 4=rounded, 5=mammilate, 6=indented [n=10].
Fruit, surface texture (rugosity) Where 0=absence, 3=slight, 5=intermediate, 7=intense [n=10].
Fruit, mature ridge colour (anthocyanin intensity) Where 0=absent, 3=slight, 5=intermediate, 7=intense [n=10].
Fruit, ridge pair disposition Where 1=equidistant, 2=paired [n=10].
Fruit, primary ridge separation Where 1=slight, 2=intermediate, 3=wide [n=10].
Fruit, ridge prominence Where 1=slight, 2=intermediate, 3=pronounced [n=10].
Fruit, weight (g)
Fruit, length (cm) [n=10].
Fruit, width (cm) [n=10].
Fruit, pod wall thickness (mm) [n=10].
Bean, number [n=20].
Bean, total wet bean weight (including mucilage) [n=20]
Bean, total wet bean weight (excluding mucilage) [n=20]
Bean, shape Where 1=oblong 2=elliptic 3=ovate [n=40]
Bean, cotyledon colour Where 1=white, 2=grey, 3=light purple, 4=medium purple, 5=dark purple, 6=mottled [n=40].
Cotyledon length (cm) [n=20].
Cotyledon width (cm) [n=20].
Cotyledon thickness (cm) [n=20].
Cotyledon weight (g) [n=20]
Bean, total dried bean weight (including testa) [n=20]
Pod index (number of pods required 1 kg of dried cocoa without testa)

Materials and methods

The morphological characterization of the 20 cultivars (TSH 730, 919, 973, 1076, 1095, 1102, 1104, 1188, 1220, 1313, 1315, 1330, 1344, 1347, 1350, 1352, 1356, 1362, 1364 and 1380) under study was based on 23 fruit and 12 flower traits. The characterization used morphological descriptors according to the standard protocol described by Bekele et al. (1992; 1994; 2006) and Bekele and Butler (2000). These descriptors were selected based on the findings of Bekele et al. (1994), Bekele and Bekele (1995 a and b; 1996), Bekele and Butler (2000) and Bekele (1991 a and b) and are listed in Tables 1 and 2. They were found to be the most discriminative and taxonomically useful and precluded redundancy (Bekele et al. 1994). In addition, they were also selected for ease of observation, reliability of scoring, and, in the case of seed characters, agronomic/economic value (Bekele et al. 1999). Traits for the five parents used in the TSH breeding programme (ICS 1, IMC 67, POUND 18, SCA 6 and ICS 95) included nine for fruits and seven for flowers.

Data was collected over the period 2002 to 2007 using 5 to 6 year-old clonal trees from the La Reunion Estate, Trinidad. The mother trees are planted at a density of 1679 trees per ha. Trees of *Erythrina* spp. planted 8 m apart provide shade. The soil type is Cunupia clay loam with restricted internal drainage. The mean annual

rainfall in this region is approximately 2400mm and the average temperature is 26°C. The plants are irrigated as necessary during the dry season (January – June) each year.

Data were collected during the same season for each group of descriptors. This allowed for the effects of season and time of collection on the expression of descriptors. Flower data were collected throughout the rainy season (July to December), and fruit data during the main and light harvest periods, which occur during the dry season.

In the field, ten open flowers were collected from at least four trees where possible. Disease-free flowers with pearl-coloured thecae were randomly collected from the trunk and branches and measured. The number of ovules per ovary was counted according to the method prescribed by Lucas and Reffye (1981). Ten healthy, mature, ripe pods were randomly harvested from as many trees as possible for each accession to be observed and measured.

Statistical Analysis

Descriptive statistics and principal component analysis were derived using MINITAB version 15 and cluster analysis was performed using Genstat 12th Edition.

The multivariate techniques Principal Component Analysis (PCA) and Cluster Analysis (Sneath and Sokal 1973) were used to examine the level of diversity and grouping of the TSHs and their parental types.

Data for the 35 descriptors used were first standardised to eliminate the effects of different scales of measurement.

Results and conclusions

The qualitative fruit characters of the 20 TSH cultivars encompassed the full range of descriptor states in six of the nine characters measured. Anthocyanin intensity went from absent in 12 cultivars to intense in one. Just over 50% of the TSHs were angoleta in pod shape. Pod apex form varied widely from attenuate to indented. Pod rugosity was absent in one type and intermediate to intense in most types. All cultivars had paired ridge disposition, with most possessing intermediate ridge separation and 50% had large pod size. The external phenotypic traits of the pods of these cultivars are quite diverse.

Table 2: Mean quantitative floral trait values for 20 Trinidad Selected Hybrids cacao cultivars

Cultivar	Sepal Length (mm)	Sepal Width (mm)	Staminode Length (mm)	Pedicel Length (mm)	Ligule Width (mm)	Style Length (mm)	No. Of Ovules
TSH 730	8.31 (0.87)	2.65 (0.59)	7.06 (0.49)	16.27 (0.81)	2.72 (0.14)	2.63 (0.17)	52 (5.5)
TSH 919	7.26 (0.72)	2.29 (0.19)	7.45 (0.38)	17.6 (1.75)	2.58 (0.19)	2.25 (0.16)	55.6 (5.58)
TSH 973	8.1 (0.39)	2.24 (0.14)	6.7 (0.52)	14.97 (1.21)	2.66 (0.13)	2.37 (0.23)	56.9 (5.24)
TSH 1076	6.87 (0.61)	2.14 (0.25)	5.87 (0.59)	15.95 (2.27)	2.46 (0.32)	2.29 (0.14)	54.1 (5.36)
TSH 1095	6.3 (0.44)	2.31 (0.15)	6.82 (0.4)	18.63 (2.08)	2.75 (0.26)	2.64 (0.15)	54.8 (3.82)
TSH 1102	8.01 (0.5)	2.46 (0.26)	6.97 (0.8)	16.01 (1.51)	2.95 (0.17)	2.29 (0.36)	66.5 (4.65)
TSH 1104	6.48 (0.52)	2.31 (0.14)	6.21 (0.4)	16.05 (1.12)	2.26 (0.17)	2.36 (0.13)	46 (3.43)
TSH 1188	7.58 (0.56)	3.09 (0.28)	7.18 (0.49)	18.32 (2.26)	2.74 (0.15)	2.64 (0.17)	56.6(3.72)
TSH 1220	8.75 (0.41)	2.69 (0.25)	7.11 (0.6)	20.1 (2.6)	2.86 (0.25)	2.18 (0.17)	47.6 (4.79)
TSH 1313	7.65 (0.24)	2.17 (0.25)	6.66 (0.39)	15.05 (2.29)	2.71 (0.1)	2.57 (0.24)	48.7 (2.41)
TSH 1315	6.21 (0.29)	2.08 (0.18)	6.2 (0.89)	14.48 (1.51)	1.95 (0.24)	1.9 (0.19)	57.2 (4.13)
TSH 1330	7.78 (0.38)	2.21 (0.16)	7.62 (0.63)	16.67 (2.37)	2.51 (0.22)	2.39 (0.11)	54.3 (6.43)
TSH 1344	7.93 (0.56)	2.32 (0.26)	6.76 (0.57)	12.62 (2.58)	2.42 (0.25)	2.34 (0.14)	52.7 (4.57)
TSH 1347	7.55 (0.41)	2.86 (0.66)	6.56 (0.33)	16.69 (1.14)	2.81 (0.19)	2.28 (0.14)	55.7 (3.71)
TSH 1350	8.25 (0.45)	2.77 (0.15)	8.4 (0.59)	14.2 (1.76)	3.14 (0.16)	2.11 (0.21)	55.2 (2.2)
TSH 1352	7.41 (0.54)	2.38 (0.15)	6.93 (0.56)	15.02 (1.77)	2.99 (0.2)	2.46 (0.12)	56.33 (2.55)
TSH 1356	7.35 (0.65)	2.17 (0.13)	7.23 (0.58)	15.87 (1.72)	2.38 (0.15)	2.31 (0.13)	46.3 (4.55)
TSH 1362	8.48 (0.4)	2.61 (0.24)	7.21 (0.51)	15.11 (1.85)	2.68 (0.15)	2.59 (0.25)	56.4 (4.62)
TSH 1364	8.31 (0.52)	2.69 (0.14)	7.98 (0.59)	14.08 (2.26)	3.04 (0.19)	2.16 (0.16)	48.9 (4.18)
TSH 1380	6.67 (0.82)	2.29 (0.25)	6.33 (0.5)	13.27 (1.22)	2.31 (0.12)	2.38 (0.11)	47.3 (4.27)
COV (%)	6.9	8.8	7.8	11.5	7.2	7.4	8.1

COV- average coefficient of variation values; Values within parentheses are standard deviations

Table 3: Mean quantitative fruit trait values for 20 Trinidad Selected Hybrids cacao cultivars

Cultivar	Pod Length (cm)	Pod Width (cm)	Pod Weight (g)	Pod Wall Thickness (mm)	Total Wet Bean Wt (TWBW) (g)	TWBW Without Mucilage (g)	Cotyledon Length (cm)	Cotyledon Width (cm)	Cotyledon Thickness (cm)
TSH 730	21.9 (1.13)	10.05 (0.42)	844.54 (91.22)	16.6 (1.58)	250.51 (29.34)	111.84 (10.22)	2.67 (0.12)	1.3 (0.05)	0.85 (0.1)
TSH 919	21.10 (0.88)	9.72 (0.46)	847.62 (68.44)	15.2 (1.69)	225.31 (18.41)	99.95 (6.04)	2.46 (0.13)	1.22 (0.05)	0.77 (0.08)
TSH 973	22.14 (2.23)	9.93 (0.64)	970.2 (219.51)	18.5 (3.24)	199.6 (27.39)	94.6 (10.71)	2.28 (0.13)	1.17 (0.05)	0.7 (0.16)
TSH 1076	22.08 (1.22)	9.27 (0.35)	877.65 (103.42)	18.6 (1.07)	216.03 (26.98)	93.96 (8.45)	2.25 (0.09)	1.19 (0.07)	0.85 (0.1)
TSH 1095	24.65 (1.42)	9.13 (0.23)	831.73 (53.89)	14.6 (1.43)	230.33 (23.61)	113.59 (13.96)	2.52 (0.11)	1.35 (0.09)	0.96 (0.09)
TSH 1102	22.28 (1.65)	10.11 (0.47)	988.23 (143.89)	16.5 (2.59)	274.95 (36.67)	127.1 (16.12)	2.52 (0.24)	1.23 (0.15)	0.72 (0.16)
TSH 1104	21.04 (1.42)	9.28 (0.61)	802.91 (163.56)	16.1 (2.33)	263.9 (49.45)	104.31 (15.27)	2.42 (0.17)	1.4 (0.1)	0.82 (0.11)
TSH 1188	22.51 (2.09)	9.76 (0.71)	839.36 (187.95)	17.1 (1.91)	208.27 (33.17)	88.98 (11.67)	2.4 (0.12)	1.17 (0.06)	0.95 (0.08)
TSH 1220	22.33 (1.79)	10.28 (0.47)	938.77 (162.64)	20.0 (2.71)	210.15 (34.99)	94.4 (12.26)	2.56 (0.16)	1.16 (0.13)	0.9 (0.08)
TSH 1313	17.67 (1.49)	8.38 (0.62)	569.40 (115.96)	13.1 (2.08)	201.8 (33.11)	108.2 (17.57)	2.38 (0.12)	1.39 (0.08)	0.76 (0.08)
TSH 1315	16.75 (1.18)	8.44 (0.26)	465.92 (66.57)	13.0 (1.33)	154.7 (36.3)	78.65 (15.78)	2.4 (0.15)	1.33 (0.06)	0.79 (0.07)
TSH 1330	21.49 (1.44)	10.21 (0.48)	903.19 (88.04)	16.8 (2.25)	218.5 (19.94)	99.18 (12.74)	2.59 (0.10)	1.3 (0.06)	0.79 (0.09)
TSH 1344	19.94 (1.59)	9.52 (0.78)	722.03 (150.3)	16.7 (2.58)	187.13 (42.2)	88.43 (16.4)	2.51 (0.19)	1.34 (0.09)	0.78 (0.11)
TSH 1347	17.31 (1.24)	10.59 (0.65)	813.79 (170.15)	15.4 (1.26)	193.11 (34.97)	87.03 (13.25)	2.76 (0.19)	1.22 (0.07)	0.82 (0.09)
TSH 1350	20.9 (0.88)	9.41 (0.27)	810.99 (98.48)	16.1 (1.29)	222.66 (33.56)	91.1 (7.29)	2.43 (0.18)	1.32 (0.06)	0.77 (0.08)
TSH 1352	18.45 (1.39)	9.93 (0.48)	758.46 (144.51)	15.0 (2.26)	220.27 (24.22)	99.44 (12.34)	2.36 (0.24)	1.3 (0.11)	0.73 (0.1)
TSH 1356	16.35 (1.71)	8.90 (0.7)	654.1 (118.28)	14.7 (1.89)	209.36 (25.17)	93.36 (13.64)	2.47 (0.21)	1.34 (0.1)	0.84 (0.05)
TSH 1362	20.32 (1.32)	9.58 (0.5)	812.30 (138.98)	14.0 (1.56)	286.29 (53.45)	107.98 (16.09)	2.55 (0.12)	1.45 (0.08)	0.8 (0.07)
TSH 1364	21.71 (1.51)	9.78 (0.42)	886.9 (166.66)	18.1 (1.91)	194.21 (32.65)	87.76 (14.03)	2.44 (0.14)	1.29 (0.09)	0.83 (0.08)
TSH 1380	21 (1.43)	9.73 (0.75)	852.33 (177.64)	18.9 (1.97)	210.51 (30.47)	89.3 (10.26)	2.29 (0.18)	1.0 (0.15)	0.68 (0.16)
COV (%)	7.1	5.4	16.3	12.0	15.0	13.1	6.3	6.8	12.3

COV- average coefficient of variation values; Values within parentheses are standard deviations

Table 4: Mean quantitative economic trait values for 20 Trinidad Selected Hybrids cacao cultivars+

Cultivar	Bean nos.	Dry bean Weight (g)	Cotyledon wt (without testa) (g)	Pod Index	Minimum Pod Index	Maximum Pod Index
TSH 730	52.1 (0.97)	1.5 (0.03)	1.401 (0.02)	13.77 (0.36)	11.83	15.5
TSH 919	52.4 (1.88)	0.789 (0.02)	0.738 (0.02)	26.16 (0.7)	23.30	31.66
TSH 973	49.9 (0.82)	1.104 (0.03)	1.027 (0.03)	19.72 (0.64)	17.30	24.3
TSH 1076	52.2 (0.96)	1.196 (0.04)	1.109 (0.04)	17.5 (0.69)	14.87	22.99
TSH 1095	52.1 (1.73)	1.582 (0.06)	1.489 (0.06)	13.18 (0.6)	10.82	17.01
TSH 1102	61.4 (2.89)	1.488 (0.06)	1.403 (0.06)	12 (0.67)	8.76	15.55
TSH 1104	51 (2.04)	1.44 (0.05)	1.362 (0.05)	14.84 (0.92)	11.60	21.37
TSH 1188	48.1 (2.43)	1.241 (0.06)	1.184 (0.06)	18.36 (1.27)	13.45	25.33
TSH 1220	48.4 (1.96)	0.877 (0.03)	0.824 (0.04)	25.76 (1.22)	20.66	30.86
TSH 1313	46.4 (1.23)	1.353 (0.06)	1.267 (0.06)	17.52 (1.1)	14.34	26.18
TSH 1315	42.2 (2.42)	1.271(0.02)	1.222 (0.02)	20.03 (1.17)	14.03	25.9
TSH 1330	50.1 (2.24)	1.324 (0.03)	1.263 (0.03)	16.34 (1.16)	13.16	25.06
TSH 1344	46.3 (2.67)	1.376 (0.03)	1.293 (0.03)	17.4 (1.21)	12.32	23.67
TSH 1347	49.6 (2.31)	1.34 (0.04)	1.263 (0.04)	16.31 (0.69)	13.19	19.52
TSH 1350	52.2 (1.55)	1.181 (0.04)	1.132 (0.04)	16.79 (0.45)	13.90	18.52
TSH 1352	51.7 (0.98)	1.349 (0.04)	1.275 (0.04)	15.47 (0.85)	12.54	20.13
TSH 1356	49.4 (2.1)	1.37 (0.07)	1.3 (0.06)	16.14 (0.85)	11.30	21.19
TSH 1362	50.9 (2.28)	1.511 (0.05)	1.435 (0.05)	14.14 (0.89)	9.80	19.74
TSH 1364	50 (1.99)	1.253 (0.04)	1.177 (0.04)	17.51 (1.1)	13.43	24.65
TSH 1380	48.7 (1.48)	1.283 (0.04)	1.226 (0.04)	17.1 (0.79)	12.86	20.86
Mean	50.26	1.291	1.220	17.30		
LSD (1%)	7.144(180df)	0.162(177df)	0.157(178df)	3.34(178df)		
COV (%)	12.20	10.8	11	16.60		
F ratio*	3.54	20.28	19.64	15.7		

*corresponding p-values are less than 0.001; standard errors are within parentheses. LSD- Least Significant Difference; COV- Coefficient of Variation; +The economic traits of the parents used in the TSH breeding programme are as follows; Bean number: 39, 35, 48,53, 45; cotyledon wt. (g): 1. 29, 1.29, 1.04, 0.89, 0.54; Pod Index: 19.87, 22.14, 20.03, 21.19, 43.57, respectively for ICS 1, ICS 95, IMC 67, POUND 18 and SCA 6.

The coefficient of variation of quantitative traits for fruits ranged from low values of 5.4 to 7.1 % for pod and cotyledon length and width respectively; to intermediate values for bean dry weight (10.8%), cotyledon weight (11%) and number of beans per pod and pod wall thickness (12%). While that of average wet bean weight per fruit, pod index and pod weight ranged from 15 to 16.6% (Table 3).

The variation observed among flower quantitative traits was of a lower magnitude (Table 2) with six traits ranging from 6.9% to 8.8% (sepal length, staminode length, style length, sepal width, ligule width and ovule numbers). This further supports the use of flower traits for taxonomic studies as found by Engels (1981) and Bekele et al., (1994)

The variation expressed by the clones under study in terms of both fruit and flower qualitative traits was very high. This reflects the heterogeneity expected within this hybrid population. The characteristics of economic interest, *viz.*, bean number, cotyledon weight and PI ranged from 42.2 (SEM 2.4) to 61.4 (2.9); 0.74g (0.02) to 1.49g (0.06) and 12.0 (0.67) to 26.2 (0.7), respectively. TSH 1102 was significantly superior to all other cultivars at the 1% LSD level in number of beans per pod (Table 4). This is supported by its high mean value of ovule number (66.5).

TSH 919 and 1220 grouped together with the highest PI values while TSH 730, 1095, 1102, 1104, and 1362 had the lowest PI values at the 1% LSD level and possessed similarly high cotyledon weights. This result will suggest that cotyledon weight is making a greater contribution than number of beans per pod to PI for this group of cultivars. Freeman (1969) described his methods to achieve dry bean weights exceeding 1.4 g in the earlier

TSH selections. Most of the mean PI values of the TSHs in this study were under 17 and was much lower than those recorded among the eight groups of Trinitario accessions used in a study by Bekele et al. 2009 that ranged from 20.4 to 28.9. This supports the genetic gains achieved by the TSH breeding programme in producing cultivars with superior economic traits compared to those of the parents used and that of other recognized groups of Trinitario accessions. Table 5 shows the various parental combinations used in the breeding of some of the TSH cultivars used in this study (MFPLMA 2010).

The first and second principal components obtained from analyzing the combined TSH progeny and parents accounted for 56.7% of the total phenotypic variation expressed. However, the third and fourth components accounted for an additional 19.9%, bringing that expressed by the first four components to 76.6%.

Table 5: Parentage of some Trinidad Selected Hybrids (TSH) cacao cultivars

Cultivar	Parentage
TSH 730	IMC 67 x ICS 95
TSH 919	IMC 67 x TSH 538 (ICS 1 x SCA 6)
TSH 1076	POUND 18 x TSH 758 (TSA 641 x OPEN)
TSH 1095	POUND 18 x TSH 753
TSH 1102	POUND 18 x TSH 792 (TSA 644 x OPEN)
TSH 1188	POUND 18 x TSH 753
TSH 1220	TSH 565 (SCA 6 x ICS 1) x IMC 67
TSH 1315	TSH 938 x TSH 1095
TSH 1330	IMC 67 x TSH 923
TSH 1344	IMC 67 x TSH 932
TSH 1350	IMC 67 x TSH 728 (ICS 95 x IMC 67)
TSH 1356	TSA 654 x TSH 923
TSH 1364	TSH 1105 x TSH 1103

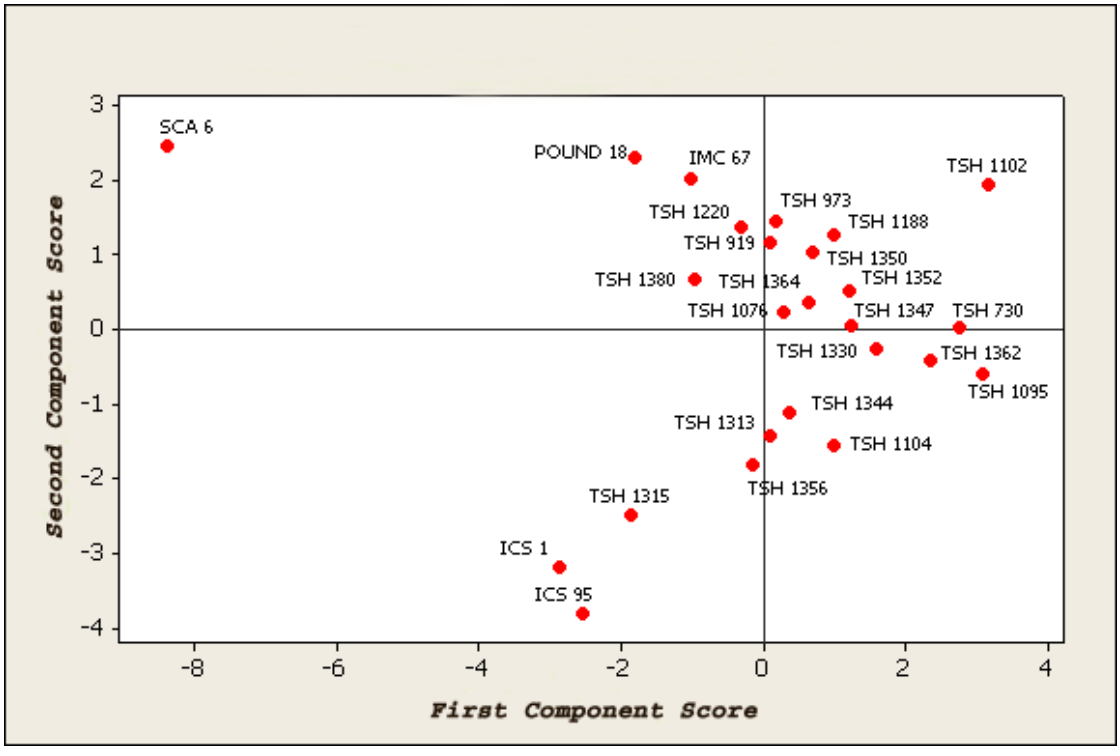

Figure 1: Principal component score plot of 20 Trinidad Selected Hybrids cacao cultivars and their five parental types based on 15 interval/continuous quantitative traits.

The data presented in two-dimensional plane (Fig 1) showed a separation of the parental types from the progeny. Wet bean weight, pod index, pod width, cotyledon length and cotyledon weight contributed significantly to the separation of the clones in the first plane. This finding is comparable to that in the study by Bekele et al. (2006). In the second plane, cotyledon width and the number of beans per pod accounted for most of the variation expressed in addition to ligule width, cotyledon thickness and ovule numbers.

With regard to the phenotypic diversity (Fig.1) expressed in the clones studied, SCA 6 was disparate while ICS 95 and ICS 1 grouped closely together and resembled TSH 1315, TSH 1356 and TSH 1313. Two of these three cultivars were selected from third generation crosses of TSH types with strong gene influence from ICS 1 and 95.

IMC 67 and POUND 18 were distinct and grouped closely together as Upper Amazon Forastero types, but related closely to TSH 1220, 919, 973 and TSH 1380. IMC 67 was used as single parent clone in the first three listed cultivars. The parental candidates of W.E. Freeman are well supported through the choice of heterotic combinations. The TSHs generally clustered together with this pattern repeated among sub groups as in the case of TSH 1330, 1362, 1095, 1344 and 1104 and TSH 1188, 1350, 1352, 1364, and 1347.

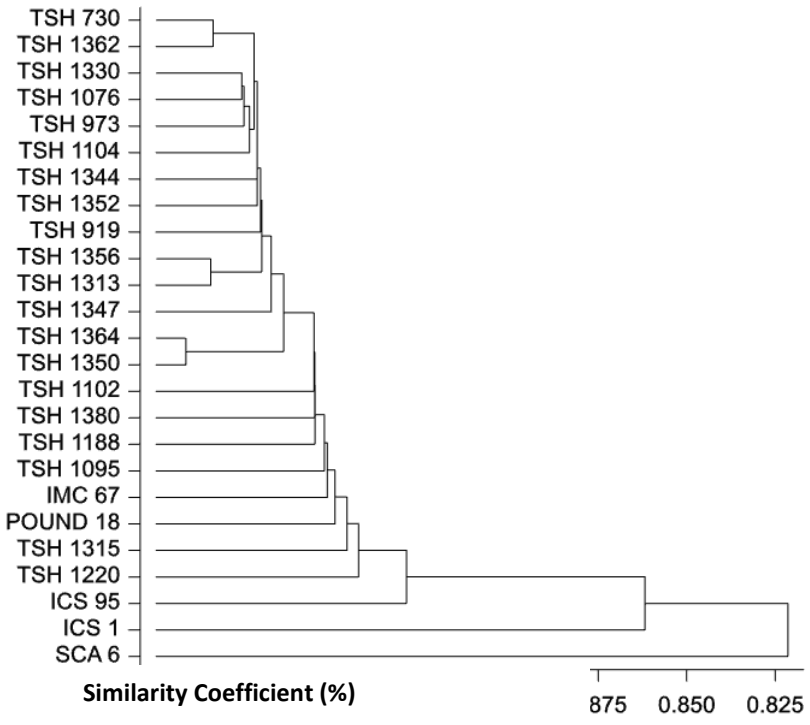

Figure 2: Dendrogram showing relationships between 20 Trinidad Selected Hybrids cacao cultivars and five parental types after cluster analysis using 15 quantitative variables.

This is further supported by the results of Cluster Analysis, (Fig 2), which revealed that SCA 6, ICS 95 and ICS 1 were very distinct from the TSH progeny. SCA 6 was very distinct at a very low level of similarity. IMC 67 grouped (at the 95% level) with eighteen of the TSHs in this study. The other similar group of SCA 6, ICS 1, ICS 95, POUND 18, TSH 1315 and TSH 1220 are all behaving as parents. The two TSH types in this group have descriptive fruit values, which are similar to the parental types and possessed strong IMC 67 ancestry.

In this study, the parents used in the breeding programme are distinct from the progeny. A large improvement in certain traits has been found. This suggests that useful heterotic combinations were achieved. The identification of the TSHs is now simplified through the use of these phenotypic descriptors and parents are now being discriminatively selected from this population for incorporation into an enhanced breeding effort by MFPLMA to improve *Phytophthora* resistance.

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