CARIBBEAN FOOD CROPS SOCIETY

49

Forty-ninth Annual Meeting 2013

Port of Spain, Trinidad and Tobago
Vol. XLIX

PROCEEDINGS

OF THE

49TH ANNUAL MEETING

Caribbean Food Crops Society
49TH Annual Meeting
June 30 – July 6, 2013

Hyatt Regency Hotel
Port of Spain, Trinidad and Tobago

"Agribusiness Essential for Food Security: Empowering Youth and Enhancing Quality Products"

Edited
by
Wanda I. Lugo, Héctor L. Santiago, Rohanie Maharaj, and Wilfredo Colón

Published by the Caribbean Food Crops Society

ISSN 95-07-0410

Copies of this publication may be obtained from:

Secretariat CFCS
P.O. Box 40108
San Juan, Puerto Rico, 00940

or from:

CFCS Treasurer
Agricultural Experiment Station
Jardín Botánico Sur
1193 Calle Guayacán
San Juan, Puerto Rico 00936-1118

Proceedings of the Caribbean Food Crops Society. 49:256-266. 2013

EARLY FIELD PERFORMANCE OF 20 TRINIDAD SELECTED HYBRID (TSH) CACAO CULTIVARS BASED ON SURVIVABILITY, GROWTH, YIELD AND PEST AND DISEASE RESISTANCE OVER A SIX- YEAR PERIOD

K. Maharaj and D. Ramnath. Ministry of Food Production, Research Division. Central Experiment Station. Centeno, Trinidad and Tobago

ABSTRACT: Trinidad and Tobago is an exclusive producer of fine or flavour cocoa, which is produced from selected Trinitario genetic germplasm. This country participated in a Common Funds for Commodities/ International Cocoa Organisation/Bioversity Germplasm Project from 2000 to 2010. Twenty TSH clones (nine commercial types: TSH 730, 919, 1076, 1077, 1095, 1102, 1104, 1188 and 1220 and 11 TSH 1300 series) were evaluated over this period for growth, yield and disease resistance parameters in a replicated field trial located at La Reunion Estate, Centeno. Over the first three years significant differences were found between clones for survival rates in the field (X^2 = 2.51, 38df P≥0.001); field resistance to damage caused by the Cocoa Beetle, *Steirastoma breve*; presence or absence of vegetative brooms formed from Witches Broom Disease infection and precocity. A significant correlation (R^2=-0.789; P=0.001) existed between girth and vigour for 3-year old trees. Dry bean yield data from 2003 to 2005 is presented, showing significant differences between cultivars, with TSH 730, 1076, 1330, 1344, 1350, 1347 and 1380 achieving 3-yr cumulative yields close to or exceeding 2 t ha^{-1}. Cultivars with good yield and disease resistance traits are very discernible from this trial.

Keywords: Cacao, *Theobroma cacao*, Trinidad Selected Hybrids, Yields, disease resistance.

Introduction

The reputation of Trinidad and Tobago as a producer of 100% fine or flavour cocoa is well known, with its premium Trinitario origin beans widely sought by niche chocolate producers (ICCO, 2006). The breeding programme that produced the Trinidad Selected Hybrids cacao varieties is considered one of the most successful in the world. It involved uninterrupted cycles of hybridisation and recurrent selections conducted over 60 years (Kennedy et al., 1987), and still continues today. Initial goals were aimed at Ceratocystis (CR) and Witches' Broom (WBD) disease resistance, large bean size, early bearing, low pod index and maintenance of the traditional fine or flavour status of Trinidad and Tobago cocoa (Shripat, 1993).

The Ministry of Food Production in Trinidad commercially propagates fifteen TSH varieties as seedlings, grafted clones and clonal cuttings for sale and distribution to farmers. These TSH clones are now widely grown on commercial estates in Trinidad and Tobago (Abdul-Karimu et al., 2003). On an annual basis, over 200,000 cocoa plants are distributed to farmers; however, annual cocoa production in Trinidad and Tobago is not reflective of this considerable investment in cocoa plant production. A

better understanding of differences in varieties related to early growth and survivability will provide an insight into the performance of clones during the early establishment period.

High seedling mortality during the establishment phase of cocoa has become a critical constraint to sustainable cocoa production and is attributed to overhead shade and soil fertility (Toxopeus, 1968; Frimpong et al., 1999), soil water deficits and drought (Alvim, 1959; Anim-Kwapong and Frimpong 2006)and to the inherent genetics of the planting material (Padi et al., 2013). In addition, young established plants are very vulnerable to cocoa beetle (*Steirastoma breve*) damage and Witches' Broom Disease (WBD) infestation.

Trinidad and Tobago participated in an international cacao Germplasm Project organised and funded by the Common Funds for Commodities (CFC), the International Cocoa Organisation (ICCO) and Bioversity International from 2000 to 2010. Twenty TSH cultivars (nine commercial types: TSH 730, 919, 1076, 1077, 1095, 1102, 1104, 1188 and 1220 and eleven TSH 1300 series) were rigorously evaluated over this period in a Local Clone Trial for growth, yield and pest and disease incidence and resistance parameters. The results from the early evaluation of the TSH clones during the period 2001 to 2005 are presented to assist in influencing varietal selection and to guide choices in management practices, which are crucial for successful establishment and early growth of the cocoa crop. The objectives of this study were:

1. To determine the survival rates of the individual TSH clones during early establishment
2. To examine the growth and bearing performance of 20 TSH clones up to six years
3. To identify TSH clones with better resistance to Beetle damage, Witches' Broom disease and Phytopthora Pod Rot (Ppr) also known as Black Pod disease (BPD) infestation

Materials and Methods

The Local Clone Trial was established on the La Reunion Estate, Centeno, Trinidad in 2000 as a randomised block design with six replicates. The 20 TSH cultivars used were comprised of older selected varieties: TSH 730, 919, 1076, 1077, 1095, 1102, 1104, 1188 and 1220 and newer selections: TSH 1313, 1315, 1330, 1344, 1347, 1350, 1352, 1356, 1362, 1364 and 1380. The phenotypic and agro-economic traits of these varieties are documented in a study by Maharaj et al. (2010). The soil type at the site is Cunupia Fine Sand Clay Loam with moderate fertility and internal impeded drainage. The mean annual rainfall in this region is approximately 2200 mm and the average temperature is 26° C. The clonal plants used in the trial were propagated by hypocotyl budding from rootstocks of TSH 919 x TSH 1188 progenies. The trial was established in 2000 at a planting density of 1679 trees ha^{-1} (2.4m x 2.4 m), with overhead shade trees of *Erythrina poeppigiana* planted at 8m x 8m spacing and thinned to 16 m apart. Each individual plot contained eight labelled trees with rows of border trees separating each

replication. The young plants were furrow irrigated in the dry season. Routine agronomy practices were applied evenly to all blocks and entailed formation and annual maintenance pruning, manual weed control (three times per year) and drainage. All plants received two applications of a 3:1:2 NPK fertiliser (250 g plant^{-1} between age 1-3 and 500 g at 4 – 5 years. Insecticides and fungicides were not used in this trial since field resistance of the clones to pest and diseases were determined as a major objective of this trial. Dead cocoa plants were replaced over the first two years of the trial.

Crop Measurements and Statistical Analyses

The protocols used are described in Eskes et.al (2000) and entailed the sampling of all trees from within a plot. The following measurements were conducted:

a. Trunk circumference measured at 15cm from soil level on an annual basis
b. Early vigour using a visual observation scale of 1-5, 1 and 5 refer to the largest and smallest trees respectively. This was done at end of Year 1 and 2
c. Cocoa beetle *Steirastoma breve* damage incidence using a visual ranking scale from 1 to 5; where 1=no damage, 3= medium damage and 5= intense damage. Damage was assessed at 2nd and 3rd Year
d. Witches' Broom Disease (WBD) incidence at Year 2 and 3, using a scale of A, B and C where A= Absence of disease (no vegetative brooms), B= 1 to 5 brooms present and C=>5 brooms present.
e. Precocity of the clones: indication of flowering and bearing at the end of YR3
f. Clone survival rates were derived from a count of dead trees at the end of YR 1,2 and 3
g. Yield was calculated based on converting wet bean weight per plot to dry bean weight using a conversion factor of 30%. Plot weights were converted to yield (kg/ha) on the basis of the planting density of 1679 plants ha^{-1} (Mooleedhar and Lauckner, 1987)
h. The percentage of Phytophthora pod rot and Witches' Broom disease infected pods was calculated from a total pod count of all trees in the trial at each harvest interval, with the particular disease infected pods counted separately and a percentage infection derived.

SPSS Inc (www.01.ibm.com) software was used for cross tabulation of data and Chi Square analysis for hypotheses testing. Analysis of variance (ANOVA) of yield and disease incidence data was done using Minitab Ver 12.

Results and Discussion

There were significant differences (P=0.01) between the one year clones for stem girth thickness with TSH 1364, 1315, 1220, 1077 and 1330 having larger tree girth. However, when clones were 2- and 3-years old there were no significant differences in tree girth. This is probably attributed to a carryover effect from the nursery where the young propagated trees spent over six months in polybags. There was a significant correlation between girth and tree vigour for 3-year old trees (R=-0.79; P=0.001). Trees with larger

girth had more vigorous canopy growth and larger crowns. This relationship is illustrated in Table1. Food reserves in the cocoa tree are stored in the wood of the trunk and translocated for growth and bearing.

Table 1. Relationship between tree vigour level and tree girth (cm) of 3-year old Trinidad Selected Hybrid cacao clones.

Vigour Level*	Mean tree girth (cm)	SEM
1	18.3	0.11
2	16.0	0.15
3	13.3	0.19
4	11.5	0.34
5	10.0	0.72

SEM-Standard error of mean
* Visual observation scale of 1-5, where 1 and 5 refer to the largest and smallest trees respectively

Replanting of dead trees were done twice during the three year period after establishment. The data collected on number of trees by varieties and age, surviving at the end of each year over the first 3-year period was cross tabulated (Tree Age x Cultivar) and Chi Square (X^2) analysis was used to test the hypothesis that the clones had similar survival rates. The results of the X^2=251 (38 df); P=0.001 rejects the hypothesis, indicating that differences do exists between clones for survival rates (Table 2). Clones with survival rates of over 70% were TSH 1076, 1330, 1347 and 1380 while lower performing ones were TSH 1095, 1188 and 1220. These differences can be attributed to genetics, beetle damage leading to death, rootstock and scion incompatibility issues or other environmental effects. Padi et al. (2013) found a differential response to survival among thirty-seven families involving various cacao clones. Those of Scavina origin had the most positive contribution to survival. N'Goran and N'Guessan (2004) also had high mortality rates in families produced from selfing.

The results of Witches' Broom disease assessment during the 2nd and 3rd years were cross-tabulated according to Broom Score Rating x Cultivar and Chi Square (X^2) analysis was used to test the hypothesis that all clones will show equal field resistance to WBD. The results for 2-year and 3-year old clones respectively were X^2=68.5(38df), P=0.001 and X^2=141.3(76df), P=0.001. The hypothesis is rejected, showing that highly significant differences do exist between clones for field resistance to WBD. Clones with >90% absence of vegetative brooms at both ages were TSH 1076, 1347, 1350 and 1356, with more susceptible clones being TSH 919 and 1188 (Table 3).

Table 2. Survival rates based on composition of trees (%) by age of twenty Trinidad Selected Hybrid cacao cultivar measured 3-years after planting.

Cultivar	% by age of clones		
	1-year	2-year	3-year*
TSH 1330	2.1	16.7	81.3
TSH 1352	13.3	8.9	77.8
TSH 1347	6.4	17.0	76.6
TSH 1380	27.3	0.0	72.7
TSH 1076	2.1	25.5	72.3
TSH 1364	10.9	19.6	69.6
TSH 1315	2.1	29.8	68.1
TSH 1077	21.7	10.9	67.4
TSH 1344	12.8	21.3	66.0
TSH 1362	14.9	21.3	66.0
TSH 1313	10.4	25.0	64.6
TSH 730	17.8	20.0	62.2
TSH 919	16.5	22.0	61.5
TSH 1102	38.9	0.0	61.1
TSH 1350	33.3	9.5	57.1
TSH 1220	8.5	36.2	55.3
TSH 1356	33.3	15.6	51.1
TSH 1104	8.5	44.7	46.8
TSH 1095	47.2	12.4	40.4
TSH 1188	5.4	60.9	33.7
Average	16.7	20.7	62.6

*This reflects the percentage of trees, which survived from the original establishment

Table 3. Incidence (%) of vegetative brooms produced from Witches' Broom Disease derived from a field assessment rating* of 2-year and 3-year old Trinidad Selected Hybrid cacao cultivars.

Cultivar	2-year old trees			3-year old trees		
	%A	%B	%C	%A	%B	%C
TSH 1076	97.7	2.3	-	93.6	4.3	2.1
TSH 1347	95.7	4.3	-	95.7	4.3	-
TSH 1350	94.1	5.9	-	100	-	-
TSH 1356	91.4	5.7	2.9	90.7	9.3	-
TSH 1220	97.9	2.1	-	85.1	14.9	-
TSH 1362	93.0	7.0	-	89.4	10.6	-
TSH 1380	82.4	14.7	2.9	95.5	2.2	2.3
TSH 1344	87.2	12.8	-	85.1	14.9	-
TSH 730	88.1	11.9	-	84.4	13.4	2.2
TSH 1104	84.3	13.5	6.7	87.2	10.7	2.1
TSH 1352	87.2	12.8	-	84.4	15.6	-
TSH 1313	89.4	10.6	-	81.3	14.5	4.2
TSH 1095	84.1	13.0	2.9	87.4	12.6	-
TSH 1330	86.7	13.3	-	79.2	16.5	4.2
TSH 1315	87.0	10.8	2.2	74.5	19.1	6.4
TSH 1102	70.8	29.2	-	85.7	14.3	-
TSH 1077	78.6	14.3	7.1	93.5	6.5	-
TSH 1364	86.0	11.7	2.3	69.6	30.4	-
TSH 1188	79.8	13.5	6.7	59.8	32.6	7.6
TSH 919	72.6	16.4	11.0	74.7	25.3	-
Average	86.7	8.8	4.5	84.8	11.5	3.7

*A rating assessment scale of A, B and C was used, where A= Absence of Witches' Broom Disease (no vegetative brooms), B= the presence of 1-5 vegetative brooms and C= >5 vegetative brooms.

The cocoa beetle (*Steirastoma breve*) is an important economic insect pest of cocoa in Trinidad and Tobago. All clones in the trial were assessed for incidence and severity of damage at 2 and 3 yr, respectively. The results of Cultivar x Beetle damage scores were cross-tabulated and subject to Chi Square analysis to test the hypothesis that all clones will show equal resistance to cocoa beetle damage. The results for Age 2 and Age 3 clones, respectively, were X^2=215 (95df) P=0.001 and X^2=177(76 df) P=0.001. The hypothesis is rejected for both Age 2 and Age 3 trees showing that clones are significantly different in their behaviour to beetle damage. Almost 70% of the 2-year old trees had medium to high damage compared to 25% among the 3-year old trees (Table 4). This variation observed over two years can be attributed to climatic differences and the susceptibility of the tissues of younger plants to damage. Cultivars showing lower damage intensities were TSH 730, 1077, 1220, 1313, 1344, 1347, 1350 and 1362, while TSH 1102, 1188 and 1364 had greater levels of damage. Morillo et al. 2008 found significant differences between clonal families in their behaviour to attack from *Steirastoma breve* in Venezuela. Hybrids of Amazonian origin were found to have little or no damage.

Table 4. Incidence (%) of *Steirastoma breve* beetle damage intensity (DI) on two and three year old trees of twenty Trinidad Selected Hybrid cacao cultivars

Cultivars	% DI of 2 yr old trees					% DI of 3 yr old trees				
	%1	%2	%3	%4	%5	%1	%2	%3	%4	%5
TSH 730	11.9	31.0	54.8	2.4	-	-	68.9	31.1	-	-
TSH 919	2.7	24.3	56.8	8.1	8.2	-	72.5	27.5	-	-
TSH 1076	2.2	17.8	71.1	8.9	-	-	78.7	19.1	2.1	-
TSH 1077	-	39.0	51.2	9.8	-	-	93.5	6.5	-	-
TSH1095	11.9	14.9	49.3	16.4	7.5	-	72.7	27.3	-	-
TSH 1102	-	8.3	66.7	25.0	-	-	44.4	55.6	-	-
TSH 1104	6.7	8.9	75.6	8.9	-	-	85.1	14.9	-	-
TSH 1188	4.5	18.0	67.4	9.0	1.1	-	79.3	17.4	-	3.3
TSH 1220	2.1	34.0	44.7	17.0	2.1	-	80.9	17.0	2.1	-
TSH 1313	8.5	42.6	44.7	4.3	-	-	85.4	14.6	-	-
TSH 1315	8.7	13.0	62.5	13.0	-	-	61.7	38.3	-	-
TSH 1330	-	19.1	63.8	14.9	2.1	-	81.3	18.8	-	-
TSH 1344	8.5	44.7	42.6	4.3	-	-	78.7	21.3	-	-
TSH 1347	2.2	45.7	37.0	15.2	-	6.4	80.9	12.8	-	-
TSH 1350	6.3	28.1	59.4	3.1	3.1	-	73.2	24.4	2.4	-
TSH 1352	10.3	17.9	51.3	17.9	2.6	-	57.8	35.6	6.7	-
TSH 1356	17.1	31.4	48.6	2.9	-	2.3	79.5	18.2	-	-
TSH 1362	8.5	31.9	57.4	2.1	-	-	76.6	23.4	-	-
TSH 1364	2.3	6.8	72.7	15.9	2.3	-	73.9	26.1	-	-
TSH 1380	8.8	24.3	57.6	10.2	1.8	-	59.1	36.4	4.5	-
Average	6.1	24.3	57.6	10.2	1.8	0.4	74.7	23.9	0.8	0.3

*A damage intensity assessment scale of 1 to 5 was used to determine beetle damage, where 1= no damage, 3=medium damage and 5= extensive damage to trunk and stems of trees

Flowering and fruiting occurred in some cultivars at 2-year old, which were also some of the bigger bearers at the third year (Table 5). This includes TSH 1347, 730 and 1330. Highly significant differences were found among varieties for yield of dry bean per hectare over 2003 to 2005. This was also true for differences among varieties for incidence of pod infection from WBD and BPD, respectively. Five varieties, TSH 1347, 730, 1330, 1076 and 1344 had cumulative 3-year yields of over 2000 kg/ha, while six, TSH 1350, 1380, 1364, 919, 1220 and 1315, had cumulative yields between 1500 to 2000 kg/ha. The low bearing cultivars were TSH 1077, 1095, 1104 and 1362. Some of the individual cultivar yield results over the three-year period, point to a pattern of slow early bearing which accelerates with age. Cultivars showing this trend are TSH 1076, 1188 and 1350.

The yields obtained by Mooleedhar and Lauckner (1990) for a spacing trial using three of the TSH cultivars (TSH 730, 919 and 1188) during 1985 to 1987 compares differently for TSH 730 and 919, which are higher in this trial, but have a somewhat similar trend for TSH 1188. This can be attributed to environmental factors and differences in the method for propagating the experimental clones used in both trials i.e. hypocotyl budding vs. rooted cuttings. It is not uncommon for hybrid trials to produce 3-year

cumulative early yields exceeding 4000 kg ha^{-1} as reported in Papua New Guinea by Efron et al. (2004).

Average Pod infection rates for both WBD and Ppr diseases were similar at 5% for the years 2004 and 2005. This is unusual, since Phytophothora pod rot usually exceeds WBD pod infection in the typical field situation in Trinidad. Cultivars showing good field resistance to Ppr and with less than 3% pod infection were TSH 1102,1104,1220,1347, 1352 and 1364, while those with low resistance were TSH 1313 and 1315. Shripat (2003) also reported high resistance with TSH 1220 from pod inoculation studies. Cultivars showing good field resistance to WBD with less than 3% pod infection were TSH 1102, 1076, 1347 and 1350. The last three listed cultivars also had >90% absence of broom scores for incidence of vegetative brooms as listed in Table 3. The cultivars with high levels of pod infection were TSH 919, 1313, 1315 and 1330. Most of these results conform to leaf inoculation testing using the Spray method and Agar Drip technique for evaluation of resistance by cocoa clones to WBD (Thevenin and Umaharan, 2002) in which TSH 1347, 1344, and 1350 showed the best resistance and TSH 919, 1313, 1315, 1330 being susceptible.

Conclusions

1. The mortality of young established cocoa trees over the first three years can be quite significant. Some cultivars with better survival rates are TSH 1076, 1330, 1347 and 1380. It is advisable to employ other practices to encourage successful growth such as irrigation in the dry season, adequate shade and general care and maintenance of young trees.
2. Damage to 2 and 3 yr old plants by the cocoa beetle (*Steirastoma breve*) can be quite intense. Some clones showing better tolerance to damage are TSH 730, 1077, 1220, 1313, 1344, 1347, 1350 and 1362.
3. Some of the TSH clones are capable of giving cumulative 3- year yields from their fourth year after establishment of over 2000 kg ha^{-1} of dry beans. These are TSH 1347, 730, 1330, 1076 and 1344.
4. TSH clones with better resistance to Witches' Broom and Black Pod diseases are TSH 1102, 1076, 1347 and 1350 and TSH 1102,1104,1220,1347, 1352 and 1364, respectively.

Acknowledgements

The authors are grateful for the support provided by the staff of the Cocoa Research Section, Centeno for fieldwork and data collection associated with this study and the funding and support provided by CFC/ICCO/IPGRI. The biometry support provided by Mr Bruce Lauckner of CARDI, together with technical guidance from Dr Bertus Eskes of IPGRI, was critical to the outcome.

Table 5. Precocity, annual and 3-year cumulative dry bean yields (kg ha^{-1}) and 2-year averages of pod infection (%) from Witches' Broom Disease (WBD) and Phytophothora pod rot (Ppr) Disease respectively of twenty Trinidad Selected Hybrid cacao cultivars.

Cultivar	Precocity +	Dry bean yield*			Cumulative 3-yr bean yield	[a]2-yr (%) average WBD pod infection*	[a]2-yr (%) average Ppr pod infection*
		2003	2004[2]	2005[2]			
TSH 1347	Yes	840	577 (75)	1195 (84)	2612	1.2	2.6
TSH 730	Yes	714	575 (81)	1077 (92)	2366	5.6	7.1
TSH 1330	Yes	671	695 (73)	782 (81)	2148	8.6	7.6
TSH 1076	No	266	750 (70)	1040 (78)	2056	2.3	5.1
TSH 1344	No	387	775 (71)	840 (79)	2002	3.1	6.6
TSH 1350	Yes	358	599 (78)	1038 (86)	1995	3.0	5.7
TSH 1380	Yes	624	566 (72)	692 (83)	1882	5.9	5.7
TSH 1364	Yes	591	465 (81)	758 (92)	1814	3.4	1.9
TSH 919	Yes	478	513 (54)	804 (60)	1795	9.7	5.6
TSH 1220	Yes	519	440 (78)	675 (89)	1634	4.8	2.8
TSH 1315	Yes	625	464 (82)	512 (93)	1601	9.0	15.2
TSH 1313	No	460	484 (93)	514 (106)	1458	11.6	11.4
TSH 1356	Yes	442	337 (77)	497 (86)	1276	3.3	3.8
TSH 1352	No	392	339 (74)	540 (83)	1271	4.1	2.9
TSH 1188	No	172	242 (51)	614 (56)	1028	4.7	3.9
TSH 1102	No	0	196 (101)	763 (116)	959	1.5	1.3
TSH 1077	No	61	240 (80)	394 (89)	695	3.5	1.8
TSH 1095	No	93	133 (52)	436 (59)	662	7.2	3.7
TSH 1104	No	21	57 (79)	533 (88)	611	3.9	1.3
TSH 1362	No	127	33 (88)	204 (101)	364	3.7	5.1
SED/ (Average)		199.1 (95df)	-	-		(5.0)	(5.1)

+ An indication of flowering and bearing at 2 years; [2]Values in parenthesis are SEMs-standard error of the means; SED- standard error of difference of means; * denotes significance of the means at P=0.001

[a] 2-year average derived from years 2004 and 2005 pod infection.

Literature Cited

Abdul-Karimu, A., Butler, D.R., Iwaro, A.D., Sukha, D.A., Bekele, F., Mooleedhar, V. and Shripat, C. (2003). Farmers' perceptions of cocoa planting material and factors affecting the cocoa industry in Trinidad and Tobago. *Tropical Agriculture* (Trinidad) Vol. 80 (October 2003): 261-266.

Alvim, P. T. (1959): Water requirements of cocoa. First FAO Technical Cocoa meeting. Accra, Ghana, Feb 8-15, 1959. Bib. Orton IICA/CATIE, 17 pp.

Anim-Kwapong, G. J., and E. B. Frimpong, (2006): Vulnerability of agriculture to climate change- impact of climate change on cocoa production. In: Report on vulnerability and adaptation assessment under the Netherlands climate change studies assistance programme phase 2(NCCSAP2). Cocoa Research Institute of Ghana. 44 pp.

Efron, Y., Epaina, P., Marfu, J., Saul, J., Hollywood, N., Butubu, J., Nideson, J. and Nideson, D. (2004). Final Report (1998 to 2003) CCI Papua New Guinea pp 1-60 In: IPGRI eds CFC/ICCO/IPGRI Project on Cocoa Germplasm Utilisation and Conservation: A Global Approach. Final Individual Institute Reports April 1998 September 2003 Volume 2: Asia, Africa and Pacific, Europe.

Eskes, A.B., Engels, J.M.M., and Lass. R.A., editors (2000). Working Procedures for Cocoa Germplasm Evaluation and Selection. Proceedings of the CFC/ICCO/IPGRI Project Workshop, 1-6 February 1998, Montpellier, France. International Plant Genetic Resources Institute, Rome, Italy

Frimpong, E. B., Y. Adu-Ampomah, and A. Karimu, (1999): Efforts to breed for drought resistant cocoa in Ghana. In: Proceedings of the 12th International Cocoa Research Conference, Salvador, Bahia Brazil, November 1996, pp 375—381.

ICCO (2006). Review of the cocoa market situation – December 2006. (Document-EX/131/3, 7 November 2006. ICCO Executive Committee- 131st Meeting, EBRD offices, London 5-6 December 2006. http://www.icco.org/economics/cost.aspx (accessed 13/10/2009).

Kennedy, A.J., Lockwood, G., Mossu, G., Simmonds, N.W. and Tan, G.Y. (1987) Cocoa Breeding: Past, Present and Future. Cocoa Growers Bulletin 38: 5-21

Maharaj, K., Maharaj, P., Bekele, F.L., Ramnath, D., Bidaisee, G.G., Bekele, I., Persad, C., Jennings, K., and Sankar, R. (2011). Trinidad Selected Hybrids: An invesitgation of the phenotypic and agro- economic traits of 20 selected cacao culivars. *Tropical Agriculture (Trinidad)* Volume 88 (4).

Morillo, F., Sanchez, P., Giron, C., Valera, A., Munoz, W. and Guerra, J. (2008) Behaviour of cacao hybrids (Theobroma cacao) to attack by *Steirastoma breve* (Coleoptera:Cerambycidae). Revista Colombiana de Entomologia 34 (2) 151-155

MINITAB INC. (1997) MINITAB User's Guide 2: Data analysis and quality tools. Release 12 for Windows. USA: Minitab Inc.

Mooleedhar, V. and Lauckner, B (1990) Effects of spacing on yield in improved clones of *Theobroma cacao* L. Tropical Agric. (Trinidad) 67(4):376-378

N'Goran, J. and N'Guessan, F. (2004) Final Report (1998 to 2003) CNRA, Cote d'Ivoire pp 1-50 In : IPGRI eds CFC/ICCO/IPGRI Project on Cocoa Germplasm Utilisation and Conservation : A Global Approach. Final Individual Institute Reports April 1998- September 2003 Volume 2: Asia, Africa and Pacific, Europe.

Padi, F.K., Ado-Gyamfi, P., Akpertey, A,. Arthur, A. and Ofor, A. (2013): Differential response of cocoa (Theobroma cacao) families to field establishment stress. Plant Breeding 132, 229-236. Blackwell Verlag GmbH

Shripat, C. (1993) The recent cocoa (Theobrom.a cacao L.) germplasm conservation initiatives Proceedings of the International Workshop on Conservation, Characterisation, and Utilisation of Cocoa Genetic Resources in the 21st Century, September 13-17 1992, Port of Spain, Trinidad, Cocoa Research Unit, pp. 239-243

Thevenin, J. and Umaharan, R. (2002). Evaluation of the resistance of TSH clones to Black Pod and Witches' Broom Diseases. Report for the Ministry of Agriculture, Land and Marine Resources. Cocoa Research Unit. The University of the West Indies. Trinidad

Toxopeus, H., (1968): Establishment of cocoa clones in Nigeria. Euphytica 17, 38-45.