Journal of South Pacific Agriculture, Volume 22, 2019
http://www.journalofsouthpacificagriculture.com/index.php/JOSPA

Assessing morphological characteristics of elite Cocoa accessions (*Theobroma cacao* L.) in Makira Island, Solomon Islands

Elison Toramo[1A]; Nandakumar Desai[1]; Falaniko Amosa[1]; Yan Diczbalis[2] and Natalie L.Dillon[2]

ABSTRACT

Characterization in *Theobroma cacao* L. based on the suggested Australian Center for International Agricultural Research (ACIAR) guidelines is observed to be important to encourage fine quality Cocoa production, and to realize remunerative income. Hence, 40 Cocoa accessions collected from fields distributed under different wards of Makira Island of the Solomon Islands were characterize for nine quantitative and qualitative morphological traits. Among the identified Cocoa accessions, Principal Component Analysis (PCA) grouped all the traits into three major Principal Components (PC) accounted 46.2% of total variation. PC axis one accounted for 23.1% of total variation explained by pod weight, pod circumference, cotyledon length, pod length, cotyledon width, pod external thickness, mature pod ridge color (anthocyanin), pod surface texture, pod surface shape and pod shape. The 12.2% of total variation in PC axis two was considerably attributed by the qualitative traits cotyledon color, pod surface texture , mature pod ridge color (anthocyanin), pod surface shape, cotyledon width, pod shape and tree vigor. While, PC axis three accounted for 10.9% of total variation referred to traits pod neck, pod surface shape, pod surface texture, pod length, tree vigor, pod internal thickness, weight of the bean per pod, pod external thickness, number of beans per pod, pod weight and reaction to black pod. Unweighted Pair Group Mean with Arithmetic Average (UPGMA) classified the 40 accessions in to three clusters. Under Cluster 1, 95.5% of identified accessions were grouped by traits such as cotyledon length and cotyledon width, red pods tree. While, Cluster 2 made up of 5% of total number of accessions with traits least pod weight, least pod external thickness, least cotyledon length and red podded trees. A single accession in Cluster 3 characterized by longest pod and constituted only 2.5% of the total accession. The frequency distribution of the nine qualitative traits confirmed that, 90% of identified accessions exhibited pod surface texture as smooth and slightly rough, 97% with pod surface shape as slightly furrowed with medium furrows and 85% with Amelonado pod shape. Most of the identified Cocoa accessions, grouped into three pod apex shapes traits such as Mammelate, Acute and Obtuse, accounting for 44, 25 and 20%, respectively. Of the total accessions studied, 63% had no anthocyanin on the mature pod ridge. Each of 72% measured as the strength of the accessions to withstand *Phytophthora palmivora*, and vigorous. The Shannon Weaver Diversity Index characterized and suggested that the Cocoa accessions in Makira Island mainly resemble to Amelonado (bulk) type, usually classified as Forasterio variety.

INTRODUCTION

Theobroma cacao L. is a diploid fruit tree species (2n = 20) (Aikpokpodion, 2012) originated from South America to the east of Andes (International Cocoa Organization, 2013). Initially, *Theobroma cacao* L. was identified as the botanical family of Sterculiaceae. However, it was re-classified as the Malvaceae family (Aikpokpodion, 2012). Scientific claims for the home of Cocoa include several areas in Central and South America. Despite Cacao as a native tree species to the regions of Central and South America, it is grown largely in West and Central Africa (Aikpokpodion, 2012). In the global Cocoa production the share of Africa amounted to 75.8% followed by 16.1%t for Latin America and 8.1% for Asia (International Cocoa Organization, 2017).

Cocoa beans provide the main raw material in the manufacturing of chocolate, confectioneries and a few cosmetic products (Aikpokpodion, 2012). Chocolate manufacturing contributes significantly to global economy as it generates export revenue, income for the growers, and creates employment opportunities in the Cocoa producing nations. During 2011, for the first time chocolate confectionary industry exceeded the limit of $100 billion (Gayi and Tsowou, 2012). Importantly, Cocoa provides livelihood for about 40 to 50 million people around the world (Houston and Wyer, 2012; Gayi and Tsowou, 2012 and World Cocoa Foundation, 2018).

In Solomon Islands, Cocoa earns foreign revenue through the export of dry Cocoa beans (Commodities Export Marketing Authority, 2015). The crop provides employment for men and women of more than 24,000 small holders who carry out different activities at growing and post-harvest processing stages of Cocoa (Vadnjal and Pelomo, 2014).

Looking to the crop, many authors suggested measuring the existing variability in Cocoa crop that influence the beans quality. Hence, for identifying the Mexican Criollo type of Cocoa, Garcia- Alamilla *et al.* (2012) suggested the use of morphological traits such as the pod length, pod diameter, pod weight (wet weight), internal and external thickness (of pod/rind) and number of beans per pod and bean weight. In addition, textural characters described, mainly include pod color, roughness, shape, base, apex and ridges. Based on these traits, worldwide Cocoa pods are characterized into four types such as Amelonado, Calabacillo, Angoleta and Cundeamor (Ha *et al.*,

[1]The University of the South Pacific, Alafua campus, Samoa
Email:toramoe@yahoo.com, Mobile Telephone +6777950568
[2]Department of Agriculture Fisheries and Forest, Queensland, Australia

2016). Fruits with ovoid shape, smooth skin, and dark purple cotyledon and without a prominent point portrays Amelonado. Cundeamor / Cundeamor is used for elongated cylindrical fruits with a pronounced bottleneck, dark purple cotyledon and a sharp point. Round fruits with no point are described as Calabacillo and Angoleta are specified as long fruits without a bottleneck and pointed ends. Pod shape of Amelonado and Calabacillo are attributed to fruits of Forastero while Angoleta and Cundeamor are attributed to Criollo types of pods. Hence, the morphological traits of Cocoa are very important to measure variability in the Cocoa genotypes (Aikpokpodion, 2010). Morpho-agronomic characteristics of pods, seeds and flowers were used to evaluate relationships among Cocoa genotypes. Morphological descriptors are useful for identifying and selecting the best accessions for future breeding programs. Generally, the phenotypic traits of Cocoa pods play an important role in defining the types of Cocoa (Ballesteros *et al*., 2015). As indicated by Wood and Las (1985) white to pale purple cotyledons are features of the finest Cocoa variety while bulk varieties have generally dark purple colors.

The objective of this study was to determine the morphological characteristics of the identified elite Cocoa trees (*Theobroma cacao* L.) grown by farmers in Makira Island of the Solomon Islands.

MATERIALS AND METHODS

Location of study

The study was conducted in Makira Island formerly known as Santa Cristobal Island in Makira Ulawa Province of the Solomon Islands (Figure 1). Makira Island is located at 10.60º South and 161.85º East (Island directory, 1998). The average annual rainfall in Makiara Island amounts to 3600mm to 4000mm with no dry season. In the southeastern part of the Island, higher rainfall is in the month from May to Occtober while, in the western part of Makira, it is recorded from Novermber to April. On the other hand, in the mountainous regions of the southeast, the rainfall per annum recorded 8000 mm (Allen *et al.*, 2006).

Figure 1 Map of Makira Island showing wards and the geographical locations of the elite cocoa accessions in green triangles. (Source: GIS Unit, Ministry of Agriculture and Livestock, 2018).

Method of selecting elite Coco trees

Selection of identified elite Cocoa trees were done through participatory discussions with the farmers who owned the Cocoa fields. The farmers preferred and identified productive elite Cocoa trees between 7 to 25 years which may have the phenotypic characters of Amelonado or Trinitario were used for the study. Identification of elite Cocoa trees were done by employing the elite Cocoa tree marking protocol adopted and modified from the Department of Agriculture, Fisheries and Forest (DAFF) in Queensland, Australia (Dillon *et al.*, 2014)

Plant Material

In total, the study collected morphological data from identified 40 elite Cocoa trees from 40 farmers' fields in wards 10, 11, 8 and 7 listed in Table 1.

Data collection

Data on morphological traits were recorded in two categories including each of nine quantitative and qualitative traits. The quantitative traits were recorded with a caliper, horse brand wooden ruler and tape measure. Abron digital electronic balance was used to record the weight of the pod and beans. In recording Cocoa bean data, a fine cut was made along the pod with a sharp knife to expose the cotyledon color. In accessions, all the beans were cut symmetrically with small sharp kitchen knife to enable further to compare the observed total color of the cotyledon and beans with Royal Hort. Society color chart. During this procedure, a laminated gray card was used as a background where pods and bean cotyledons were placed for color observations. The quantitative and qualitative morphological traits observed for this study are listed in Table 2 and Table 3.

Table 1. Accession number, field location, ward number and geographical location of the elite Cocoa trees in Makira Island

Accession Number	Field Location	Ward	Longitude S	Latitude E
1LN1	Togori	10	10º27.674	161º56.299
2VK1	Tawaitara	10	10º27.330	161º56.330
3JH1	Tawaitara	10	10º27.631	161º56.363
4CT1	Pawa	10	10º27.693	161º56.428
5DP1	Pawa	10	10º27.509	161º56.314
6VB1	Pawa	10	10º27.581	161º56.258
7JT1	Togori	10	10º27.370	161º56.020
8VBJ1	Togori	10	10º27.431	161º56.003
9CM1	Pawa	10	10º27.588	161º56.288
10BN1	Maona	10	10º27.580	161º56.472
11KG1	Maniahu	11	10º30.063	161º52.552
12MS1	Ngarianagahuto	11	10º30.524	161º57.449
13PN1	Maniahu	11	10º30.215	161º57.756
14CT1	Toratataka	11	10º30.195	161º50.037
15RG1	Ngarianagahuto	11	10º30.688	161º57.766
16JH1	Ngarianagahuto	11	10º30.702	161º57.672
17RK1	Ngarianagahuto	11	10º30.447	161º57.787
18BT1	Barabaraora	11	10º29.615	161º50.118
19SD1	Maopa	11	10º29.996	161º57.858
20JH1	Maopa	11	10º29.957	161º57.803
21MM1	Asimanioha	8	10º15.092	161º29.231
22JK1	Asimanioha	8	10º14.880	161º28.033
23OA1	Asimanioha	8	10º14.866	161º.27.997
24DB1	Asimanioha	8	10º14.893	161º27.881
25CP1	Asimanioha	8	10º15.037	161º27.931
26AM1	Asimanioha	8	10º14.863	161º27.536
27MF1	Asimanioha	8	10º14.875	161º29.355
28JT1	Boroni	8	10º16.111	161º30.025
29MR1	Boroni	8	10º16.102	161º30.023
30JCW1	Boroni	8	10º16.380	161º.29.605
31JMT1	Heuru	7	10º13.778	161º25.720
32RH1	Heuru	7	10º13.731	161º25.763
33ET1	Heuru	7	10º13.601	161º21.868
34RU1	Heuru	7	10º13.550	161º25.869
35ST1	Heuru	7	10º13.572	161º25.917
36CM1	Heuru	7	10º13.412	161º25.929
37MD1	Heuru	7	10º13.084	161º25.695
38JB1	Heraniau	7	10º13.145	161º25.562
39WK1	Tawaniau	7	10º13.233	161º26.476
40AS1	Tawaniau	7	10º13.376	161º26.564

Table 2 Quantitative morphological traits

Variable	Character
1.	Pod length
2.	Pod weight (wet weight)
3.	Pod circumference
4.	Pod external thickness
5.	Pod internal thickness
6.	Number of beans per pod
7.	Weight of beans per pod
8.	Cotyledon length
9.	Cotyledon width

Adopted from Garcia-Alamilla *et al*. (2012); Aikpokpodion (2010)

Table 3 Qualitative morphological descriptors

Variable	Character	Modality
1.	Pod surface texture	1. Smooth 2. Slightly rough 3. Rough 4. Rough and warty
2.	Pod surface shape	1. Un-furrowed 2. Slightly furrowed 3. Medium furrowed 4. Deep furrows
3.	Pod shape	1. Amelonado 2.Cundeamor 3. Angoleta 4.Calabacillo
4.	Pod apex shape	1. Attenuate 2. Acute 3. Obtuse 4. Rounded 5. Mammelate 6. Indented
5.	Pod neck	0. Absent 1. Slight 2. Intermediate 3. Strong 4. Wide shoulder
6.	Cotyledon color	1. Dark purple 2.Medium purple 3. Light purple 4. Light pink
7.	Mature pod ridge colour	0. Absent 1. Present 2. Red pods
8.	Reaction to black pod	1. Susceptible 2. Moderately susceptible 3. Moderately resistant 4. Resistant
9.	Tree vigor	1. Weak 2.Intermediate 3. Vigorous

Adopted from Ballesteros, Logos and Ferny (2015); Aikpokpodion (2010)

Data analysis

Descriptive statistics for all traits were obtained and analyzed and all the nine quantitative variables showed normal distribution. In addition, the following analyses were performed with the Statistical Tool for Agriculture Research (STAR) version 2.0.1 (2014). All the identified 18 morphological traits went through Principal Component Analysis (PCA) to show the traits with high variability responsible for variation between the accessions. The Eigen values ≥ 0.95 were selected to define variations among the morphological traits. To cut short and to define variability responsible for variations between the accessions the PC axis indicating total variation of more than 10% only are indicated in the Table 4. The 110 sample pods from 40 accessions data used in tabulating the frequencies of the first seven qualitative traits. On the other hand 40 accessions reaction to black pod and tree vigor data used in tabulating the frequencies. While, the cluster analysis performed based on unweighted pair group method with the arithmetic mean (UPGMA) to group the accessions with similarities together. Three clusters were performed with the cophenetic correlation of 0.724. Clustering was performed with Euclidean distance method based on the average clustering method. Phenotypic diversity of qualitative traits were analyzed with Shannon-Weaver Diversity Index (SWDI) with the formula mentioned below and with the assistance of Excel calculator.

$$H = \sum_{i=1}^{s} - (P_i * \ln P_i)$$

Where, H = the Shannon diversity index, Pi = Fraction of the entire population made up of traits i (proportion of a trait i relative to total number of traits present, not encountered) and S = Numbers of traits encountered (Beals *et al.,* 2000).

RESULTS

Principal component analysis

The Principal Component Analysis (PCA) of 18 morphological traits of 40 Cocoa accession in Makira Island results with Eigen value of 4.16, 2.20 and 1.97 for the PC axis 1, PC axis 2 and PC axis 3, respectively are presented in the Table 4.

The PCA of the 18 morphological traits showed the first three Principal components accounted for 46.2% of the total variation among Cocoa accessions (Table 4). Principal component (PC) axis one accounted for 23.1% of the total variation and the quantitative traits such as pod weight (g), pod length (cm), pod circumference (cm), cotyledon length (cm), cotyledon width (mm) and weight of beans per pod (g) were mainly responsible for this variation and the scores amounting to 0.4355, 0.351, 0.3887, 0.363, 0.3452 and 0.3102 respectively. Qualitative traits contribute to the variations in PC axis 2 and PC axis 3 accounting for 12.2 and 10.9%, respectively. The variation observed for the second PC axis was due to the traits namely, the cotyledon color, pod ridge color, pod surface texture and pod surface shape and the respective scores observed are 0.5086, 0.3797, 0.4208 and 0.3750. While, the variation registered for the third PC axis was due to, pod neck, pod surface shape, pod surface texture and the respective score observed as 0.5012, 0.4209 and 0.4081 respectively. In the fourth PC axis, pod internal thickness, pod neck and cotyledon length (cm) made up to 8.1% of the total variation. The fifth PC axis accounted for 7.4% of the total variation where pod shape, tree vigor, reaction to black pod and the number of beans per pod were the main contributing traits. Principal component axis number 6 had 6.4% of the total variation mainly attributed to the traits, apex shape, pod external thickness and pod length. The seventh PC axis traits such as, pod shape, tree vigor, and cotyledon width and pod internal thickness accounted for 6.3% of the total variation. Principal component axis eight accounted 5.3% of the total variation for which the responsible traits were reaction to black pod, pod external thickness, pod apex shape and mature pod ridge color (anthocyanin). In total, all eight PCs' together accounted for 79.7% of the total variation among the accessions in Makira Island.

Table 4: Principal component analysis of eighteen traits of forty Cocoa accessions in Makira Island

Parameters	PC1	PC2	PC3
Eigen Values	4.16	2.20	1.97
Total Variation (%)	23.1	12.2	10.9
Cumulative (%)	23.1	35.3	46.2

Character	PC1	PC2	PC3
Pod length (cm)	0.3510	-0.0724	0.2665
Pod circumference (cm)	0.3887	-0.0728	-0.1969
Pod weight (g)	0.4355	-0.1844	0.0370
Pod external thickness (cm)	0.1773	-0.1876	0.0916
Pod internal thickness (mm)	-0.0207	-0.0130	0.1350
Number of beans per pod	-0.1958	-0.2878	0.0739
Weight of beans per pod (g)	0.3102	-0.1817	0.1199
Cotyledon length (cm)	0.3630	-0.1111	-0.0371
Cotyledon width (mm)	0.3452	0.1111	-0.1215
Pod surface texture	0.1322	0.4208	0.4081
Pod surface shape	0.0675	0.3750	0.4209
Pod shape	0.0065	0.0246	-0.2154
Pod apex shape	-0.0938	-0.2031	-0.0497
Pod neck	-0.0411	-0.0574	0.5012
Cotyledon color	-0.0161	0.5086	-0.1938
Mature Pod ridge colour (anthocyanin)	0.1436	0.3797	-0.3291
Reaction to black pod	-0.1892	-0.1173	0.0104
Tree vigor	-0.1717	0.0121	0.1910

Correlation analysis

The correlation coefficients for the quantitative traits of identified Cocoa accessions in Makira are presented in the Table 5. The results indicated that the quantitative trait, the pod length showed positive and significantly higher correlation (+ 0.7406) with pod weight followed by cotyledon length (+ 0.4525) and pod circumference (+ 0.4384) at the probability level of one percent. While, the pod circumference trait showed the greater correlation between the pod weight (value), cotyledon length, the cotyledon width and weight of beans per pod registered positive and significant coefficients at the probability level of once percent whose values were (+) 0.7721, (+) 0.6387 and (+) 0.4749 respectively. On the other hand, the quantitative trait pod weight established higher positive and significant correlation ship at the probability level of one percent between weight of beans per pod followed by cotyledon length and cotyledon width and assumed the value of (+) 0.6328, (+) 0.5862 and (+) 0.4429 accordingly. Whereas, the quantitative traits such as, weight of beans per pod and cotyledon length established positive and significant correlation relationship at the probability level of one percent between cotyledon length and cotyledon width whose value observed as (+) 0.4045 and (+) 0.6711 respectively. For all other quantitative traits, the relationships observed to be non-significant.

Table 5: Correlation matrix of quantitative traits of forty Cacao accessions in Makira Island

Parameters	Pod	Pod	Pod	Pod	Pod	Beans	Beans wt.	Cotyledon
Pod circumference	0.438**							
Pod weight	0.741**	0.772**						
Pod external thickness	0.181^{ns}	0.181^{ns}	0.383^{ns}					
Pod internal thickness	0.130^{ns}	-0.073^{ns}	-0.030^{ns}	0.004^{ns}				
Beans per pod	-0.235^{ns}	-0.310^{ns}	-0.233^{ns}	0.014^{ns}	-0.097^{ns}			
Beans wt. per pod	0.399^{ns}	0.404**	0.633**	0.283^{ns}	0.055 ^{ns}	0.102^{ns}		
Cotyledon length	0.453**	0.639**	0.586**	0.194^{ns}	-0.182^{ns}	-0.225^{ns}	0.405**	
Cotyledon width	0.266^{ns}	0.475**	0.443**	0.228^{ns}	-0.089^{ns}	-0.370^{ns}	0.387^{ns}	0.671**

p-level**=$p<0.01$; ns=not significant respectively

Cluster Analysis

The Figure 2 referring to the dendrogram where in 18 traits grouped 40 Cocoa accessions of Makira Island in three Clusters. The UPGMA cluster analysis based on 18 traits classified the 40 accessions of Makira Island into three clusters, thereby indicating moderate diversity. The Cluster 1 (C_1) comprised of 92.5% of accessions with long and wide cotyledons, Amelonado shape, light purple to light pink cotyledons, red-podded trees, rough natured pods, strong pod neck, obtuse pod apex shape and trees with vigorous growth and intermediate pod neck. While, two Cocoa accessions (2VK1 and 5DP1-Table 1) included in Cluster 2 (C_2) and made up of 5% of the total number of identified accessions with traits including least pod weight, least pod external thickness, and least cotyledon length. On the contrary, only one accession (4CT1-Table 1) included in the Cluster 3 (C_3) and constituted only 2.5% of the accessions representing a single accession with the long pod, large pod circumference, and high number of beans per pod, large pod internal and external thickness.

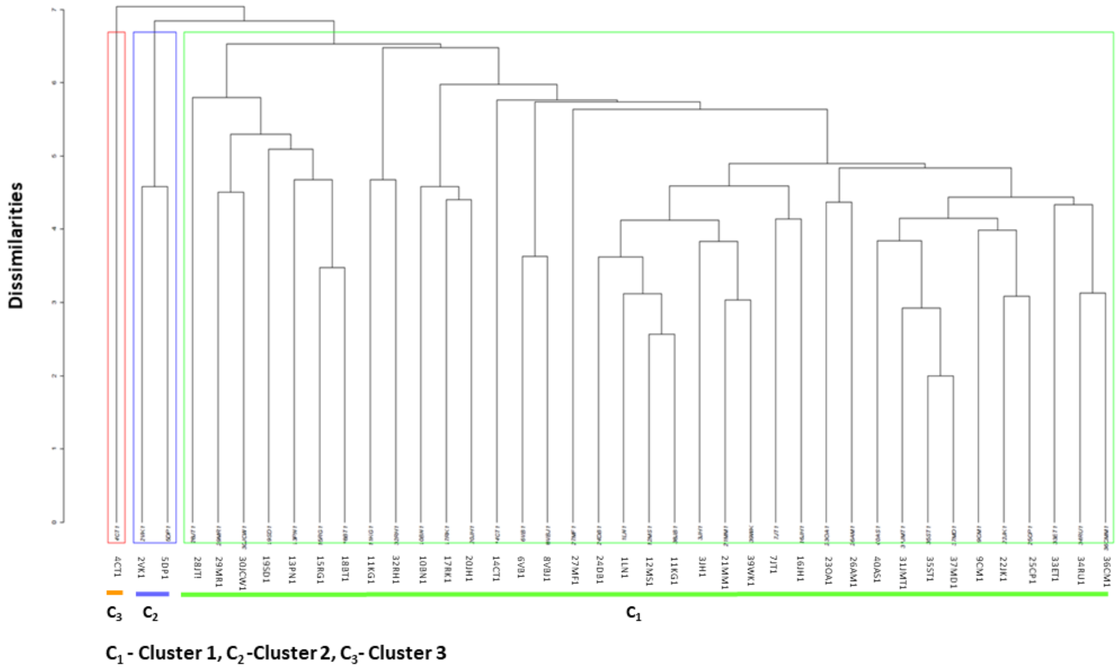

Figure 2: Dendrogram for 40 accessions of Makira Island based on UPGMA cluster analysis

Frequency distribution of qualitative traits

The results on the frequency distribution of nine qualitative traits related to the identified accessions in the farmers' Cocoa fields in Makira Island are presented in the Table 6. For the first trait referring to the pod surface texture, the maximum of 46% of the accession samples distributed in the smooth texture followed by 44% in the slightly rough and the least of 10 percent in the rough state. Second trait the pod surface shape categorized the identified accessions and accounted maximum of 72% in the total, and followed by 25% and the least of 3% for the slightly furrowed, medium furrowed and deep furrowed state respectively. Whereas, for the third trait pod shape, in the total number of accessions the highest of 85% categorized as Amelonado state, and 43, 9 and the lowest of 3% of accessions grouped as the state of Calabacillo, Cundeamor, and Angoleta respectively. On the other hand, the fourth trait pod apex shape the maximum of 44% followed by 25, 20, 9 and a minimum of 2% of the identified as accessions related to the Mammelate, Acute, Obtuse, Round and Attenuate state accordingly.

For the fifth pod neck qualitative trait the maximum of 42% of the total accessions observed, the absent of pod neck state. While, the remaining 37, 12 and 9% of identified Cocoa accessions characterized by the presence of slight, intermediate and strong neck state accordingly. In the similar way for the total number accession the sixth trait the cotyledon color exhibited higher of 46% for the dark purple, 27% for light purple, 22% for medium purple and least of 5% for light pink state respectively. For the seventh trait mature pod ridge color (Anthocyanin), the maximum of 63% of the total categorized as absence of Anthocyanin accessions and remaining 24 and 13% of accessions categorized as red pods and presence of Anthocyanin state accordingly. While, for eighth and ninth traits, each of 72% measured as the strength of the accessions to withstand *Phytophthora palmivora* and vigorous states.

Table 6: Frequency distribution of nine qualitative traits in farmers Cocoa fields in Makira Island

Character	state	Frequency	Percentage
Pod surface texture	1- Smooth	51	46
	2- Slightly rough	48	44
	3- Rough	11	10
Pod surface shape	1- Un furrowed	0	0
	2- Slightly furrowed	79	72
	3- Medium furrowed	28	25
	4- Deep furrows	3	3
Pod shape	1- Amelonado	93	85
	2- Cundeamor	4	4
	3- Angoleta	3	3
	4- Calabacillo	10	9
Pod apex shape	1- Attenuate	2	2
	2- Acute	28	25
	3- Obtuse	22	20
	4- Rounded	10	9
	5- Mammelate	48	44
	6- indented	0	0
Pod Neck	0- Absent	46	42
	1- Slight neck	41	37
	2- Intermediate	13	12
	3- Strong	10	9
Cotyledon color	1- Dark purple	51	46
	2- Medium purple	24	22
	3- Light purple	30	27
	4. Light pink	5	5
Mature pod ridge color (Anthocyanin)	0-Absent	70	63
	1-Present	14	13
	3- Red pods	26	24
Reaction to black pod	1- Susceptible	0	0
	2-Moderately susceptible	0	0
	3-Moderately resistance	11	28
	4-Resistance	29	72
Tree Vigor	1-Weak	0	0
	2-Intermediate	11	28
	3-Vigorous	29	72

Shannon Weaver Diversity Index

An estimation of phenotypic diversity (Table 7) showed a high level of Shannon-Weaver Diversity Index measuring 1.29 for pod apex shape and followed by 1.21 for pod neck and 1.04 for the cotyledon color. With this group of characters, the phenotypic evenness in the site observed to be much higher. On the other hand, the Shannon Weaver Diversity Index for the characters such as pod surface texture, Anthocyanin on mature pod ridge, pod surface shape, pod shape, reaction to black pod and tree vigor exhibited low phenotypic diversity and their respective index value observed as 0.96, 0.86, 0.69, 0.59, 0.58, and 0.5.

Table 7: Shannon Weaver Diversity Index (SWDI) (H') values for qualitative traits of Cocoa accessions in Makira Island

Character	H' values
Pod surface texture	0.96
Pod surface shape	0.69
Pod shape	0.59
Pod apex shape	1.29
Pod Neck	1.21
Cotyledon color	1.04
Anthocyanin on mature pod ridge	0.86
Reaction to black pod	0.58
Tree vigor	0.57

DISCUSSION

Principal component analysis

The Principle Component Analysis (PCA) of identified traits suggested that, the first three PCs accounted for less than 50% of the variability that was responsible for the variation between the identified Cocoa accessions. In view of this, among the identified PCs the morphological traits such as pod length, pod circumference, pod weight, pod external thickness, pod internal thickness, number of beans per pod, weight of beans per pod, cotyledon length and cotyledon width essentially attribute in differentiating Cocoa accessions. This information further corroborate with the findings of the Bekele *et al*., (2008); Efombagn *et al.* (2009); Aikpokpodion (2010) and Ballesteros *et al.* (2015).

In view of this, among the first three PCs, the morphological traits, under PC1 explained with maximum variation (23.10%) and supported in differentiating the Cocoa accessions from the rest of other accessions. Whereas, under PC2 (12.20%) and PC3 (10.90%) the morphological traits explained comparatively less variation in differentiating the Cocoa accessions from other accessions. The relatively maximum morphological traits variations explained by the first three PCs. However, the total variation based on the morphological traits suggested homogeneity among the Cocoa accessories and were categorized in eight PCs and similar observations also reported by Ballesteros *et al.*, (2015). The Principal Component Analysis (PCA) for the variability responsible for the variation between the identified Cocoa accessions categorized and first three PCs based on the traits suggested the identified accessions closely related to the Criollo and Trinitario type. While, remaining five PCs categorized remaining 60.00 percent of the identified accessions as Amelonado type.

Correlation analysis

The correlation matrix coefficients for the quantitative traits of identified Cocoa accession in Makira Island observed the dispersion of variation and calls for the utilization of all the recommended morphological traits (Aikpokpodion, 2010). However, as reported by Efombagn et al. (2009) leaves are not discriminative, therefore not used in this study. A significant positive relationship was observed between the cotyledon length and the cotyledon width ($r=0.6711$, $p<0.01$), similar to the findings by Aikpokpodion (2010) with the $r= 0.522$ at the probability level $=p<0.001$, this relationship was indicated in PC axis 1 and helped in grouping identified accession as Criollo type. Bekele *et al.*, (2008) and Efombagn *et al.*, (2009) also reported the same trend on the seed length and width.
An increase in the seed length will result in the increase in the seed width resulting in large Cocoa bean sizes. Apparently, the number of beans per pod indicated a non-significant relationship ($r= 0.1016$, $p<0.01$) with the weight of beans per pod. This observation contradicted with the findings of Aikpokpodion (2010) where the number of beans per pod had a significant relationship with the weight of beans per pod at $r = -0.131$, $p<0.0001$. Similarly, Iwaro *et al.* (2003) found a weak significant relationship between the number of beans per pod and the weight of beans per pod at $r = -0.19$, $p \leq 0.001$. The dissimilarity in these findings could be due to the low number of samples in this study.

Cluster analysis

Cluster 1 (C_1) has the highest number of the Cocoa accessions among the groups with Amelonado type of pod shape. Amelonado type of Pod shape is an important character, which portrays the phenotype of Amelonado type of cocoa. Dominance of Amelonado pod shape correspond with the report by Dillon *et al*., (2014) that the elite Cocoa trees on Guadalcanal consist mainly of Amelonado type of cocoa. In addition, Hivu (2013) wrote that Amelonado was the variety of Cocoa recommended for farmers to grow.The presence of red-podded Cocoa trees in Cluster 2 and 3 indicate some self-compatible (Johnson *et al.*, 2004) genes of ICS 1 introduced in to the Solomon Islands in the 1960's (Friend, 1970). In support of that, Wood and Lass (1985) and

Aikpokpodion (2010) wrote that red-podded trees have traits of Trinitario and Criollo types of Cocoa.A farmer who applied Integrated Pest and Disease Management (IPDM) pruning method revealed that red-podded trees produce high yield with no significant occurrence of *Phytophthora palmivora*. In addition, a spacing of 4mx4m was ideal for the red-podded trees to overcome *Phytophthora palmivora*. This information of the study clearly suggested that with improved management practices the plant productivity and the quality of the Cocoa beans could be improved. As such, the red-podded Cocoa trees were considered high yielding similar to the report by Aikpokpodion (2010).

The Cocoa accession in Cluster 3 (C_3) has a traditional history that the genotype was taken directly into Makira Island recently from Panama by someone from Makira Island who was a sailor. The farmers who grow this genotype estimated that it has a pod index of 20. Bartley (2005) wrote that variation of the phenotypes expressed the resultant actions of the different alleles that occur in the genes, which controls the specific characteristics and the total number of the alleles, which make up the plant genotype.

Frequency distribution of qualitative traits

The pod surface texture had two most frquent observed traits viz, smooth and slightly rough. Those two traits are dominant in the Amelonado type of Cocoa. Dominance of slightly furrowed and medium furrowed in the pod surface shape were traits also present in Amelonadoas discribed by Bartley (2005); Wood and Lass (1985); Aikpokpodion (2010) and Ha *et al*., (2016). When the percentage of Amelonado pod shape was added to that of Callabacillo pod shape, they indicate a very strong trait of Amelonado type of Cocoa in the Makira Island Cocoa accessions studied.

In this study, the percentage weightings of mammelate , followed by obtuse and rounded types of pod apex shape also showed that Amelonado was dominant in the Cocoa accessions studied. A shift of 51 percent from Amelonado was expressed in the pod neck. Forty-one percent was found to have no pod neck, which could be a trait of SCA6 since it has no pod neck and similar observation also reported by Bekele, Butler and Bidaisee, (2008), SCA 6 was a type of Cocoa made part of the Cocoa population of the Solomon Islands in 1964 (Friend, 1970). Hence, nine percent of the identified Cocoa accession in the study area showed strong neck of Criollo type. This observation confirmed by the statements made by Friend (1970) and Proposals on Processing and Marketing of Cocoa in the British Solomon Islands (1961) recommended the Criollo hybrids and was already grown by farmers in their fields before Amelonado was imported for trials. However, the low percentage of strong neck showed very little influence of Criollo genes on the accessions studied. This correspond with the low percentage of red pods, a trait under the control of a single dominant gene of Criollo and Trinitario types (Bartley, 2005 and Aikpokpodion, 2010).

This study found four types of cotyledon colors among the Cocoa accessions. They were dark purple, medium purple, light purple and light pink. Dark purple attributed to Amelonado (Wood and Lass, 1985 and Bartley, 2005). In this study, cotyledon colors with dark purple and medium purple categorized as dark purple. Hence, larger numbers of identified Cocoa accessories carried with trait categorized Amelonado type. On the other hand, very little number of Cocoa accessions showed the existence of light purple and light pink cotyledon color traits of Trinitario types in the Cocoa population in Makira Island.

The weightings by percentage in accession vigorousness correspond to the strength to resist *Phytophthora palmivora* (Table 6). Strong tree vigor and resistance to *P. palmivora* are traits common in Amelonado. Hence, these are traits desired in Amelonado for adoptability which is used widely for hybridization with other varieties especially, Criollo type (Zhang and Motial, 2016).

Based on the results of the frequency distribution of qualitative traits one could infer that, identified Cocoa accessions in the Makira Island expressed that, the Cocoa population dominated by the Amelonado type and little extent by Criollo and Trinitario type.

Shannon Weaver Diversity Index

The Shannon-Weaver Diversity Index results (Table 7) on the analysis of phenotypic diversity with qualitative traits indicated relatively higher index values for pod apex shape, pod neck and cotyledon color as compared to pod surface texture, Anthocyanin on mature pod ridge, pod surface shape, pod shape, reaction to black pod and tree vigor. Based on this information one can infer that, the identified Cocoa accessions in the study area with higher index values showed greater amount of evenness with larger number of species clustered in Cluster 1 (92.5%) and with lesser percentage of accessions in the site belong to Criollo and Trinitario type. On the contrary the identified Cocoa accession in the Makira Island with lower Shannon-Weaver Diversity Index ranges (from 0.5 to 1.3) suggested that, lesser amount of diversity and unevenness with lesser species with lesser larger percentages of individual accession belong to one species namely Amelonado.

Further, this analysis information confirms with the study results observed under Principal Compound Analysis (PCA), Correlation analysis, Cluster analysis and Frequency distribution of qualitative traits. Hence, all qualitative traits observed to be useful in analyzing and drawing meaningful conclusions on the existence of phenotypic diversity in the Makira Island. These results also confirm with the findings of Efombagn *et al.* (2009); Bekele *et al.* (2008).

CONCLUSION

The study found phenotypic variation in the quantitative and qualitative traits among the 40 elite Cocoa accessions studied in the cocoa population in Makira Island of Makira Ulawa province of the Solomon Islands. Morphology of the pod surface texture, pod surface shape, pod shape, pod apex shape, cotyledon colour and tree vigor with the ability of the tree to withstand *Phytophthora palmivora* exhibited strong traits of Amelonado as the dominant variety showing greater amount of evenness with larger number of accessions cluster together in Cluster 1 . These traits strongly suggest the Cocoa population in Makira as consisting mainly of Amelonado with lesser diversity among the accessions grouped in the

Cluster 1, but the grouped accessions showing higher variability for identified traits. On the other hand, the presence of red pods implies little influence of Criollo and Trinitario types of Cocoa. Under Makira existing Cocoa production scenario findings of the study justify that, Cocoa beans produced by farmers are of bulk type and realize relatively lesser amount income as compared to the fine type Cocoa beans.

Based on these facts of the study the existing farmers' cocoa gardens need to be upgraded from bulk to fine quality beans producing cocoa gardens. In view of the sustainable fine quality cocoa production and to scale up the economic returns study suggested for phase wise upgrading of existing farmers Cocoa fields from bulk quality Cocoa of Amelonado type to fine quality Cocoa of Criollo and Trinitario type. Further, the presence of red pods Cocoa plants in some of identified location and depicting fine quality Cocoa of Crillo and Trinitario would be the best source of planting material for the production of fine quality Cocoa grafts. With these technical interventions under the Makira Island situation over the period of time the overall production of Cocoa would shift from bulk type to fine quality and improves Cocoa farmers' economic conditions.

ACKNOWLEDGEMENTS

The Australian Government through ACIAR project HORT/2014/078 supported this research financially.
The authors are grateful to the considered comments from the reviewers in reviewing this paper.

REFERENCES

AIKPOKPODION, O. P. 2010. Variation in agro-morphological characteristics of Cacao, *Theobroma cacao* L., in farmers' fields in Nigeria, *New Zealand Journal of Crop and Horticultural Science*. 38(2): 157-170.

AIKPOKPODION, O. P. 2012. Defining genetic diversity in chocolate tree. *Theobroma cacao* L grown in West and Central Africa. In: Caliskan M (ed) .*Genetic diversity in plants*. ISBN: 978-953-51-0185-7, Intech, Chapter 10. [pdf] Available from: http://cdn.intechopen.com/pdfs/31478 [Accessed: 30 June 2017]

ALLEN, M.G., BOURKE, R.M., EVANS, B.R., IRAMU, E., MAEMAURI, R. K., MULLEN, B.F., POLLARD, A.A, WAIRIU, M., WATOTO, C. AND ZOTALIS, S. 2006. *Solomon Islands Smallholder Agriculture Study*. *Common wealth of Australia, 4 Provincial Reports.* [pdf] .Available at: http://repository.usp.ac.fj/id/eprint/9646 [Accessed: 3 January 2018]

BALLESTEROS, P. W., LOGOS, C. AND FERNY. H. 2015. Morphological characterization of elite cacao trees (*Theobroma cacao* L.) in Tumaco, Nariño, *Colombia, Revista Colombiana de Ciencias Horticolas*. 9(2), 313-328.

BARTLEY, B.G.D., 2005. *Genetic Diversity of Cacao and its Utilization*. [e-book] CABI. Available at https://ebookcentral.proquest.com/lib/uspfj-ebooks/reader.action?docID=295077&ppg=39 [Accessed: 15 December 2017]

BEKELE F.L., BUTLER, D. R. AND BIDAISEE, G.G. 2008. Upper Amazon Forastero cacao (*Theobroma cacao* L.) 1: An assessment of phenotypic relationships in the International Cocoa Gene bank, Trinidad. *Trop. Agric. Trinidad.* 85(1): 1-15.

BEALS, M. L., GROSS, L. AND HARRELL, S. 2000. *Diversity indices: Shannon's H and E,* [Online] Available at http://www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html [Accessed: 7 May 2017]

COMMODITIES EXPORT MARKETING AUTHORUTY. 2015. Pacific Island

DILLON, N., HUCKS, L., DICZBALIS, Y. AND KETE, T. 2014. Evaluation of molecular marker technology for identification of elite cocoa germplasm in the South Pacific. PC/2014/032, ACIAR, GPO Box 1571, Canberra ACT 2601, Australia

EFOMBAGN, M. I. B, O., SOUNIGO, O., NYASSÉ, S., MANZANARES- DAULEUX, M. AND ESKES, A. B. 2009. Phenotypic variation of cacao (*Theobroma cacao* L.) on farms and in the gene bank in Cameroon. *Journal of Plant Breeding and Crop Science.* 1(6): 258-264.

FRIEND D. 1970. *A report on cocoa growing in the British Solomon Islands Protectorate*. Department of Agriculture, Government printer. British Solomon Islands Protectorate

GARCIA-ALAMILLA, G. P., GONZÁLEZ-LAUCK, V.W., DE LA CRUZ-LÁZARO, E., LAGUNES-GÁLVEZ, L.M. AND GARCÍA- ALAMILLA, R. 2012. Description and physical properties of Mexican Criollo cacao during post-harvest processing. *Revista Iberoamericana de Tecnología Postcosecha.* 13(1) 58-65.

GAYI, S. K. AND TSOWOU, K. 2012.Cocoa industry: *Integrating small farmers into the global value chain United Nations Conference on trade and development.* [pdf] Available at: http://unctad.org/en/PublicationsLibrary/suc2015d4_en. [Accessed: 12 March 2018]

HA, L., THAI HANG, P., EVERAERTI, H., ROTTIERS, H., TUNGANH, L., NHANDUNG, T., DUCPHUOC, P., THANH TOAN, H., DEWETTINCK, K. AND MESSENS, K. 2016. Characterization of Leaf, Flower and Pod Morphology among Vietnamese Cocoa Varieties (*Theobroma cacao*). *Pakistan Journal of Botany* .48(6): 2375-2383.

HIVU, D. O. 2013. A Case Study in the Solomon Islands on the Impact of Small Holder Cocoa Production on Rural Livelihoods. *Master of Agric Science thesis. Massey University.*, [Online] Available at: https://mro.massey.ac.nz/bitstream/handle/10179/5981/02_whole.pdf?sequence=2&isAllowed=y [Accessed: 22, June 2016]

HOUSTON, H. AND WYER, T. 2012. Why Sustainable Cocoa Farming Matters for Rural Development. *Center for Strategic & International Studies.* [Online] Available at: https://www.csis.org/analysis/why-sustainable-cocoa-farming-matters-rural-development

ICCO (International cocoa organization), 2013. *What is the origin of Cocoa tree?* [Online] Available at: https://www.icco.org/faq/51-cocoa-trees/114-what-is-the-origin-of-the-cocoa-tree.html [Accessed: 29 April 2018]

ICCO. 2017. *ICCO Quarterly Bulletin of Cocoa Statistics*, Vol. XLIII, No. 3, Cocoa year 2016/17. [Online] Available at: https://www.ecosia.org/search?q=ICCO+Quarterly+Bulletin+of+Cocoa+Statistics%2C+Vol.+XLIII%2C+No.+3%2C+Cocoa+year+2016%2F17&ref=waterfox [Accessed: 29 April 2017]

ISLAND DIRECTORY. 1998. *Islands of Solomon Islands.* [Online] Available at: http://islands.unep.ch/CLU.htm [Accessed: 21 December 2017].

IWARO, A. D., BEKELE, F. L. AND BUTLER, D.R. 2003. Evaluation and utilization of cacao (*Theobroma cacao* L.) germplasm at the International Cocoa Gene bank, Trinidad. *Cocoa Research Unit, Euphytica* 130: 207–221.

JOHNSON, E., BEKELE F. AND SCHNELL, R. 2004. *Field Guide to the ICS Clones of Trinitario.* [e-book] CABI. Available at: https://books.google.ws/books/about/Field_Guide_to_the_ICS_Clones_of_Trinida.html?id=KCEOAQAAIAAJ&redir_esc=y [Accessed: 6 April 2018]

PROPOSALS ON THE PROCESSING AND MARKETING OF COCOA IN THE BRITISH SOLOMON ISLANDS. 1961. *British Solomon Islands Protectorate.*

COMMODITIES EXPORT MARKETING AUTHORITY. 2015. *Statistical Bulletin*, Honiara, Solomon Islands.

STAR, VERSION 2.0.1 2014. Biometrics and Breeding Informatics, PBGB Division, *International Rice Research Institute*, Los Baños, Laguna.

VADNJAL, D. AND PELOMO, M. 2014. Solomon Islands cocoa value chain analysis, *World Bank*, *Australian Department of Foreign Affairs and Trade*, Mondelez International. [pdf] Available at https://openknowledge.worldbank.org/bitstream/handle/10986/17802/860440WP0P08920ain0Analysis000FINAL.pdf?sequence=1&isAllowed=y

WOOD, R. A. G. AND LASS, A.R. 1985. *Cocoa.* [e-book] John Wiley & Sons. Available through: ProQuest E-book Central https://ebookcentral.proquest.com/lib/uspfj-ebooks/reader.action?ppg=1&docID=470294&tm=1521168781338 [Accessed:16 March 2018]

WORLD COCOA FOUNDATION. 2018. *Knowledge center*. [Online] Available at: http://www.worldcocoafoundation.org/category/program-region/worldwide/ [Accessed: 12 March 2018]

ZHANG, D. AND MOTILAL, L. 2016. Origin, Dispersal, and Current Global Distribution of Cacao Genetic Diversity. In: Bailey, B.A and Meinhardt, L .W (eds). 2016. *Cocoa diseases. A history of old and new encounters*. Springer International Publishing Switzerland.