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ORIGINAL RESEARCH ARTICLE

Cacao materials (*Theobroma cacao* L.) from different production areas in Colombia: A morphological study

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ABSTRACT

The characteristics of agricultural products are influenced by the ecosystem, from the perspective of biotic and abiotic factors, which produce in the plant physiological responses and in turn in the fruit unique physicochemical properties, which are the basis for designations of origin and strategies to add value to the product in the current market. In the present work, ten cocoa materials (*Theobroma cacao* L.) were selected for their outstanding productivity (FSV41, FLE3, FEAR5, FSA12, FEC2, SCC23, SCC80, SCC55, ICS95 and CCN51), which were established in the departments of Santander (931 m a.s.l.), Huila (931 m a.s.l.), Huila (931 m a.s.l.), Huila (931 m a.s.l.), Huila (931 m a.s.l.), Huila (931 m a.s.l.) and Huila (931 m a.s.l.). These were established in the departments of Santander (931 m a.s.l.), Huila (885 m a.s.l.) and Arauca (204 m a.s.l.), the main cocoa-producing areas in Colombia. For the evaluation of the physical characteristics of the collected materials, 21 quantitative descriptors were used to determine the physical variability of the fruit according to clone and place of collection. The data collected were analyzed by means of Pearson's correlation matrix and principal component analysis, it was possible to identify those descriptors that contribute most to the variability among materials (ear index, diameter length ratio, seed weight and diameter, and fruit weight and length). In addition, it was possible to verify the effect of the place of harvest on the physical characteristics of the materials, high-lighting the importance of the adaptation study prior to the planting of the cocoa material, with the objective of guaranteeing a premium, productive and quality cocoa crop for the industry, which is competitive in the market.

Keywords: Descriptors; Genetic Diversity; Main Components; Environmental Influence; Genotype

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1. Introduction

The populations of individuals that make up a plant species are under a continuous interaction of adaptation, where physical, biological, biochemical and anatomical factors intervene, so each species adapts the information contained in the genome according to its needs[1]. The result of the above is the accumulation of genetic information that each species stores among the members of its population and transmits it to subsequent generations over time; thus, although the population of a species shares common characteristics, it may present many individual variants, which are called genetic variability, which allows each species to adapt to the changes that occur in its environment[2].

The cocoa plant *Theobroma cacao* L. is highly allogamous, indicating that cross-pollination is 95%, although there is a possibility that some materials are self-pollinated; as a consequence, most of the genetic materials are heterozygous[3]. From the economic point of view, Colombia is a country that has comparative advantages for cocoa production because it has a wide genetic diversity and is in a strategic geographical position, due to its location in the equatorial zone, with a wide variety of thermal floors and availability of water resources[4]. Cacao is a species belonging to the class of dicotyledons, family Malvaceae and genus *Theobroma*, it grows at altitudes of 0 to 1,200 m.a.s.l., which has a relevant impact on the variability of the fruit characteristics, as well as on the genetic material[5].

In Colombia, crop modernization was carried out in 2000 through the planting of cocoa clones, which led to an increase in genetic diversity. Since 2006, Fedecacao and Agrosavia have had experimental plots in six cocoa-growing regions of the country, where they have five regional materials SCC (Colombia Corpoica Selection) 23, 41, 52, 58, 80, five regional Fedecacao materials FLE 3 (Fedecacao Lebrija), FEAR 5 (Fedecacao Arauquita), FSA 12 (Fedecacao Saravena), FEC 2 (Fedecacao El Carmen), FSV 41 (Fedecacao San Vicente) and two materials introduced to Colombia as controls ICS 95 and CCN 51[6]. According to the research of González *et al.*[7], they carried out the identification and evaluation of elite cocoa trees, with production, adaptability and outstanding quality characteristics in the Urabá subregion, selecting four groups by cluster analysis; the first group was characterized by having high yields unlike the other groups, recommending to evaluate the compatible relationship of the clones with respect to the other materials already propagated and established. For their part, Martínez *et al.*[6] carried out a morpho-agronomic characterization of 42 genotypes and molecular characterization of 70 genotypes, collected in different producing regions of Colombia, managing to verify the existing relationship between the selected genotypes and parents used in genetic improvement programs. Ten cocoa materials selected by Fedecacao and Agrosavia for their high yields in productivity and basic quality parameters (FSV41, FLE3, FEAR5, FSA12, FEC2, SCC23, SCC80, SCC55, ICS95 and CCN51) were characterized morpho-agronomically, established in different areas of the country with the purpose of evidencing the influence of the collection place on its physical characteristics.

2. Materials and methods

The morpho-agronomic characterization of 10 cocoa materials: FSV41, FLE3, FEAR5, FSA12, FEC2, SCC23, SCC80, SCC55, ICS95 and CCN51, from Santander (931 m a.s.l.), Huila (885 m a.s.l.) and Arauca (204 m a.s.l.), main producing areas of the country, was carried out. The collection was managed under the guidelines indicated in Resolution 1466 of December 03, 2014. For the morpho-agronomic characterization, six fruits per tree were selected from each material at physiological maturity stage, preserving uniformity in color, shape and size, in addition to the absence of bio-logical damage. The samples were transported to the Agro-food Sciences laboratory of the C.I. Nataima of the Corporación Colombiana de Investigación Agropecuaria - AGROSAVIA (Espinal, Tolima) where 21 descriptors were evaluated according to the established protocol (**Table 1**).

Table 1. Morpho-agronomic descriptors evaluated in the characterization of ten cocoa (*Theobroma cacao* L.) materials

	Descriptor	Code		Descriptor	Code
Fruit	Fruit weight	P.F.	Seed	Seed weight with mucilage	P.S.H.
	Fruit length	L.F.		Percentage of seed with mucilage	R.S.H.
	Fruit diameter	D.F.		Seed weight without mucilage	P.S.S.
	Ratio length diameter	R.L.D.		Percentage of seed without mucilage	R.S.S.
Shell	Shell weight	PC.		Cob index	I.M.
	Percentage of shell	R.C.		Grain index	I.G.
	Shell thickness	G.C.		Seed length	L.S.
				Seed diameter	D.S.
Placenta	Placenta weight	P.PL.		Seed thickness	G.S.
	Placenta percentage	R.P.	Mucilage	Mucilage weight	P.P.
Seed	Number of seeds	N.S.		Percentage of mucilage	R.P.

Source: Authors.

The respective weights were determined with an Ohaus® brand analytical balance, model Adventure Pro AV412 of precision 0.01 g, recording the values in grams (g). The length, diameter and thickness of the different characters were measured with a digital caliper with a precision of 0.01 mm (Mitutoyo®), reporting the values in millimeters (mm). Fruit color was determined according to Munsell's table of plant tissues. The number of seeds refers to the number of seeds in each cocoa fruit. The pod index is the average number of fruits or pods needed to obtain one kg of dry cocoa and the bean index is the average bean weight in grams, taken from a sample of 100 dry cocoa beans.

2.1 Statistical analysis

Data collected from morpho-agronomic characterization were analyzed using general linear and mixed models, considering collection site and materials as fixed effects and repetition as a random factor. These models were selected according to the Akaike and Bayesian information criteria. The mean comparison test used was Di Rienzo, Guzman and Casanoves (DGC). The analyses described above were performed with RStudio software version 3.5.1 (RStudio Inc, Boston, USA); correlation analysis was also performed using Pearson's matrix to detect those descriptors with a high (>70%) and significant correlation. From the correlation matrix, the principal component analysis (PCA) was used to identify the descriptors that contributed the highest percentage of variability. The dispersion of the populations was plotted on the plane determined by the first two principal components. The PCA data were processed using the SPAD statistical package version 3.5[8].

3. Results and discussion

The results showed that the area, material and interaction were statistically significant ($P \leq 0.05$) (**Table 2**). In the adjusted mean comparison test (**Table 3**), it was observed that the CCN51 material from Arauca presented outstanding values of mucilage percentage and in Santander it excelled in terms of seed number; Sotomayo *et al.*[9] in their study grouped the CCN51 material together with INIAPT 094, INIAPT 484 and INIAPT 384 for sharing high values of fresh weight and healthy cobs Rojas *et al.*[10] in the search to identify potential indicators of maturity for harvesting cocoa fruits, found that the CCN51 material stood out for seed weight. The FEAR 5 material from the department of Huila, presented the highest values of fruit length and diameter length ratio, the FEC 2 from Arauca stood out for presenting the highest values of seed weight without mucilage and seed percentage.

Table 2. General Abstract of the hypothesis tests obtained from the general and mixed linear models for each of the outstanding characteristics in ten cocoa (*Teobroma cacao* L.) materials. F and *p*-values are the result of area and material factors and their interaction. The p-values with statistical differences ($P \leq 0.05$) are highlighted with bold and present double*

Feature	Zone		Material		Zone*Material	
	F-value	p-value	F-value	p-value	F-value	p-value
P.F.	40.77	<0.0001	8.79	<0.0001	12.71	<0.0001**
L.F.	17.82	<0.0001	5.85	<0.0001	9.41	<0.0001**
R.L.D.	51.51	<0.0001	10.41	<0.0001	2.30	0.0042**
R.C.	6.62	0.0019	25.26	<0.0001	15.58	<0.0001**
P.PL.	26.30	<0.0001	30.29	<0.0001	4.58	<0.0001**
N.S.	6.99	0.0014	7.37	<0.0001	2.12	0.0091**
P.S.S.	205.70	<0.0001	23.08	<0.0001	15.29	<0.0001**
R.S.S.	198.13	<0.0001	64.64	<0.0001	29.52	<0.0001**
I.M.	37,703.94	<0.0001	2,937.78	<0.0001	1,899.69	<0.0001**
G.S.	6.56	0.0020	2.04	0.0408	2.68	0.0008**
D.S.	13.48	<0.0001	25.48	<0.0001	6.55	<0.0001**
R.P.	179.16	<0.0001	14.30	<0.0001	19.39	<0.0001**

Table 3. Adjusted means, standard error and their respective significance ($P \leq 0.05$) of outstanding characteristics in ten cocoa (*Teobroma cacao* L.) materials

Zone	Clone	P.F.	L.F.	R.L.D.	R.C.	P.PL.	N.S.	P.S.S.	R.S.S.	I.M.	G.S.	D.S.	R.P.
Arauca	CCN 51	600.74 ± 28.2^{c}	209.63 ± 3.45^{d}	2.26 ± 0.04^{c}	59.12 ± 2.6^{b}	15.08 ± 1.16^{b}	48 ± 2.57^{b}	63.06 ± 5.02^{d}	10.59 ± 1.23^{f}	15.51 ± 0.16^{j}	9.96 ± 0.45^{b}	13.71 ± 0.41^{b}	27.79 ± 1.98^{a}
	FEAR 5	450.92 ± 47.12^{d}	191.4 ± 5.85^{d}	2.4 ± 0.11^{b}	65.49 ± 2.14^{b}	13.03 ± 1.6^{b}	44.2 ± 4.36^{b}	44.33 ± 5.38^{e}	9.74 ± 0.99^{f}	22.51 ± 0.16^{d}	8.82 ± 0.32^{b}	12.09 ± 0.44^{c}	21.85 ± 1.05^{b}
	FEC 2	677..24 ± 17.49^{c}	205.92 ± 434^{d}	2.36 ± 0.04^{b}	63.72 ± 2.36^{b}	11.75 ± 0.66^{b}	45.8 ± 3.6^{b}	193.49 ± 8.6^{a}	30.76 ± 0.98^{a}	5.5 ± 0.12^{t}	8.51 ± 0.49^{b}	15.4 ± 0.43^{b}	5.78 ± 1.05^{d}
	FLE 3	610.42 ± 32.9^{c}	207.61 ± 6.63^{d}	2.84 ± 0.09^{a}	63.59 ± 2.79^{b}	15.65 ± 2.43^{b}	48.2 ± 2.42^{b}	63.32 ± 8.92^{d}	10.42 ± 0.79^{f}	15.35 ± 0.14^{j}	8.64 ± 0.28^{b}	13.61 ± 0.41^{b}	23.46 ± 1.21^{b}
	FSA 12	707.8 ± 43.08^{c}	223.81 ± 6.83^{c}	2.36 ± 0.05^{b}	72.82 ± 1.86^{a}	14.71 ± 1.34^{b}	48 ± 1.9^{b}	65.46 ± 4.63^{d}	9.32 ± 0.69^{f}	16.52 ± 0.18^{i}	9.72 ± 0.2^{b}	11.75 ± 031^{c}	15.8 ± 1.04^{c}
	FSV 41	625..28 ± 51.69^{c}	195.25 ± 5.84^{d}	2.15 ± 0.07^{c}	48.19 ± 3.39^{c}	28.62 ± 3.1^{a}	46.8 ± 0.8^{b}	87.01 ± 10.17^{c}	14.09 ± 0.9^{e}	13.45 ± 0.14^{l}	9.93 ± 0.55^{b}	17.12 ± 0.58^{a}	33.18 ± 2.81^{a}
	ICS 95	494.81 ± 26.07^{d}	192.48 ± 4.88^{d}	2.4 ± 0.06^{b}	76.26 ± 1.67^{a}	3.05 ± 0.96^{d}	36.8 ± 1.39^{b}	34.36 ± 6.33^{e}	6.95 ± 1.06^{g}	27.5 ± 0.16^{b}	8.35 ± 0.27^{b}	10.88 ± 0.27^{c}	16.18 ± 1.08^{c}
	SCC 23	823.86 ± 45.54^{b}	242.08 ± 6.9^{b}	2.47 ± 0.08^{b}	79.33 ± 2.83^{a}	12.53 ± 1.72^{b}	48 ± 5.61^{b}	119.72 ± 939^{c}	14.36 ± 0.96^{e}	8.41 ± 0.16^{r}	11.74 ± 0.45^{a}	14.89 ± 0.54^{b}	4.81 ± 1.67^{d}
	SCC 80	596.04 ± 40.89^{c}	223.02 ± 6.57^{c}	2.49 ± 0.06^{b}	73.76 ± 0.65^{a}	9.47 ± 1.44^{c}	42.2 ± 3.54^{b}	42.22 ± 4.88^{e}	7.13 ± 0.56^{g}	24.58 ± 0.15^{c}	9.17 ± 0.52^{b}	11.08 ± 0.71^{c}	17.54 ± 0.77^{c}
	SSC 55	711.8 ± 57.73^{c}	205.62 ± 6.56^{d}	2.24 ± 0.06^{c}	70.33 ± 2.37^{a}	15.74 ± 2.09^{b}	40.2 ± 1.66^{b}	52.45 ± 4.9^{e}	7.41 ± 0.539	19.37 ± 0.16^{f}	9.44 ± 0.26^{b}	13.74 ± 034^{b}	20.03 ± 2.39^{b}
Huila	CCN 51	393.46 ± 28.2^{d}	207.32 ± 3.45^{d}	2.64 ± 0.04^{a}	60.67 ± 2.64^{b}	12.64 ± 1.12^{b}	49.2 ± 3.99^{b}	50.8 ± 5.02^{e}	13.48 ± 1.23^{e}	19.43 ± 0.17^{f}	8.95 ± 0.31^{b}	12.18 ± 0.41^{c}	8.39 ± 1.98^{d}
	FEAR 5	667.59 ± 47.12^{c}	266.57 ± 5.85^{a}	3.02 ± 0.11^{a}	61.78 ± 2.1^{b}	14.89 ± 1.71^{b}	45.4 ± 1.03^{b}	60.2 ± 5.38^{d}	9.3 ± 0.99^{f}	17.51 ± 0.14^{h}	10.52 ± 0.53^{a}	13.15 ± 0.44^{b}	3.97 ± 1.05^{d}
	FEC 2	622.73 ± 17.49^{c}	230.98 ± 4.34^{c}	2.68 ± 0.04^{a}	64.4 ± 2.38^{b}	8.85 ± 0.72^{c}	44 ± 4.39^{b}	54.07 ± 8.6^{e}	8.6 ± 0.98^{f}	18.4 ± 0.16^{g}	9.21 ± 0.5^{b}	13.85 ± 0.43^{b}	4.58 ± 1.05^{d}
	FLE 3	534.2 ± 32.9^{d}	230.91 ± 6.63^{c}	2.84 ± 0.09^{a}	59.48 ± 2.68^{b}	14.67 ± 2.29^{b}	46.2 ± 1.16^{b}	46.83 ± 8.92^{e}	8.88 ± 0.79^{f}	20.65 ± 0.17^{e}	9.64 ± 0.3^{b}	13.37 ± 0.41^{b}	7 ± 1.21^{d}
	FSA 12	521.97 ± 43.08^{d}	220.91 ± 6.83^{c}	2.53 ± 0.05^{b}	76.63 ± 1.88^{a}	7.69 ± 1.15^{c}	38.4 ± 4.47^{b}	42.22 ± 4.63^{e}	8.15 ± 0.69^{f}	27.43 ± 0.15^{b}	9.5 ± 0.37^{b}	1162 ± 0.31^{c}	3.27 ± 1.04^{d}
	FSV 41	424.55 ± 51.69^{d}	201.67 ± 5.84^{d}	2.46 ± 0.07^{b}	46.68 ± 3.3^{c}	15.22 ± 1.8^{b}	43.6 ± 1.89^{b}	69.67 ± 10.17^{d}	16.53 ± 0.9^{d}	14.47 ± 0.14^{k}	9.24 ± 0.5^{b}	15.34 ± 0.58^{b}	7.66 ± 2.81^{d}
	ICS 95	390.13 ± 26.07^{d}	212.37 ± 4.88^{d}	2.83 ± 0.06^{a}	71.97 ± 1.66^{a}	4.73 ± 0.95^{d}	39 ± 1.64^{b}	48.73 ± 6.33^{e}	12.68 ± 1.06^{e}	22.35 ± 0.19^{d}	10.3 ± 0.55^{a}	13.42 ± 0.27^{b}	3.37 ± 1.08^{d}
	SCC 23	506.48 ± 45.54^{d}	222.63 ± 6.9^{c}	2.7 ± 0.08^{a}	76.41 ± 2.76^{a}	6.16 ± 1.29^{d}	39.6 ± 5.84^{b}	33.05 ± 9.39^{e}	6.51 ± 0.96^{g}	30.48 ± 0.15^{a}	10 ± 0.65^{b}	13.29 ± 0.54^{b}	2.6 ± 1.67^{d}
	SCC 80	674.75 ± 40.89^{c}	244.91 ± 6.57^{b}	2.68 ± 0.06^{a}	62.76 ± 0.73^{b}	9.05 ± 1.42^{c}	35 ± 5.72^{b}	36.93 ± 4.88^{e}	5.38 ± 0.56^{g}	27.58 ± 0.15^{b}	9.05 ± 0.25^{b}	12.56 ± 0.71^{c}	4.79 ± 0.77^{d}
	SSC 55	477.7 ± 57.73^{d}	206.44 ± 6.56^{d}	2.51 ± 0.06^{b}	76.59 ± 2.48^{a}	8.95 ± 1.5^{c}	36.8 ± 1.16^{b}	42.5 ± 4.9^{e}	9.07 ± 0.53^{f}	24.36 ± 0.21^{c}	9.22 ± 0.5^{b}	13.12 ± 0.34^{b}	2.65 ± 2.39^{d}
Santan-der	CCN 51	760.77 ± 28.2^{b}	225.41 ± 3.45^{c}	2.32 ± 0.04^{c}	65.25 ± 2.76^{b}	21.14 ± 1.24^{a}	56 ± 3.65^{a}	145.11 ± 5.02^{b}	19.1 ± 1.23^{d}	7.28 ± 0.01^{s}	9.17 ± 0.82^{b}	14.91 ± 0.41^{b}	12.87 ± 1.98^{c}
	FEAR 5	621.84 ± 47.12^{c}	224.42 ± 5.85^{c}	2.53 ± 0.11^{b}	73.37 ± 2.25^{a}	13.37 ± 1.62^{b}	44 ± 2.55^{b}	109.96 ± 5.38^{c}	17.84 ± 0.99^{d}	9.08 ± 0.01^{p}	9.91 ± 0.32^{b}	14.18 ± 0.44^{b}	6.66 ± 1.05^{d}
	FEC 2	665.89 ± 17.49^{c}	216.17 ± 4.34^{d}	2.42 ± 0.04^{b}	73.2 ± 2.54^{a}	10.77 ± 0.68^{b}	45.4 ± 2.48^{b}	109.66 ± 8.6^{c}	16.46 ± 0.98^{d}	8.82 ± 0.01^{q}	9.67 ± 0.56^{b}	14.28 ± 0.43^{b}	8.73 ± 1.05^{d}
	FLE 3	516.09 ± 32.9^{d}	209.18 ± 6.63^{d}	2.54 ± 0.09^{b}	70.72 ± 3.01^{a}	11 ± 1.85^{b}	49 ± 6.86^{b}	95.43 ± 8.92^{c}	21.03 ± 0.79^{c}	10.47 ± 0.00^{n}	10.1 ± 0.48^{b}	13.68 ± 0.41^{b}	8.73 ± 1.21^{d}
	FSA 12	577.44 ± 43.08^{c}	209.06 ± 6.83^{d}	2.41 ± 0.05^{b}	73.7 ± 1.87^{a}	12.56 ± 1.28^{b}	41.2 ± 1.85^{b}	85.61 ± 4.63^{c}	14.81 ± 0.69^{e}	11.69 ± 0.01^{m}	9.86 ± 0.42^{b}	12.17 ± 0.31^{c}	9.31 ± 1.04^{d}
	FSV 41	690.96 ± 51.69^{c}	213.61 ± 5.84^{d}	2.29 ± 0.07^{c}	57.11 ± 3.97^{b}	26.12 ± 2.8^{a}	44.4 ± 1.21^{b}	175.84 ± 10.17^{a}	25.57 ± 0.9^{b}	5.68 ± 0.02^{t}	10.94 ± 0.93^{a}	17.8 ± 0.58^{a}	13.49 ± 2.81^{c}
	ICS 95	747.85 ± 26.07^{b}	231.67 ± 4.88^{c}	2.6 ± 0.06^{a}	80.4 ± 1.69^{a}	8.28 ± 0.92^{c}	41.4 ± 3.43^{b}	103.79 ± 6.33^{c}	13.98 ± 1.06^{e}	9.46 ± 0.0^{p}	11.55 ± 0.47^{a}	14.56 ± 0.27^{b}	4.52 ± 1.08^{d}
	SCC 23	463.1 ± 45.54^{d}	203.29 ± 6.9^{d}	2.26 ± 0.08^{c}	43.76 ± 2.09^{c}	15.7 ± 1.99^{b}	45.4 ± 0.81^{b}	108.37 ± 9.39^{c}	23.71 ± 0.96^{b}	9.24 ± 0.01^{p}	9.75 ± 0.8^{b}	14.62 ± 0.54^{b}	29.13 ± 1.67^{a}
	SCC 80	699.62 ± 40.89^{c}	231.93 ± 6.57^{c}	2.55 ± 0.06^{b}	76.77 ± 0.63^{a}	9.57 ± 1.45^{c}	52.6 ± 1.17^{a}	102.02 ± 4.88^{c}	14.64 ± 0.56^{e}	9.95 ± 0.01^{o}	9.94 ± 0.6^{b}	12.32 ± 0.71^{c}	7.24 ± 0.77^{d}
	SSC 55	1,071.12 ± 57.73^{a}	252.55 ± 6.56^{b}	2.48 ± 0.06^{b}	82.31 ± 2.58^{a}	25.24 ± 3.32^{a}	36.4 ± 1.86^{b}	94.29 ± 4.9^{c}	8.8 ± 0.53^{f}	10.63 ± 0.02^{n}	10.92 ± 03^{a}	13.5 ± 0.34^{b}	6.58 ± 2.39^{d}

Note: n = 6 ± standard error; means with a common letter are not significantly different ($P > 0.05$).

FSV41 is a material selected by the Colombian Federation of Cocoa Growers - FEDECACAO for being resistant to *Moniliophthora roreri* and for its quality[11]; high values of placenta weight and mucilage percentage were identified for this material from Arauca, and those from Santander stood out for high values of seed diameter and cob index. With respect to the SCC23 material, it was observed that the material from Arauca was one of the materials with the greatest seed thickness. The SCC55 material from Santander had the highest values for fruit weight, husk percentage, placenta weight and seed thickness, although with values below those reported by Argüello *et al.*[12]

There are two descriptors of great relevance to determine yield, these are ear index and grain index. The ear index is influenced by genetic and environmental factors such as plant age, fruit location on the tree, and soil and fertility conditions[13]. Martínez *et al.*[14] made a classification of materials according to grain index, qualifying as high those with grain index ≥1.8 g, medium 1.4–1.7 g and low 1.3 g. In this sense, SCC23 from Huila was one of the materials with the highest ear index and lowest bean index, undesirable characteristics for the cocoa liquor processing industry and its derivatives. The FEC2 material from Arauca reported low values in cob index and high values in bean index, showing its promising characteristics for processing and processing.

Pearson correlation analysis evidenced high (≥0.70) and significant ($P \leq 0.0001$) correlations with the variables: fruit weight with shell weight (r = 0.92) and fruit diameter (r = 0.70); grain index with seed weight without mucilage (r = 0.92) and with seed weight with mucilage (r = 0.74); seed weight with mucilage with placenta weight (r = 0.70); mucilage weight with percent mucilage (r = 0.89); seed length with seed diameter (r = 0.73); percent seed without mucilage with percent seed with mucilage (r = 0.85) and with percent placenta (r = 0.84); percent husk with husk weight (r = 0.70). Negative correlations corresponded to percent husk with percent placenta (r = -0.80) and percent seed with mucilage (r = -0.90); cob index with percent seed without mucilage (r = -0.85) and grain index (r = -0.85).

As a result of Pearson's correlation analysis, nine (D.F., P.C., G.C., R.P., P.S.H., R.S.H., I.G., L.S. and P.P.) of the twenty-one initial descriptors, which were not taken into account in the principal component analysis, were deleted.

The eigenvalues and total variance explained for each of the main components are shown in **Table 4**. This analysis allowed us to establish three factors that explain 70.26% of the total variance.

Table 4. Eigenvalues and variance explained in principal component analysis (PCA) in the morpho-agronomic characterization of cocoa (*Theobroma cacao* L.)

Lambda	Own Value	Proportion	Cumulative Ratio
1	4.29	33.00	33.00
2	3.34	25.71	58.71
3	1.50	11.55	70.26
4	1.17	8.98	79.24
5	1.01	7.79	87.03
6	0.83	6.39	93.41
7	0.36	2.77	96.18
8	0.22	1.71	97.89
9	0.17	1.28	99.17
10	0.07	0.54	99.71
11	0.03	0.23	99.94
12	0.0076	0.06	100.00
13	0.0001	0.00	100.00

Source: Authors.

Table 5. Correlation between the original variables and the first three principal components in the characterization of cocoa (*Theobroma cacao* L.)

VARIABLES	CP 1	CP 2	CP 3
P.F.	0.14	-0.87	0.14
L.F.	-0.15	-0.65	0.62
R.L.D.	-0.53	-0.09	0.63
R.C.	-0.52	-0.71	-0.21
G.C.	-0.20	-0.57	-0.32
P.PL.	0.70	-0.09	0.30
N.S.	0.55	0.22	0.26
P.S.S.	0.87	-0.32	-0.15
R.S.S.	0.76	0.29	-0.19
I.M.	-0.88	0.32	0.03
G.S.	0.28	-0.66	0.22
D.S.	0.82	-0.01	0.18
R.P.	-0.04	-0.57	-0.32

Source: Authors.

The 33.0% of the total variance is explained by the first principal component (**Table 4**), correlating principal variables attributable to the seed such as seed weight without mucilage (0.87), cob index (-0.88) and seed diameter (0.82). The second principal component explains 25.71% of the variability, and is mainly composed of fruit weight (-0.87). Finally, the third principal component explains 11.55% of the variability and is mainly composed of variables related to fruit dimension such as fruit length (0.62) and diameter length ratio (0.63) (**Table 5**).

Figure 1 shows the level of grouping of the populations, based on the first two principal components. It can be seen that, in spite of being the same material, the conditions of the harvesting zones influenced the physical characteristics evaluated in this study, as is the case of those collected in Santander, which were located in quadrants two and three (except FSA12), those collected in Huila in quadrants one and four (except FSV41), while those from Arauca were dispersed in the four quadrants. Based on the direction of growth of the vectors of the descriptors evaluated, it was observed that the materials located in quadrant three (FSV41-S, FEC2-A, CCN51-S, FEC2-S, FEAR5-S, FLE3-S, SCC80-S, ICS95-S, SCC55-S, SCC23-A) have high values in terms of seed diameter, placenta weight, seed weight without mucilage, seed thickness and fruit weight and low values in cob index and mucilage percentage, the opposite to those located in the one (ICS95-A, FSA12-H, SCC80-H, SCC80-A, SCC55-H, ICS95-H, FEC2-H, FLE3-H, FEAR5-A, CCN51-H, FLE3-A); materials in quadrant two (CCN51-A, FSV41-H, FSV41-A, SCC23-S) are characterized by high values for number of seeds without mucilage and percentage of seeds without mucilage and low values for diameter length, percentage of shell, shell thickness and fruit length, as opposed to materials in quadrant four (SCC23-H, SCC55-A, FSA12-A, FSA12-S, FEAR5-H).

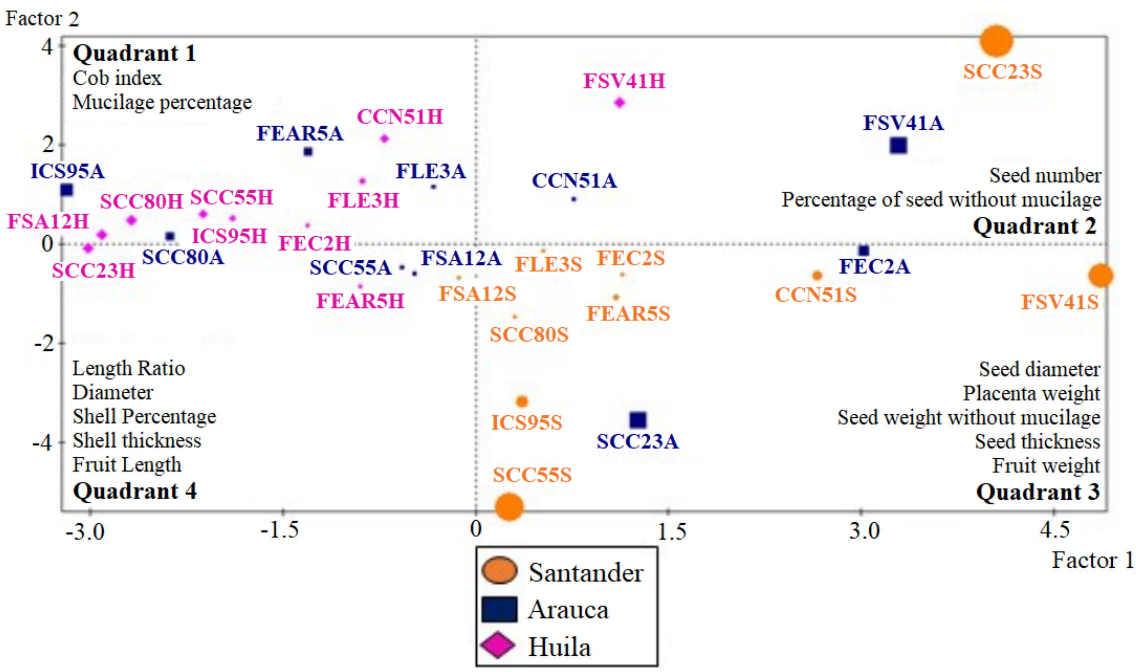

Figure 1. Grouping level of ten cocoa (*Theobroma cacao* L.) materials from different producing areas, based on the first two principal components.

The materials farthest from the origin of the coordinate are those that present values above the average, as is the case of SCC23-S, FSV41-S, SCC55-S, ICS95-A, which can be correlated with the values observed in **Table 3**. For the selection of a cocoa material, the industry takes into account the following parameters: bean size, percentage of shell, fat content, butter hardness and moisture[15]. According to NTC 1252[16], in order to catalog a prize cocoa, it must possess a minimum kernel weight of 1.2 g. From this perspective, promising materials for the industry would be located in quadrants two and three.

4. Conclusion

The environment is a determining factor in the morpho-agronomic development of cocoa fruits, which interacts with the genotype of the material, resulting in the fact that those that have outstanding yield characteristics in one region do not present them in another, making it necessary to carry out an adaptation study before propagation. The descriptors that contribute most to the variability among cocoa materials, according to the principal component analysis, are ear index, diameter length ratio, seed weight and diameter, and fruit weight and length. The promising materials for the chocolate industry according to the outstanding characteristics found in this study are CCN51, FSV41, SCC23, FEC2, FEAR5, FLE3, SCC80, ICS95 and SCC55.

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Conflict of interest

The authors declare that they have no conflict of interest.

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