Original Article

RESCUE OF COCOA NATIONAL VARIETY: GENETIC POTENTIAL OF SELECTION

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Abstract

The research focused on fine aroma cocoa is a priority for Ecuador. The objective of this work was to identify stable, high-yielding accessions. The genetic base was based on 2222 cocoa accessions from the germplasm bank of the Tenguel Aroma Cocoa Center - Ecuador. An index was applied for selecting 150 accessions based on yield and health status. A descriptive analysis, principal component analysis by the factor extraction method between the meteorological parameters and the variables evaluated, was used. A multiple regression and stability analysis was also performed using the method of Eberhart & Russell (1966) modified by considering the years as the different environments and multivariate principal component analysis. Variables related to high CV % yield ranged from 93 to 112 %. The highest yields were observed in 2003, 2004 and 2005. The flowering intensity was influenced by rainfall, temperature and relative humidity and thus by the yield of the accessions. The predictor variables for yield were healthy pods, diseased pods and flowering intensity with a correlation of 0.95, 0.33 and 0.07, respectively, and an R2 = 0.899. The following were selected for their stability and average yield per tree 2.1 kg tree-1: L17H38, L33H45, L53H4, L49H4, L41H70, L49H4, L21H56, L13H11, L30H1, L30H46, L42H80, L30H45 and L32H72. The characteristics of the selected accessions constitute a contribution to cocoa breeding programs in Ecuador and other cocoa-producing regions.

Keywords: Eberhart and Russell, Moniliophthora perniciosa, Theobroma cacao productivity, tolerance.

Introduction

Cocoa has its center of origin in the upper Amazon, in what is now known as Colombia, Ecuador and Peru. It then passed to the Mexican empire of the Olmecs, who domesticated it and sent it to the Mayas and Aztecs. On the other hand, other studies propose that the distribution of cocoa is from South America to Mesoamerica. (Motamayor et al., 2008; Schmitz and Shapiro, 2012). Therefore, the interest of crop breeders both nationally and internationally is focused on effectively managing populations to conserve adequate genetic variation; Breeding is achieved through the selection of outstanding and genetically stable individuals. (Morillo et al., 2014).

Stability is slight variations of a genotype in the same locality but in different years (Lin and Binns, 1988), and the work developed to evaluate the stability of cocoa is scarce. These problems include pests and diseases, decreased soil fertility and plant aging that limits yield (Agung et al., 2015). In addition, cocoa production is affected by rising temperatures and changing rainfall patterns in many producing countries, hence the importance of assessing yield stability to develop sustainable production (Sanchez-Mora et al., 2014; Santosa et al., 2018).

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The genetic base of Ecuador's national cocoa, on which productive and disease-tolerant accessions were identified, was the product of collections made during several expeditions along the Ecuadorian Coastal Region in the 1940s (Loor et al., 2009). The collection provides invaluable residual information evaluated by researchers from the State Technical University of Quevedo. For eight years have recorded aspects related to the productivity and good phytosanitary behavior of cocoa from the germplasm bank of the Tenguel Aroma Cocoa Center (CCAT). The germplasm bank (CCAT) is considered one of the most important in the country according (Lerceteau et al., 1997) and with great genetic richness.

The availability of genetically improved varieties with higher productivity than CCN51 is a priority within Ecuador's fine and aroma cocoa breeding programs (Tarqui et al., 2017). Based on the above. The present study was conducted on the above to identify high-yielding, stable, and disease-resistant accessions in a collection of Nacional cocoa germplasm.

Materials and methods

LOCATION

The research was carried out in Tenguel, Guayaquil canton, Guayas province, Ecuador (3º00' south latitude and 79º 47' west longitude). The average annual temperature of the site is 23.6ºC, precipitation 34 mm in June to 426.8 mm in April, relative humidity of 87 %, altitude 25 m asl, pH 6.2, sandy loam soil with good fertility (National Institute of Meteorology and Hydrology, 2014).

EXPERIMENTAL MATERIAL

The selection of accession was made from 2222 accessions, considering productivity and health status characters, applying a selection index (SI). The standard deviation (SD) was estimated to calculate the index, following the procedure of Rodríguez et al. (2013):

- Yield index (YI); Yield per accession = YPA; Average yield per accession (AYPA): (Equation 1) $IR = \frac{YPM-AYPM}{SD}$
- Percentage of healthy pods index (PHPI); Percentage of healthy pods = (PHP); an average of the percentage of healthy pods (APHP): (Equation 2) $PHCI = \frac{PHC-APHC}{SD}$
- Index of witches' broom intensity (IWBI); Witches' broom intensity = (WBI); average witches' broom intensity (AWBI): (Equation 3) $IWBI = \frac{WBI-AWBI}{SD}$
- Selection index (SI): (Equation 4) $SI = \frac{YI+PHCI-IWBI}{3}$

The accessions are coded with the letters L (Line) and H (Row), indicating the position of the original accession in the CCAT collection (Sanchez-Mora et al., 2015).

AGRONOMIC VARIABLES RECORDED

The records of agronomic traits such as incidence of Moniliophthora perniciosa witches' broom (WBI) evaluated at the level of the branches, flowering intensity (FI), the number of healthy (HPN) and diseased (DPN) pods, fresh weight (FW), dry cocoa yield per accession (YPA) and in kg ha-1 year (YPH), was evaluated continuously from 2002 to 2009 monthly for the 2222 accessions.

Methods used in the determination of agronomic characteristics

The incidence of witches' broom (WBI) and flowering intensity (FI) was recorded biannually based on the scale used by Medina & Vasco (2013).

The recording of the HPN and DPN consisted of harvesting and counting the number of healthy or diseased pods per accession, according to the presence or absence of disease caused by M roreri, counted every 15 days at the time of harvesting, and then obtaining an annual average. The percentage of healthy pods for each accession was then calculated by dividing the HPN by the TPN multiplied by 100 (Medina & Vasco 2013).

The FW was evaluated considering the weight of fresh almonds expressed in kilograms using a precision balance. In addition, the YPM and YPH of cocoa were considered using the methodology of Medina & Vasco (2013).

Evaluation of stability

This variable was evaluated using the method proposed by Eberhart & Russell (1966), modified by considering the eight years as different environments. The method estimated the environmental index from the average of all the accessions each year minus the general average of all years.

CONDUCTION OF THE EXPERIMENT

The evaluation of morpho-agronomic variables was carried out on all the accessions found on the 14.5-hectare farm, which are at a planting distance of four by four, established under (guabo) Inga edulis and (saman) Samanea Samán. In order to maintain the plantation in good condition, mechanical and chemical weed control was carried out at the beginning and end of the rainy season, elimination of basal suckers with pruning shears, disinfection of the wounds with a paste based on agricultural lime plus Mancozeb + copper sulfate (cuprofix) in a ratio (3:1). Maintenance and sanitary activities at the end of the dry season were also carried out. To maintain soil fertility, ammonium nitrate was applied at a dose of 200 g per plant and complete fertilizer 10-30-10 at 300 grams per accession at the beginning and end of the rainy season.

Statistical analysis

Data analysis was performed using means, standard deviation, linear regression, and variance analysis of an ANOVA factor to observe differences between means according to the years. The separation of means was performed using Tukey's test ($p \leq 0.05$) with the statistical program SAS version 9.3 (SAS Institute Inc, 2011).

Multivariate analysis

The data reported in the meteorological yearbook of INAMHI from 2002 to 2009 (Instituto Nacional de Meteorología e Hidrología, 2014) was considered to explain the relationship between the parameters evaluated in the 150 selected accessions of National cocoa for temperature, precipitation and relative humidity conditions in Tenguel.

Principal component analysis was performed based on the factor extraction method, analyzing the association of the variables through the correlation matrix of the meteorological parameters. To observe the order of the variables, the VARIMAX method was used within each rotating component to analyze the correlations with only a few variables using the SPSS program (IBM Corp., 2011).

The principal component analysis was performed to observe the grouping between accessions based on their distinctive characteristics, which included Pearson's correlation analysis to observe the correlation between yield variables and those related to diseases and flowering intensity. Such analysis indicated the variables that could serve as regressors using the SAS version 9.3 program (SAS Institute Inc, 2011).

Multiple linear regression analysis was applied to propose a regression model to describe performance as a function of the other variables and the step-by-step method of selecting regressor variables. Residual analysis was also performed using the SPSS program (IBM corp, 2011) to select the variables that are part of the model. The schematic multiple linear regression model was used: $Y = aX1 + bX2..... + nZn + c + e$. Where: Y= dependent variable; X, Z= independent variables; a, b, n= coefficients that accompany the independent variables; c= model constant; e= model error.

In order to analyze stability, the linear regression coefficient and the coefficient of determination R2 were calculated, from which the respective inferences were made about the type of stability that a given genotype presented.

The confidence interval for MR was applied, using the formula: Equation 5 where: μ = Confidence interval; X = Population mean; Z= 95 % normal standard curve value; δ= Standard error; √n = Sample size.

Results

MATERIAL SELECTION INDEX AND PHENOTYPIC VARIATION

The index applied to select 150 accessions from 2222, which showed a contrasting behavior in terms of productivity, was between IS=-1.60 and IS=1.77. According to Tukey, the descriptive analysis allowed differences between accessions at $p < 0.05$ in all the variables analyzed. The variables related to HP yield, FW, DW, YPA, YPH and DP showed a high (CV) between 93.29 % and 112.08 %, compared to those of broom intensity WBI 37.39 % and flowering intensity FI 20.20 %. Tukey's multiple range test showed statistical differences at $p < 0.05$ between the years. The highest yields were obtained in 2003, 2004 and 2005, while the lowest was in 2008, a year with a high rate of diseased pods, with 2009 being the year with the highest intensity of witches' brooms (Table 1).

Table 1. Productivity behavior during eight years in T. cacao L.

YEAR	HP	FW	DW	YPA	YPH	DP	WBI	FI
2002	48.16b	4.98b	2.04b	1.99b	1244b	20.26a	2.53b	1.75d
2003	60.77a	6.37a	2.6a	2.55a	1591a	11.45b	2.51b	1.87cd
2004	65.21a	6.89a	2.82a	2.76a	1723a	10.97b	2.57b	1.86cd
2005	63.54a	6.66a	2.73a	2.66a	1664a	5.7c	1.67d	2.04bc
2006	49.58b	5.11b	2.09b	2.05b	1278b	11.89b	2.01c	2.42a
2007	43.63bc	4.67bc	1.91bc	1.87bc	1166bc	20.95a	1.64d	1.26e
2008	33.35d	3.68d	1.52d	1.47d	920.3d	20.78a	2.5b	2.49a
2009	39.64cd	4.11cd	1.7cd	1.64cd	1027cd	13.73b	2.99a	2.15b
Media	50.49	5.31	2.18	2.12	1327.00	14.45	2.30	1.98
Dev std	65.14	6.44	2.65	2.58	1610.00	18.89	1.27	0.90
CV %	129.01	121.28	121.55	121.69	121.32	130.72	55.21	45.45

HP= healthy pods, FW= fresh weight Kg-1, DW= dry weight Kg-1, YPA= yield per accession Kg-1, YPH= yield per hectare Kg-1, DP= diseased pods, WBI= broom index, FI= flowering index.

The accessions above the average yield 2.12 kg-1 per accession, with variables related to productivity (HPN, FW, DW, RA and YPH) were (L12H8, L17H36, L41H70, L28H48, L29H4, L33H8, L42H80, L44H88, L48H92). 63.33 % of the accessions were between 2 and 50 HP; 36.67 % presented between 51 and 300 HP. Forty-two percent showed an incidence of witches' broom (WBI) of zero to two and 58 % higher than three.

EFFECTS OF TEMPERATURE, PRECIPITATION AND RELATIVE HUMIDITY ON MORPHO-AGRONOMIC CHARACTERS OF T. CACAO L., APPLYING PRINCIPAL COMPONENT ANALYSIS IN CONJUNCTION WITH FACTOR ANALYSIS

Based on the data reported in the meteorological yearbooks for 2002 to 2009 in the Tenguel area, the average relative humidity was 93.1 %, temperature 25.6 °C and precipitation 412.9 mm.

The principal component analysis used as a factor extraction method showed that the total variance was grouped into three components that accumulated 92.28 % of the variation. The first component showed 54.21 %, the second 24.07 % and the third 13.88 %. In the first component, those contributing to the most significant variability are related to performance with a direct positive correlation (0.99), while DP (-0.80) has a negative inverse correlation. In the second component, the meteorological characteristics contribute the most; humidity (0.88), temperature (0.81), precipitation (0.68) and FI with an inverse negative contribution (-0.657). The third component BI, with a contribution of 0.94 (Table 2).

Table 2. Eigenvalues and components in the interrelationship between morpho-agronomic and meteorological variables.

	Total	% Variance	% Cumulative	Total	% variance	% Cumulative	Variable	C1	C2	C3
1	6.11	55.55	55.55	5.96	54.21	54.21	HP	0.992	0.038	-0.093
2	2.64	24	79.55	2.64	24.07	78.29	DP	-0.807	0.522	-0.1
3	1.38	12.62	92.18	1.52	13.88	92.18	FW	0.991	0.054	-0.111
4	0.46	4.26	96.44				DW	0.992	0.05	-0.107
5	0.28	2.62	99.06				IBW	-0.118	0.141	0.946
6	0.1	0.92	99.99				FI	-0.13	-0.657	0.558
7	0	0	100				YPA	0.991	0.055	-0.112
8	9.13E-14	8.30E-13	100				YPH	0.991	0.053	-0.111
9	4.44E-14	4.03E-13	100				RH	0.348	0.882	-0.114
10	3.01E-15	2.73E-14	100				MT	-0.047	0.813	0.449
11	-6.94E-14	-6.31E-13	100				RAI	-0.492	0.688	0.197

HP= healthy pods, DP= diseased pods Kg-1, FW= fresh weight Kg-1, DW= dry weight Kg-1, IF= flowering index, YPA= yield per accession Kg-1, YPH= yield per hectare Kg-1, WBI= broom index, RH= relative humedity, MT= average temperature, RAI=precipitation.

In order to observe differences between the variables of component two (relative humidity, temperature, precipitation and FI), a one-way analysis of variance was performed, which showed $p < 0.05$ differences p = 4.712E-18. The Tukey test's contrast showed $p < 0.05$ differences between the relationships of the parameters FI and RH; RH and T; precipitation with FI, HR and T as a function of the arrangement by year. A cluster analysis was performed using Euclidean distance with the arrangement of IF, relative humidity, temperature and precipitation variables for years. According to the analysis, it was observed that two groups were formed. In the first one, the year 2002 was located, which is separated from the rest, probably because it was one of the years with the highest rainfall. The second group is subdivided into two contrasting subgroups with the highest yielding, 2004 with 2.76 kg·accession-1 and 2005 with 2.66 kg·accession-1 with the lowest yielding (Table 1).

LINEAR CORRELATION AND MULTIPLE REGRESSION BETWEEN VARIABLES AS PREDICTORS OF PERFORMANCE

The variables FW and HP showed a strong correlation (r=0.95), and a weak correlation was observed between DP and FW (r= 0.33) as well as between HP and DP, with BI and FI (r= 0.28) showing significant differences between the correlation.

The FW and DW variables were excluded in the multiple regression analysis because of collinearity. Then, when the stepwise regression analysis was performed, the IE variable was excluded as it was not significant in the model. The most important variables were HP, DP and FI, with correlations of 0.95, 0.33 and 0.07. respectively, which adequately predicted yield. This allowed us to obtain a multiple linear regression to explain the annual yield with a coefficient of determination R2 = 0.899 at a significance level of p = 0.004. The above allowed inferring that 89.9 % of the yield variability is explained by the three independent variables HP, DP and FI.

According to the regression analysis of variance, the model was chosen based on the parameters of the regression model vs. the residue, which showed a difference according to the analysis of variance with a probability of ($p < 0.05$), indicating the model fit. The predictor variables (constants) were: HP, DP and FI, with RI being the independent variable.

Model validation

In the correlation matrix, it was observed that no value exceeded 0.95, so there is no high multicollinearity between pairs of variables. When examining the variance inflation factors (VIF), the values are less than five, so multicollinearity does not represent a problem in estimating the model. The model proposed by Durbin-Watson was performed with a significance level of 5 %. Therefore, it should be between 1.85 and 2.15. Based on this criterion, none of the variables in the model presented autocorrelation.

The performance predictive model was expressed as follows: RI= B+(B1*HP) +(B2*DP) +(B3*FI) Where: RI= independent variable; B= Constant: B= 0.0274; B1= 0.03667; HP= healthy pods; B2= 0.00911; DP= diseased pods; B3= 0.07724; FI= Flowering intensity.

Expression of the mathematical model: RI= -0.00274+(0.03667*HP) +(0.00911*DP) +(0.07724*FI)

The results of the yield predictive model were applied as an example to 20 great cocoa accessions (Table 3). The selected variables of the model have a direct relationship with yield, especially because flowering precedes fruiting. In addition, yield increases the number of healthy pods and decreases the number of diseased pods.

Table 3. Yield per accession and using the multiple regression model in unique accessions of Ecuadorian National cocoa

N°	ID	YA	PYA	N°	ID	YA	PYA	N°	ID	YA	PYA	N°	ID	YA	PYA
1	L10H28	3.39	3.63	6	L18H58	5.68	5.32	11	L30H45	5.25	5.3	16	L49H4	4.39	3.3
2	L12H8	8.98	9.02	7	L21H56	5.43	7.72	12	L32H72	5.33	2.84	17	L49H80	0.54	0.72
3	L13H11	3.78	3.9	8	L29H7	5.59	4.4	13	L42H80	9.08	9.79	18	L53H4	4.46	4.92
4	L17H36	7.14	8.16	9	L30H1	6.00	5.02	14	L44H88	7.47	7.42	19	L58H34	0.42	0.53
5	L17H38	4.73	5.03	10	L30H32	0.41	0.39	15	L48H12	0.76	0.85	20	L60H23	0.92	0.65

*N°= order number, ID= accession, YA = yield per accession Kg-1 and PYA= predicted yield per accession Kg-1.

PERFORMANCE STABILITY PER ACCESSION YPM

The analysis made it possible to define the stability of the YPA, according to Eberhart and Russell, employing an environmental index. The average yield of the accessions was 2.12 kg-1. In order to carry out the selection, the confidence interval 1.47 was applied, from which the accessions above the yield, upper limit 3.59 and lower limit 0.65, were selected. For the regression coefficient (environmental index) ß1, the average was 1, the confidence interval was 0.61, the upper limit was 1.69 and the lower limit was 0.31. Based on these parameters, out of the 150 accessions, those with desirable performance characteristics were selected. Those with a ß1 = 1.0 with a confidence limit above 3.59 YPA considered stable were L17H38, L21H38, L30H46, L49H4 L53H4. R2 between 0.60 and 0.84 was observed for accessions L13H37. L10H28, L32H72, and L42H80. L44H88, L46H75. L48H92. The other accessions shown in (Table 4) exceed the average yield, with B1 ≥1 and B1 ≤1 being the most adaptable in both favorable and unfavorable environments.

Table 4. Stability of AR using the Eberhart and Russell (1966) model for Ecuadorian National cocoa accession.

CODE	MYA	B_1	s/u	R^2	CV %	SD	SIG	SE
L10H28	3.39	4.11	(u)	0.64	46.51	1.58	*	1.25
L12H27	3.84	3.16	(s)	0.38	54.21	2.08	ns	1.65
L13H37	3.88	3.79	(u)	0.76	28.53	1.11	**	0.88
L17H38	4.73	0.35	(s)	0.01	39.84	1.88	ns	1.5
L18H58	5.68	-1.72	(s)	0.24	27.68	1.57	ns	1.25
L21H38	4.39	0.63	(s)	0.02	57.84	2.54	ns	2.02
L30H46	3.83	1.44	(s)	0.17	42.16	1.61	ns	1.28
L32H72	5.33	3.84	(u)	0.82	17.23	0.92	**	0.73
L42H80	9.27	8.17	(u)	0.77	25.47	2.31	*	1.82
L42H97	5.58	4.24	(s)	0.38	51.56	2.82	ns	2.22
L44H88	7.59	4.75	(s)	0.67	23.3	1.74	ns	1.37
L46H75	4.22	2.91	(u)	0.69	24.34	1.01	*	0.79

L48H92	9.87	5.29	(s)	0.6	23.1	2.25	ns	1.77
L49H4	4.4	0.65	(s)	0.03	47.51	2.08	ns	1.64
L53H4	4.5	1.06	(s)	0.14	30.71	1.37	ns	1.08

MYA: mean yield per accession; B1: environmental index s/u: stable/unstable; R2= coefficient of determination; CV % coefficient of variation; SD= standard deviation; SE= standard error; SIG significance = ($p<0.05$) **: highly significant; *: significant; and ns: not significant.

PRINCIPAL COMPONENT ANALYSIS

The PCA indicates that the first three PC principal components explain 92.26 % of the total variability. The first explains 67.08 %, the second 17.00 % and the third 8.18 % of the variation. In CP1, the variables with the highest variability are related to yield: HP, FW, DW, YPA and YPH with a positive correlation of 0.41 and 0.43. In CP2, it is defined by associated variables BI and IF with 0.70 and 0.67 correlation, respectively. Finally, CP3 is determined by the variables related to the number of diseased pods with a negative correlation of -0.51.

The average clustering according to Ward's Minimum Variance Criterion (1963) for the 150 accessions showed three defined groups. In group one, accessions had the lowest average yield of 0.67 kg·accession-1 and the highest BI average of 2.35 (5-10 %= light); in group two, intermediate yielding 3.51 kg·accession-1 and in group three were those with the highest average yield 8.13 kg·accession-1.

In group one, 88 accessions were located: L15H32, L17H53, L21H13, L21H6, L26H45, L27H22, L34H4, L35H64, L47H27. L48H12, L53H46, LL53H71, L55H58 and L58H34. Therefore, even though they have a low average RI of 0.49 kg·accession-1, they can be considered a source of resistance to broomrape and monilia in breeding programs.

Group two grouped 53 accessions, 11 with stability characteristics according to Eberhart & Russell (1966) for RI: L13H11, L17H38, L21H56, L25H64, L29H7. L30H1, L30H45, L33H45, L42H97. L49H4 and L53H4. Because the incidence of broomrape and monilia affect the growth and the yield of cocoa (Hernández-Villegas, 2016; Solís et al., 2015), the accessions above can be considered as outstanding for yield. Finally, nine accessions were located in group three; L33H8, L17H36, L12H8 and L41H70 stand out for their stability in RI.

DISCUSSION

The differences in the variables analyzed in the selected accessions could be used as distinctive morpho-agronomic characteristics for selection purposes. The high coefficient of variation obtained may be related to the wide variability of the genotypic characteristics of each accession and its interaction with the environment (Sánchez-Mora et al., 2014).

The highest number of diseased pods obtained in 2008 was similar to those reported by Sanchez-Mora et al. (2015), who evaluated the sanitary and productive potential of 12 National cocoa clones in Ecuador, one of the zones being the Tenguel parish.

The CV of the variable WBI indicates low variability in disease incidence, considering that this constitutes a plantation established in the 1940s. This can be contrasted with what was reported by Sotomayor & Tarqui (2017), who evaluated an initial segregating population of national cocoa with CV values (127.37 %), indicating high variability in the incidence of this disease.

Regarding climatic conditions, it is essential to consider that the Tenguel area is located at 25 m above sea level and 20 km from the Pacific Ocean. The proximity to the ocean allows high humidity to remain stable throughout the year; this, coupled with temperature and precipitation, results in good growth and development of the cocoa crop (Suarez et al., 2015). However, Cárdenas et al. (2017) and Ramírez Gil (2016) state that agroclimatic conditions such as relative humidity and constant rainfall are related to a rapid onset of diseases, thus causing low yields in this crop.

The results infer that the flowering process is an essential factor in the physiological process of the development of cocoa accessions since it leads to the formation of pods and, finally, the amount of them, as well as their health and yield. These results are consistent with those reported by Suárez et al. (2015), who express that the cocoa plant is sensitive to the lack of moisture in the soil and its absence affects the low flowering and, consequently, the production of fruits. Furthermore, Schroth et al. (2016) report that cocoa fruit does not fully develop during droughts, and very heavy rains decrease flowering and fruit set; therefore, both events reduce cocoa productivity. Meanwhile, Macías Barberán et al. (2019) and Lahive et al. (2019) express that soil water deficit greatly influences the decrease of cocoa crop yield.

Regarding the results of the yield predictor variables, it can be inferred that the linear combination of the independent variables is an optimal predictor of yield and could allow selection using variables such as the number of healthy or diseased pods. Sotomayor & Tarqui (2017) obtained similar results, who obtained the highest correlation between FW and HP (0.90). These variables are considered one of the most important for evaluating performance (Álvarez et al., 2015; Sánchez-Mora et al., 2014).

The Tenguel area is traditionally known for its cocoa cultivation. However, it is essential to mention that the results of this model apply only to this area because the information from which the analysis was performed has specific soil and climatic conditions for each location. Temperature and its seasonal or daily fluctuations affect the most important physiological processes of plants and, particularly in cocoa, affect the flowering rhythm (Gomez and Azocar, 2002).

Knowing the average productivity (adaptation) and possible variations (stability) of the accessions to be analyzed constitutes basic information to reduce errors when selecting promising accessions (Zuil, 2017). From the results obtained on stability, it can be inferred that as cocoa yields increase, there is apparent stability and a tendency to tolerate the attack of pathogens affecting the fruits (Vera and Goya, 2015).

Furthermore, it can be seen that within the accessions of the national variety of cocoa from Ecuador, there are promising accessions in terms of yield and stability over time. These results agree with those reported by (Sánchez et al., 2014), who described that the productive performance found in national-type cocoa clones shows a high genetic variability that could be used in breeding programs. Likewise, as Phillips-Mora et al. (2009) described, the behavior could be related to the genetic characteristics of the genotypes evaluated.

The PCA showed clustering based on yield, which is related to seeds' fresh and dry weight. These results are similar to Sanchez-Mora et al. (2014), who describes that cocoa accessions can be discriminated through productivity or health characteristics. Likewise, Carvalho et al. (2001) state that despite the relevance of fruit production, kernel weight is the characteristic that most interests the producer.

According to the groupings observed in terms of performance, stability is a genetic characteristic. Therefore, these accessions can be considered promising for propagation or conservation in breeding programs due to their relatively predictable behavior. The stability analyzed in this study is that proposed by Lin and Binns (1988), who defined it as the slight variations of a genotype in the same locality, but in different years.

Conclusions

The promising accessions showed stability characteristics during the eight years based on morphological and agronomic indicators. Those accessions to be considered for a higher yielding and stable breeding program were L17H38, L21H38, L30H46, L49H4 L53H4, L18H58, L42H80 L10H28 and L53H4. In addition, there were accessions within the confidence interval with yields close to the average. However, L12H8 L48H92, L28H48, L42H80 stand out for having more yields than the average. They also showed tolerance to witches' brooms and diseased cobs (due to monilia), allowing future research activities to be oriented at the molecular level.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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