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Selection of self-compatible progenies of high productivity cocoa in the Ecuadorian coast

Selección de progenies autocompatibles de alta productividad de cacao en la costa Ecuatoriana

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Abstract

Cocoa in Ecuador is one of the main crops of economic importance, mainly for small and medium farmers on the coast. Sexual self-compatibility is one of the most important criteria for the selection of clonal plants from members of hybrid progeny. Trees with higher levels of self-compatibility are those that tend to produce earlier compared to self-compatible ones. The study consisted of selecting 333 trees from a group of 71 hybrid progenies, based on selection criteria such as productivity and health during 5 years of evaluation (2002-2007) and thus determining the level of self-compatibility per individual within a group of hybrid progenies. of cocoa, estimate the level of self-compatibility of the hybrid progeny under study and its relationship with yield and select self-compatible trees with high productivity. Binomial test was used, which determined a minimum of 30% of successful pollinations. The 0.05% probability level was considered as the compatibility threshold of each tree. For hybrid progenies, at least 70% of their individuals must present this characteristic, for which data were recorded at three, seven and fifteen days respectively, in order to have more precision in the process of fruit initial development and performance. The results showed that there was a wide variability regarding the self-compatibility level of the individuals within all the studied families. Only 3 of 71 studied families had a sufficient number of self-compatible individuals to be classified likewise. However, their average performance was not necessarily superior to other families that were self-compatible. On the other hand, it could also be confirmed that the compatibility of a tree, clone or cross can change its percentage of fertilization according to time and environmental conditions.

Keywords: *Sexual compatibility, cocoa, hybrid progeny, productivity, fertilization, yield.*

Resumen

El cacao en Ecuador es uno de los principales cultivos de importancia económica, principalmente para los pequeños y medianos agricultores de la costa. La autocompatibilidad sexual es uno de los criterios más importantes para la selección de plantas clonales. Los árboles con niveles más altos de autocompatibilidad son aquellos que tienden a producir antes en comparación con los autocompatibles. El estudio consistió en seleccionar 333 árboles de un grupo de 71 progenies híbridas, en base a criterios de selección como productividad y sanidad durante 5 años de evaluación (2002-2007) y así determinar el nivel de autocompatibilidad por individuo dentro de un grupo de híbridos de cacao y seleccionar árboles autocompatibles con alta productividad. Se utilizó la prueba binomial, que determinó un mínimo del 30% de polinizaciones exitosas. El nivel de probabilidad de 0.05% se consideró como el umbral de compatibilidad de cada árbol. Para las progenies híbridas, al menos el 70% de sus individuos deben presentar esta característica, para lo cual se registraron datos a los tres, siete y quince días respectivamente, con el fin de tener mayor precisión en el proceso de desarrollo y rendimiento inicial del fruto. Los resultados mostraron que existía una amplia variabilidad en cuanto al nivel de autocompatibilidad de los individuos dentro de todas las familias estudiadas. Solo 3 de las 71 familias estudiadas tenían un número suficiente de individuos autocompatibles para ser clasificados de la misma manera. Sin embargo, su desempeño promedio no fue necesariamente superior al de otras familias que eran autocompatibles. Por otro lado, también se podría confirmar que la compatibilidad de un árbol, clon o cruce puede cambiar su porcentaje de fertilización según el tiempo y las condiciones ambientales.

Palabras clave: *Compatibilidad sexual, cacao, progenie híbrida, productividad, fertilización, producir.*

Introduction

Ecuador is the world's leading producer of cocoa (*Theobroma cacao* L.) of high quality and commercial interest (Quiroz and Amores, 2002). As stated by Sánchez-Mora *et al*., (2015), in America 15% of world production is concentrated in the center and south of the continent, where Brazil and Ecuador are the largest producers. Cacao is a recognized product in international markets, and Ecuador is a supplier of 60% of the world's cacao production (Anecacao 2017).

In the country, hybridization is carried out in national cacao varieties in order to increase production with "high" certification system, and thus this undoubtedly improves the economy of the small producing family's dependent on this crop (Vera J. & Goya A. 2015). As stated by Loor-Solorzano *et al*., (2019), low yield is one of the main limitations that prevents improving cocoa production. The world average is around 0.5 t / ha, this is mainly attributed to the shortage of productive genetic materials. For Mena-Montoya *et al*., (2020), the great genetic variability of cocoa depends on the gene flow due to pollen dispersal, which is often substantial among its populations. The T. cacao presents incompatibility problems, mainly depending on the activity of pollinating insects, which ensure sustainable production. This crop reaches its productive maturity after three years of its establishment in the field, after which time its phenology is influenced by the humidity of the soil, distribution of rainfall, shade and crop management, which affect the rhythm of the flowering and harvesting (Montero-Cedeño *et al*., 2019).

National type cocoa is attributed to the use of genotypes of unknown genetic origin, unselected, mixed and of low productivity (Sánchez-Mora *et al*., 2014). For León *et al*, (2016) to compensate for the reduction in the production of "high" cocoa, research has been intensified to improve and increase its production. In the country, hybridization is carried out in national cacao varieties in order to increase production with "high" certification system, and thus this undoubtedly improves the economy of the small producing families dependent on this crop (Anecacao, 2017). Obtaining varieties with greater economic value depends on genetic improvement and selection processes conducted in research centers such as the Pichilingue Tropical Experimental Station (EETP) of the National Institute for Agricultural Research (INIAP). In this experimental station, the country has a cocoa germplasm bank made up of several living collections, in addition to observation plots and new hybrid populations created during the last decades (Sotomayor *et al*., 2017; Tarqui *et al*., 2017).

Incompatibility is a genetic phenomenon, governed by a biochemical process in the recognition, acceptance or rejection of pollen, which occurs in the pollen tube of the recipient flower and in some cases in the stigma (Aránzazu *et al*., 2008). As indicated by Macoto *et al*., (2013), in 1960, after the discovery of heterosis in cocoa, the genetic improvement programs in cocoa focused on several countries for the production of interclonal hybrids. Most of the T. cacao accessions are self-incompatible due to a gameto-sporophytic self-incompatibility system. However, some domesticated varieties long ago, such as the creole varieties of Central America, the national of Ecuador and some of their hybrid forms are self-compatible. (Loor *et al*, 2012).

The incompatibility problem is general in all the provinces of Ecuador, where cocoa growns (Moreno, 1970). As stated by Aránzazu *et al*., (2008) currently faces the productive inefficiency of hybrid plantations, of advanced age and inadequate management, as well as the existence of a large percentage of unproductive or very low production trees, caused by the phenomenon known as "sexual incompatibility". For (Quinaluisa 2010), this is because tree physiological conditions can change the compatibility system at several levels. As Montero-Cedeño *et al*. (2019) indicates, in many cocoa-producing regions, trees show an incompatibility of more than 50%, so there is more flowering than fruit production. The incompatibility of cocoa is more severe than in other fruit trees, since there are few species of pollinating insects and they only transport pollen from one tree to another at a certain time. The productive capacity of T. cacao will depend on the reproductive efficiency of the formation of fruits, flowers, pollen and ovules, which may be specific to the genotype (García-Cruzatty *et al*., 2020).

It is known that the adult cocoa plant under normal conditions can produce 6000 to 10000 flowers per year, of which only 1% become fruit. The setting or fertilization may be even lower due to the lack of specific pollinating insects such as the fly (Forcypomnia spp.) (Vera *et al*., 2016). Compatibility is translated as the ability of a cocoa plant to produce seeds, either by self-pollination (AP) or cross pollination (PC), which, in both cases can be achieved by natural (insect) or artificial methods (human). However, knowledge of compatibility systems and the incompatibility genotypes of different experimental or commercial cocoa clones constitute important information for future use in hybridization programs (Mendoza, 2015; INIAP, 2016).

Artificial pollination is the procedure used to obtain seed trees, with outstanding characteristics in terms of production, early quality, and resistance to diseases or pests. Studies carried out by INIAP have allowed the procedure to be developed, which consists of manually pollinating fresh cocoa flowers, of national origin, with which it is possible to provoke a growing expression of being able to increase the yield of decadent traditional cocoa plantations, profitably, but has not been tested on self-compatible cocoas such as the CCN-51 clone. (Vera, J. & Vera, J., 2018).

It is important to mention that hybridization or natural combination of genotypes other than cocoa has occurred in nature for hundreds of years. This fact, together with the existing bioclimatic conditions, has resulted in the current Ecuadorian cocoa maintaining its unique characteristics.

Based on the background described, the objective of this study was to estimate the level of compatibility of a group of hybrid progenies and its relationship with their performance.

Materials and methods

Experiment location and environmental conditions

The research was conducted at the INIAP Tropical Pichilingue Experimental Station (EETP), located at 5th km of the Quevedo-El Empalme road, at an altitude of 85 meters above sea level. The geographical coordinates are 79 ° 2' West Longitude and 1 ° 6' South Latitude. The average temperature is 27.3° C, annual precipitation 1640.90 mm and 772.60 light hours day (INAMHI), 2018). The soil at the experimental site has a loamy texture with a good level of fertility and moderate drainage. This study was carried out between January 2008 to February 2010 and the climatic conditions for the period in question are: mean annual temperature of 25.06 ° C, mean annual rainfall of 1856 mm and heliophany 669.95 light hours

Genotypes

In the present study, 71 hybrid families were evaluated from which 333 trees were selected, using selection criteria such as productivity and health during 5 years of evaluation (2002-2007) and thus determine the level of self-compatibility per individual within a group of hybrid progenies. of cocoa, estimate the level of self-compatibility of the hybrid progeny under study and its relationship with yield and select self-

Table 1. 71 hybrid families from the four trials for cocoa self-pollinations at the EETP, 2010

18 National-type cacao hybrids in Quevedo (1998) EET-Picchilingue.	
N°	HIBRIDOS
1	CCAT-21-19 X EET-574
2	CCAT-21-19 X EET-578
3	EET-547 X EET-578
4	CCAT-21-19 X EET-577
5	EET-547 X EET-574
6	EET-446 X EET-387
7	EET-445 X EET-400
8	EET-451 X EET-387
9	EET-454 X EET-578
10	EET-446 X EET-400
11	CCN-51 X CCAT-21-19
12	EET-445 X CCCAT-21-19
13	EET-577 X EET-574
14	EET-574 X EET-577
15	EET-454 X EET-400
16	EET-577 X EET-578
17	EET-574 X EET-578
18	EET-454 X CCAT-21-19

21 National-type cacao hybrids in Quevedo (1999) EET-Pichilingue.	
N°	HIBRIDOS
1	EET-416 X EET-400
2	EET-426 X CCN-51
3	EET-426 X EET-547
4	EET-426 X EET-233
5	EET-426 X EET- 387
6	EET-426 X EET- 578
7	EET-445 X CCN-51
8	EET-445 X EET-578
9	EET-446 X CCN-51
10	EET-446 X EET-547
11	EET-451 X EET-574
12	EET- 451 X EET-578
13	EET-452 X CCN-51
14	EET-454 X EET-577
15	EET-454 X CNN-51
16	EET-454 X EET-387
17	EET-454 X EET-574
18	EET-577 X EET-233
19	EET-577 X EET-400
20	ET-103 X EET-387 (T1)
21	CCN-51 SEMILLA (T2)

16 hybrid cacao progenies from parental clones seleccted by their resistance to Witch's broom disease, Monilia and productive capacity (2000) EET-Pichilingue.	
N°	HIBRIDOS
1	CCN-51 Autopolinizado
2	EET-19 X EET-48
3	EET-48 X EET-95
4	EET-547 X EET-534
5	EET-552 X EET-513
6	EET-552 X EET-534
7	EET-552 X EET-547
8	EET-574 X EET-513
9	EET-574 X EET-534
10	EET-574 X EET-547
11	EET-574 X EET-577
12	EET-577 X EET-513
13	EET-577 X EET-534
14	EET-577 X EET-547
15	EET-578 X EET-547
16	EET-62 X EET-103

16 hybrid cacao progenies from promising clones of National type with resistance to Witch's broom disease (2000) EET-Pichilingue.	
N°	HIBRIDOS
1	CCN-51 Autopolinizado
2	CCN-51 X EET-233
3	CCN-51 X EET-387
4	CCN-51 X EET-534
5	EET-387 X EET-534
6	EET-452 X EET-534
7	EET-233 X EET-387
8	EET-416 X EET-233
9	EET-416 X EET-387
10	EET-416 X EET-534
11	EET-450 X EET-387
12	EET-450 X EET-534
13	EET-452 X EET-233
14	EET-462 X EET-233
15	EET-462 X EET-387
16	EET-462 X EET-534

Table 2. Number of trees selected from four experimental cocoa trials at the EETP, 2010

Experiment	sown surface (ha)	Lote	Number of existed trees	N° of selected trees	N° of treatment/ experiment	N° of repeats/ experiment	N° of trees/ repetition	Total tree/ treatment
Behavior of 18 National-type cacao hybrids in Quevedo (1998)	0.75	Santa Rita	637	40	18	4	10	40
Behavior of 21 National-type cacao hybrids in Quevedo (1999)	0.87	Santa Rita	732	17	21	4	10	40
16 hybrid cacao progenies from parental clones seleccted by their resistance to Witch's broom disease, Monilia and productive capacity (2000) EET-Pichilingue	0.83	Herrera	797	152	16	5	10	50
16 hybrid cacao progenies from promising clones of National type with resistance to Witch's broom disease (2000) EET-Pichilingue	0.83	Herrera	790	124	16	5	10	50
Total	3.28		2956	333	71	18	40	180

* The selection of trees was made based on their health and production characteristics during six years of study (2002-2007).

compatible trees with high productivity (Table 1). For each trial the number of treatments/trials, number of repetitions/trials, number of trees/treatment and total trees/trial are shown in Table 2.

Employed tools

For the execution of the experiment it was necessary to tubes Eppendorf, which served both for the isolation of floral buttons and the protection of pollinated flowers. The plastic tubes were 5 ml long by 1 ml in diameter, closed at one end and weighing 0.65 g.

Pollination technique

To determine self-compatibility, the following procedure was used: one day before carrying out manual pollinations, the flower buds that are physiologically mature and ready to open the next day in the morning are selected, which are generally characterized by swelling that indicates the beginning of the opening of the button for the formation of the flower. Plastic tubes were placed on the selected buttons, this is done to ensure that at the time of opening the flower no pollinator has access to them and thus be sure that self-pollinations are carried out. This work was carried out in the afternoon of the day before the anthesis of the flower (Alvarado *et al*., 2017).

In the morning of the next day when the flower was open, the pollinations were carried out manually, these were carried out between 7:30 am to 11:30 am. On rainy days it was waited until it stopped and continued later. 20 self-pollinations were carried out per tree, reaching a total of 6660 flowers self-pollinated. The stamens of the flowers from the same tree were taken, after releasing the shell or cogulla. Holding it with the forceps, the anthers were rubbed on the stigma or style of the flower, with a smooth movement from the bottom up, until they were sure that enough pollen had been deposited on the female organ. The flower was immediately covered with the tube.

Data to evaluate

Self Compatibility

The evaluation was carried out at 3, 7 and 15 days after the manual self-pollinations were done, since within this period self-compatibility problems would be observed.

Fertilized flowers

In order to determine the number of fertilized flowers, the verification was made 15 days after the self-pollinations were carried out when the “fruit” had already taken shape.

These evaluations must be carried out in the field after 10 or 15 days of pollination to corroborate the take-off, the fall of the self-pollinated flowers begins after three (Arciniegas, 2005).

Unfertilized flowers

The registration of this variable was done jointly with the previous one, counting the number of pollinated flowers that had come off, or that remained in the tree in the process of physiological wilting (Cherelles wilt).

Fertilization percentage

This variable was estimated by counting the number of flowers fertilized at 15 days after pollinations. This calculation was made with the following formula.

$$\%\, fertilization = \frac{number\ of\ fertilized\ fruits}{number\ of\ polinizationes} x\ 100$$

In general, the interpretation of the self-pollination results was performed by transforming the values obtained in percentages considering the minimum fertilization (30%) which coincides with the Binomial Test.

Statistical analyzes based on the genotype selection criteria

Statistical analyzes were based on the analysis per family (% compatibility by family and individuals) and by each characteristic; rank/tree based on four selection criteria for the total years of evaluation:

- Potential fresh weight (PF Pot = (PF of MS + PF of ME)) = the estimated production based on total produced fruits
- Percentage of healthy (harvested) ears (% DM)
- Witch’s broom (WB) = total witch’s brooms
- Production efficiency = (PF/diameter^3)

Progeny hybrid self-compatibility and performance

For hybrid progenies at least 70% of their individuals must be self-compatible, before considering a progeny compatible. Said calculation was made with the following formula:

$$\%\, of\ autocompatibility = \frac{number\ of\ autocompatible\ trees}{total\ family\ trees} x\ 100$$

The records of this variable were presented in terms of percentage to know the self-compatibility between hybrid families. Their performance was related to it based on the analysis / family, which is one of the selection criteria of this research.

Selection of productive and self-compatible trees

This evaluation method was performed based on the total performance during the evaluation years (2002-2007) of each selected individual. Being the most important selection criterion in the study, this selection criterion was related to the percentage of self-compatibility/tree where self-compatible trees superior to 30% compatibility were selected and with good potential performance.

Statistical test to determine the percentage of self-compatibility of hybrid progenies

The binomial test was used, which allowed determining a minimum of six successful pollinations (30% fertilization), the necessary limit before considering a tree as self-compatible. The 5% probability level was used following the below formula

$$P(X) = \binom{n}{k} . p^k . q^{n-k}$$

P=probability of success
q= Probability of failure
k= Number of desired successes
n= Number of tests carried out

Results

Self-compatibility by individuals among one group of hybrid progenies

Table 3 shows the varying rates of fertilization and the presence of different degrees of self-compatibility and self-incompatibility in four trials of hybrid families, which means that each pollinated tree responded differently to this characteristic.

Of 333 pollinated trees, 154 were self-compatible, i.e. 46.25%. The pollination range of self-compatible individuals was within 27 to 83%. The 4 trials of

Table 3. Summary of selected trees, percentage of fertilization, self-compatibility and self-incompatibility by tree, performed in the four experimental trials. EETP, 2010

Experiment	Trees		% Fertilization	self-incompatible trees	% Fertilization	Null Fertilization	%
	Selected	Self-compatible					
1	40	27	67.50	13	32.50	4	10.00
2	17	12	70.59	5	29.41	1	2.50
3	152	83	54.61	69	45.39	14	35.00
4	124	32	25.81	92	74.19	21	52.50
Total	333	154	218.51	179	181.49	40	100

hybrid families showed different percentages of self-compatible trees. Trials 1, 2 and 3 recorded percentages of 67.50, 70.59 and 54.61%, respectively. While the group 4 presented the lowest percentage of self-compatible trees with 25.81%. The 53.75% of the trees studied were self-incompatible, with fertilization rates below 30%. The highest number of self-incompatible trees was recorded in trial 4 with 74.19%. Although pollinations were repeated, fertilization was absent in a total of 40 trees. More than half of these trees belong to group 4, followed by group 3 with 35% of trees that exhibited zero fertilization.

Self-compatibility level of hybrid progenies and their relationship with performance

Table 4 presents the productivity of the hybrid families that were self-compatible, through the selected trees and their yield of cocoa in fresh weight (g). It was also included comparative purposes, i.e. the average fresh weight yield of the individuals who initially formed the family, before the pre-selection by performance.

More than 70% of the individuals selected for their performance in the families, EET-577 X EET-534 and EET-547 X EET-534, were self-compatible with 83.33; 71.42 and 71.42%, respectively while such families had the characteristic of self-compatibility. The EET-577 X EET-534 Family did not have the highest percentage of self-compatible trees (71.42%) although it contains the largest number of trees selected (14). In contrast, the EET-552 X EET-547 Family with the lowest number (6) of selected trees reached the highest percentage of self-compatible trees (83.33%). The cumulative fresh weight yield of six years for the EET-577 X EET-534 family was 1226 g, which was higher than the EET-552 X EET-547 and EET-547 X EET-534 families with 11.27 and 27.01%, respectively. As expected, the trees with the highest yield belonged to the families with the highest average cumulative yield, i.e. EET-577 X EET-534 with 1226 g and EET-552 X EET-547 with 1088 g. In general, the highest productivity of such individuals was consistent throughout all the years in which data were recorded. The distance among annual average fresh weight yield and less productive tree (318 g), and the most productive one (2042 g) was 1724 g, equivalent to 542%. The least productive tree belonged to the family EET-547 X EET-534 with 318 g. The variability of performance among individuals of each family was quite noticeable.

Selection of productive and self-compatible trees

Table 5 demonstrates cumulative dry weight of six years of evaluation (2000-2007) of self-compatible and productive trees was in the range of 1924-5562 g. Tree 3 of repetition I of the EET-462 X EET-534 junction, tree 9 of repetition II of the EET-48 X EET-85 junction, tree 1 of repetition V of the CCN-51 X EET-534 junction, the tree 8 of the repetition IV of the CCN-51 X EET-233 crossing and the tree 9 of the repetition I of the EET-62 X EET-103 crossing, exceeded the average weight of 800 g/year. The average annual yield of these four materials was 856 g. If 1111 trees were planted in one hectare (3 x 3m) at eight years, the equivalent of 20.9 quintals/ha/year could be expected. This figure is quite acceptable considering that the experiment was conducted under rainfed conditions.

Some trees had no production during the first years of evaluation and were those that generally coincided with those with less production. It was also observed during 2006 when the yield of any tree was superior to that of 2007, with two exceptions. However, it is notorious that the variability observed for the yield between trees in 2006 was not consistent with the variability between trees for the dry weight accumulated during the six years of evaluation (2002-2007).

In general, the trees with more yield showed a greater number of healthy ears, less number of diseased ears and percentages of diseased ears less than 10%. It is evident that the percentage of diseased ears went from low to medium (from 0 - 21.4%), in the group of

Table 4. Potential yield of fresh weight (g) of cocoa from 3 self-compatible hybrid families evaluated in six consecutive years. EETP, 2010

Experiment	N°	Hybrid	Rep.	tree	average of fresh weight (g)/year						Yeild (g)			Self-compatibility %Self-compatibility %
					2002	2003	2004	2005	2006	2007	accumulated	Annual average	Annual average/ family	
	1	EET-552 X EET-547	1	1	480	0	1200	1480	3110	2505	8775	1463	1088 (2348)*	83.33
	2	EET-552 X EET-547	1	2	0	0	220	3180	1110	975	5485	914		
	3	EET-552 X EET-547	1	4	0	0	1520	3960	3000	2920	11400	1900		
	4	EET-552 X EET-547	1	5	0	0	130	1050	1910	695	3785	631		
	5	EET-552 X EET-547	1	6	0	0	240	1000	3120	835	5195	866		
	6	EET-552 X EET-547	1	2	180	0	0	2110	1120	1115	4525	754		
	7	EET-577 X EET-534	4	3	0	0	450	1060	1150	1260	3920	653	1226 (4168)	71.42
	8	EET-577 X EET-534	1	5	100	300	960	3650	1030	2640	8680	1447		
	9	EET-577 X EET-534	1	7	300	600	480	1480	1070	1255	5185	864		
	10	EET-577 X EET-534	1	9	100	420	160	1950	5010	4455	12095	2016		
	11	EET-577 X EET-534	1	10	0	575	100	2870	2450	2645	8640	1440		
	12	EET-577 X EET-534	2	2	0	250	400	1720	3230	1665	7265	1211		
	13	EET-577 X EET-534	2	4	0	0	0	2520	820	2330	5670	945		
3	14	EET-577 X EET-534	2	8	0	625	2850	3820	1010	2225	10530	1755		
	15	EET-577 X EET-534	2	9	0	670	2600	830	2750	3480	10330	1722		
	16	EET-577 X EET-534	2	10	120	300	500	1510	2170	975	5575	929		
	17	EET-577 X EET-534	4	1	0	175	1500	1730	1210	1250	5865	978		
	18	EET-577 X EET-534	5	2	0	0	800	1000	1520	1115	4435	739		
	19	EET-577 X EET-534	5	6	0	300	1850	1310	1260	2220	6940	1157		
	20	EET-577 X EET-534	5	10	0	0	1430	1650	2400	2365	7845	1308		
	21	EET-547 X EET-534	3	1	0	0	770	1980	800	3575	7125	1188	894 (3180)	71.42
	22	EET-547 X EET-534	3	2	0	0	520	2100	930	3755	7305	1218		
	23	EET-547 X EET-534	3	4	0	0	180	2220	610	1430	4440	740		
	24	EET-547 X EET-534	3	8	0	0	1720	180	2740	1440	6080	1013		
	25	EET-547 X EET-534	4	2	0	250	280	280	600	2505	3915	653		
	26	EET-547 X EET-534	5	6	0	0	0	350	300	1255	1905	318		
	27	EET-547 X EET-534	5	8	0	0	100	3690	1180	1790	6760	1127		

trees identified as self-compatible.

Discussion

Self-compatibility levels

The self-compatible materials presented fertilization percentages that varied from 30 to 100%, which shows that there were different ranges of self-compatibility and each tree responded in a different way to this characteristic. As reported by Quiroz (1990), this could be due to the fact that environmental conditions influence the physiology of the tree and at certain times of the year, trees tend to vary their compatibility. Moreno (1970) showed that all clones do not give equal results, because the flowers of some curdle more than the others, with which different degrees of compatibility occur. Loor (1998) stated that this situation may be due to genetic, physiological or environmental factors that include considerably in the pollination process. For Godoy *et al.* (2009) sexual incompatibility is one of the factors that contribute to the low productivity of cocoa; other factor that can influence the genotype is the variability in pollen yield. In most of the self-incompatible trees, especially those in which no flower was fertilized, all flowers with manual pollination fell before the seventh day, showing a strong reaction of self-incompatibility. On the other hand, Pastorelly (1992) reported that in some plantations there are unproductive or very low production trees, which form cobs due to their genotypic constitution but do not mature as there can also be trees that do not form fruits. The main idea is to have a basic knowledge of this characteristic in order to establish the way of planting the different cocoa materials.

In other trees it was observed that many flowers fell after 10 days of self-pollinated. Among the main factors that reduce cocoa production is the problem of the auto-incompatibility of certain trees in the plantations, a condition that according to Loor (1998), may be due to the ovarian stimulation caused by the rubbing of the anthers on the stigma. Zambrano (2000) pointed out that this abnormality can manifest up to 20 days.

It was also observed that in some trees a good number of cobs from manual pollination were affected by the phenomenon of physiological wilting or “ *Cherelles wilt* “, mainly when they were between one and two months old, which suggests a response of the tree to an overload of ears, thus regulating the number of fruits can hold.

Self-compatible hybrid progenies and their relationship with performance

With regard to the results obtained from the self-compatible hybrid families (Table 3), it suggests that this genetic characteristic is present in a dominant state in each of the individuals belonging to these families. Based on this, it is worth to mention that it would be the cause of large losses for farmers if the selected and recommended hybrid progeny were self-incompatible. For this reason, it is recommended to select self-compatible trees in cocoa breeding programs. In relation to the cumulative and average six-year fresh weight yield of the selected individuals, including all progeny trees, it can be noted that the self-compatible crossover EET-577 X EET-534 maintained its superiority of production during the evaluation years. Solís *et al.* (2015) observed a significant variation between hybrid plants in terms of the variable dry cocoa yield, which allowed the selection of high production trees. This corroborates with what was found by Saucedo (2003), who indicated that based on many researchers at different sites there is a relationship between yields and their degrees of compatibility, achieving self-compatible trees and low-productivity self-incompatible productivity.

Within the self-compatible families EET-552 X EET-547, EET-577 X EET-534 and EET-547 X EET-534, there were individuals who excelled in their accumulated performance during the evaluation years. Thus, within each of the self-compatible families there was a tree that stood out for producing 2.2% of the production, corresponding to 6 to 10% of the total accumulated weight of each of the families. Probably this superiority of the genotype is because of the genetic value of the material under study.

Selection of productive and self-compatible trees

It was found that tree 3 of repetition I of the EET-462 X EET-534 junction, tree 9 of repetition II of the EET-48 X EET-95 junction, tree 1 of repetition V of the CCN-51 X junction EET-534, tree 8 of repetition IV of crossing CCN-51 X EET-233 and tree 9 of repetition I of crossing EET-62 X EET-103, were self-compatible and the most productive with 927, 890, 853, 804 and 801 g of dry cocoa/tree/year, respectively. Possibly this is due to the genetic recombination of favorable genes of their parents. In Trinidad, Pound (1934) established basic criteria for the selection of cocoa trees with high yields. He proposed that data should be collected for 2-3 years about the total production of ears, fresh and/or dry weight of almonds that are important factors in estimating the value of selection of a tree. Within the selection indices, the number of ears and the fresh and/or dry weight of almonds are considered the most important for the performance measurement. Eskes (1999) stated that yield efficiency is a relationship that is calculated between tree production and vigor. Campi

(2013) expressed that the number of healthy ears is decisive for yield key, which has direct proportionality with the variable total fresh weight. According to Barrón *et al.* (2014), the genetic improvement of cocoa is a strategy to obtain more productive trees.

Table 5 also shows the absence of diseased ears in the six years of evaluation for the hybrids CCAT-21-19 X EET-574, EET-574 X EET-547, EET-48 X EET-95, EET-574 X EET-577 and CCN-51 X EET-534, possibly due to genetic resistance of the selection and genetic improvement processes. In the same way, it was observed with the data of Solís *et al*, (2015) who conducted a four-year research study, where the agronomic management of 11 hybrid families of cocoa resistant to moniliasis was studied in plants obtained by controlled pollination of low clones in humid tropic conditions where a general average of sick ears of 12.83 were presented. Espín (2017) evaluated 31 Interclonal hybrids of cocoa where he observed that the highest number of sick cobs was for T1. For DYRCYT-H-272 with 6.33 ears, the minimum values were reflected in the T30 and for DYRCYT-H - 301 they were 0.33 sick ears. Pastorelly (1992) showed that these low levels of infection of diseased ears could be because of the action of environment or some genetic factor of resistance or tolerance to this disease. In another study, the genetic improvement of cocoa tree was seen as an alternative to address these pathogens by conferring increasing levels of resistance (Tirado-Gallego *et al.,* 2016).

Conclusions

Wide variability was observed regarding the level of self-compatibility of individuals within all the families under study. The compatibility of a tree, clone or cross can vary the percentage of fertilization according to time and environmental conditions, even a self-compatible one at certain times of year can become self-incompatible in other situations. Only 3 of the 71 studied families presented a sufficient number of self-compatible individuals to be classified as such EET-552 X EET-547, EET-577 X EET-534 and EET-547 X EET-534. However, their average performance was not necessarily higher to other families that were self-incompatible. Self-compatibility is a genetic feature that greatly influences the good agronomic and productive behavior of cocoa cultivars.

References

Alvarado, G. D., Perez, J., Velásquez, C. G., & Maria, V. C. (2017). *Manual de Polinizaciones controladas en cacao.* Guatemala.

Anecacao. 2017. Asociación Nacional de Exportadores de Cacao. Revista Especializada en Cacao. 12va, Edición I Junio. Guayaquil, Ecuador. 42 p.

Aranzazu, H. F., Martinez, G. N., & Rincon-Guarin, D. (2008). *Autocompatibilidad e Intercompatibilidad sexual de materiales de cacao.* Bucaramanga, Colombia.

Arciniegas, L. A. (2005). Caracterizacion de arboles superiores de cacao (Theobroma cacao L.) Seleccionados por el programa de mejoramiento genetico del CATIE. *Tesis de Maestria, Escuela de Postgrado, Programa de educacion para el desarrollo y la Conservacion del Centro Agronomico Tropical de Investigacion y Enseñanza.*, Pp 144.

Barrón, G. Y. P., Azpeitia, M. A., López, A. P. A. y Mirafuentes, H. F. 2014. Metodología adaptada para la formación de híbridos F1 de cacao (*Theobroma cacao* L.) en Tabasco. Revista Mexicana de Ciencias Agrícolas. 5(5): 765 - 777

Campi, C. 2013. Caracterización fenotípica de 40 accesiones clónales de cacao (*Theobroma cacao* L.) para desarrollar su capacidad de uso. (Tesis de grado) Universidad Técnica Estatal de Quevedo, Ecuador.

Espín, G. 2017. Manejo post cosecha de 31 Híbridos Interclonales de cacao (*Theobroma cacao* L.) En la finca experimental La Represa. Tesis Ing. Agropecuaria Quevedo, EC, Facultad de ciencias Agropecuarias, Universidad Técnica Estatal de Quevedo. 74p.

Garcia-Cruzatty, L. C., Vera-Pinargote, L., Zambrano-Gavilanes, F., Zamora-MAcias, A., & Cedeño-Ortega, J. (2020). Produccion de polen en Theobroma cacao L. Genotipos de tipo Nacional y CCN-51 y su relacion con factores climaticos en la costa Ecutoriana. *Acta Agrobotanica*, Vol 73, Edicion 2.

Godoy, P. R. E., Magalhaes, S. M., Amaral, R. F., Ramos, L. P., Santos, A. I. y Dario, A. 2009. Performance polínica em cacaueiros (*Theobroma cacao* L.) autocompatíveis e autoincompatíveis. Revista Brasil. Bot. 32(3): 617-620.

INAMHI. Servicio meteorológico. 2016. Available online from: http://www.serviciometeorologico.gob.ec/wpcontent/uploads/anuarios/meteorologicos/Am 2011.pd.

INIAP. Mejoramiento y homologación de los procesos y protocolos de investigación, validación y producción de servicios en cacao y café. 2016. Publicación Miscelánea. N° 433.

León, V.F., Calderón, S. y Mayorga, Q.E. 2016 Estrategias para el cultivo, comercialización y exportación del cacao fino de aroma en Ecuador. Revista Ciencia UNEMI. 9(18): 45 – 55.

Loor, G. 1998. Obtención de híbridos de cacao tipo Nacional provenientes de materiales de alta productividad y resistencia a enfermedades. Tesis Ing. Agr. Manabí, EC. Facultad de Ingeniería Agronómica, Universidad de Manabí. 63p.

Loor, G., Fouet, O. Lemainque, A., Pavek, S., Boccara, M., Argout, X., Amores, F., Courtois, B., Risterucci, A., M. and Lanaud, C. 2012. Insight into the wild origin, migration and domestication history of the fine flavour national *Theobroma cacao* L. variety from Ecuador. Plos One. 8(2): 10.1371/annotation/2357f0f1-7dc3-4781-afb0-29a8ce56b3f0

Loor-Solorzano, R. G., Amores-Puyutaxi, F. M., Vasco-Medina, A., S., Quiroz-Vera, J. G., Casanova-Mendoza, T. d., . . . Jimenez-Barragan, J. C.-F. (2019). INIAP-EET-800 "Aroma Pichilingue!, nueva variedad Ecuatoriana de cacao fino de alto rendimiento. *Revista Fitotecnia Mexico*, Vol 42, N° 2, Pp 187-189.

Macoto, Y. J., Gelape, F. F., & Vanderlei, L. U. (2013). Rendimiento agronómico de 27 progenies de cacao y selección de plantas basada en productividad, autocompatibilidad y resistencia a enfermedades. *Ceres, Vicosa*, Vol 60, N° 4, Pp 514-518.

Mena-Montoya, M., Garcia-Cruzatty, L., Cuenca-Cuenca, E. V., & Villamar-Torres, R. y. (2020). Flujo de polen (Theobroma cacao L.) y su relacion con factores climaticos en la zona central del Litoral Ecuatoriano. *Bioagro*, Vol 32, N° 1, Pp 39-48.

Montero-Cedeño, S. L., Sanchez, R., Solorzano-Faula, R., Pinargote-Borrero, A., & Cañarte.Bermudez, E. G. (2019). Floracion y diversidad de insectos polinizadores en eun sistema monocultivo de cacao. *ESPAMCIENCIA*, Vol 10, N° 1, Pp 1-7.

Moreno, Z. 1970. Determinación de la autocompatibilidad y de la compatibilidad cruzada de 70 clones de cacao (*Theobroma cacao* L.). Tesis Ing. Agr. Guayaquil, EC. Facultad de Agronomía y Veterinaria, Universidad de Guayaquil. 23p.

Pastorelly, D. 1992. Evaluación de algunas características del cacao tipo Nacional de la colección de la zona de Tenguel. Tesis Ing. Agr. Guayaquil, EC. Facultad de Ciencias Agrarias, Universidad Agraria del Ecuador. 124 p.

Quinaluisa, C.O. 2010. Estudio de la compatibilidad de árboles seleccionados por productividad y sanidad en un grupo de progenies hibridas provenientes de cruces entre cacao (*Theobroma cacao* L.) Nacional y otros orígenes genéticos. Tesis Ing. Horticultura-Fruticultura. Universidad Técnica Estatal Quevedo, Quevedo, Ecuador. 52p.

Quiroz, J. (1990). Estudio de la compatibilidad en algunos cultivares de cacao (*Theobroma cacao* L.). Tesis Ing. Agr. Babahoyo, EC. Facultad de Ciencias Agrícolas. Universidad Técnica de Babahoyo. 41p.

Quiroz, J., Amores, F. 2002. Rehabilitación de plantaciones tradicionales de cacao en Ecuador. Manejo Integrado de Plagas 63: 73-80.

Sánchez-Mora, F.D., Vera, C.J., Zambrano, M.J., Ramos, R.A., Garcés, F.F., y Vascones, M.G. 2014. Productividad de clones de cacao tipo nacional en una zona del bosque húmedo tropical de la Provincia de los Ríos, Ecuador. Ciencia y Tecnología. 7(1):33-41.

Sanchez-Mora, F., Medina-Jara, S., Diaz-Coronel, G. R.-R., Vasquez-Moran, V., Troya-Mera, F., & Garces-Fiallos, F. y.-N. (2016). Potencial sanitario y productivo de 12 clones de cacao en Ecuador. *Revista Fitotecnia Mexicana*, Vol 38, N° 3, Pp 265-274.

Saucedo, S. 2003. Comportamiento de híbridos de cacao (*Theobroma cacao* L.) tipo Nacional en la zona de Quevedo. Tesis Ing. Agr. Babahoyo, EC, Facultad de Ciencias Agropecuarias. Universidad Técnica de Babahoyo. 83p.

Solís-Bonilla, L., Zamarripa, A., Pecina, V., Garrido-Ramirez, E., e Hernández, E. 2015. Agronomic evaluation of cocoa hybrids (*Theobroma cacao* L.) for high-yield selection and field resistance to moniliasis. Revista Mexicana de Ciencias Agrícolas. 1: 71-82.

Sotomayor, C. I., Loor, S. R., Amores, P. F., & Motomayor, J. C. (2017). Variacion fenotipica y seleccion de genotipos de cacao de alto rendimiento en Ecuador. *Revista ESPAMCIENCIA*, Vol 8, N° 2, Pp 23-33.

Tarqui, F. O., Sotomayor, C. I., Casanova, M. T., Rodriguez, Z. G., Plaza, A. L., & Zambrano, F. F. (2017). Selección de genotipos de cacao (Theobroma cacao L.) con resistencia a escoba de bruja (Moniliophthora perniciosa) en Los Ríos, Ecuador. *Ciencias Agrarias/Agricultural Sciencices*, Vol 10, N° 1, Pp 17-26.

Tirado-Gallego, PA., Lopera-Álvarez, A., Ríos Osorio, LA. 2016. Estrategias de control de Moniliophthora roreri y Moniliophthora perniciosa en *Theobroma cacao* L.: revisión sistemática. Corpoica Ciencia Tecnología Agropecuaria. 17(3): 417-430.

Vera, C. J., & Vera, B. J. (2018). *Polinizacion artificial para incrementar la productividad en huertas y la obtencion de cruces internacionales de cacao (Theobroma cacaoL).* Guayaquil-Ecuador: Grupo Compas. Sotomayor, C. I., Loor, S. R., Amores, P. F., & Motomayor, J. C. (2017). Variacion fenotipica y seleccion de genotipos de cacao de alto rendimiento en Ecuador. *Revista ESPAMCIENCIA*, Vol 8, N° 2, Pp 23-33.

Vera-Chang, J., Cabrera-Verdezoto, R., Moran-Moran, J., Neira-Rengifo, K., Haz-Burgos, R., Vera-Barhaona, J., . . . Diaz-Ocampo, E. a.-V. (2016). Evaluación de tres métodos de polinización artificial en clones de cacao (Theobroma cacao L.) CCN-51. *IDESIA, Chile*, Vol 34, N° 6, Pp 35-40.

Zambrano, J. 2000. Caracterización fenológica de 67 genotipos de cacao (*Theobroma cacao* L.) tipo Nacional y de otros orígenes en la colección de la Estación Experimental Tropical Pichilingue. Tesis Ing. Agr. Manta, EC. Facultad de Ciencias Agropecuarias Laica Eloy Alfaro de Manabí. 60p.