International Symposium on Cacao Research.
Lima, Perú. 12-17 November, 2017

CATIE
Solutions for environment and development
Soluciones para el ambiente y desarrollo

"GENERATION OF CACAO CLONES WITH DURABLE RESISTANT AGAINST MONILIASIS/FROSTY POD ROT (*Moniliophthora roreri*)"

Wilbert Phillips-Mora, Allan Mata-Quirós & Adriana Arciniegas-Leal

Cacao Breeding Program, CATIE 7170, Turrialba, Costa Rica

Moniliasis or frosty pod rot

the most destructive cacao disease

- ✓ Highly specialized fungus to destroy pods.
- ✓ Extraordinary production of spores: 44 millions/cm^2
- ✓ Easily spread by wind, water and human beings.
- ✓ Most commercial varieties are susceptible.

Climate change

Magnitude of damages

Effectiveness of management strategies

Geographical distribution






GENETIC CONTROL OF DISEASES

- ✓ ***The use of resistant varieties is the most appropriated in cacao:***
  - ✓ It has no cost to farmers
  - ✓ It is environmentally safe.

- ✓ ***Durable resistant is crucial in cacao:***
  - ✓ Permanent crop
  - ✓ Grown by small farmers with limited resources.
- ✓ ***Durable resistance (definition):***
  - ✓ It remains effective during its prolonged and widespread use in an environment favorable to the disease (Johnson 1984).

CATIE
Solutions for environment and development

Increasing durability of resistance in cacao

Ways to increase resistance durability:

- ✓ ***Knowledge on the type of reproduction of the pathogen and the level and distribution of the genetic diversity (Phillips-Mora 2003).***
- ✓ ***Accumulation of resistant genes.***
- ✓ ***Establishing clonal mixtures in commercial plantations.***
- ✓ ***Application of complementary agricultural practices.***

POLYGENIC RESISTANCE
(QUANTITATIVE, HORIZONTAL)

- ✓ ***Combining resistant (R) genes (gene pyramids) is a useful approach for increasing durability, and central to sustainable disease management.***

- ✓ ***Resistant to moniliasis is polygenic and predominantly additive.***

SELECTION AND RELEASE OF SUPERIOR VARIETIES

PRODUCTION OF CROSSES TO ACCUMULATE FAVOURABLE GENES

SELECTION OF MONILIASIS RESISTANT PARENTS

DEVELOPMENT OF VARIETIES WITH DURABLE RESISTANCE

1. Evaluation and selection of moniliasis resistant parents.

INTERNATIONAL CACAO COLLECTION AT CATIE (IC3)

one of the two universal depositories of cacao

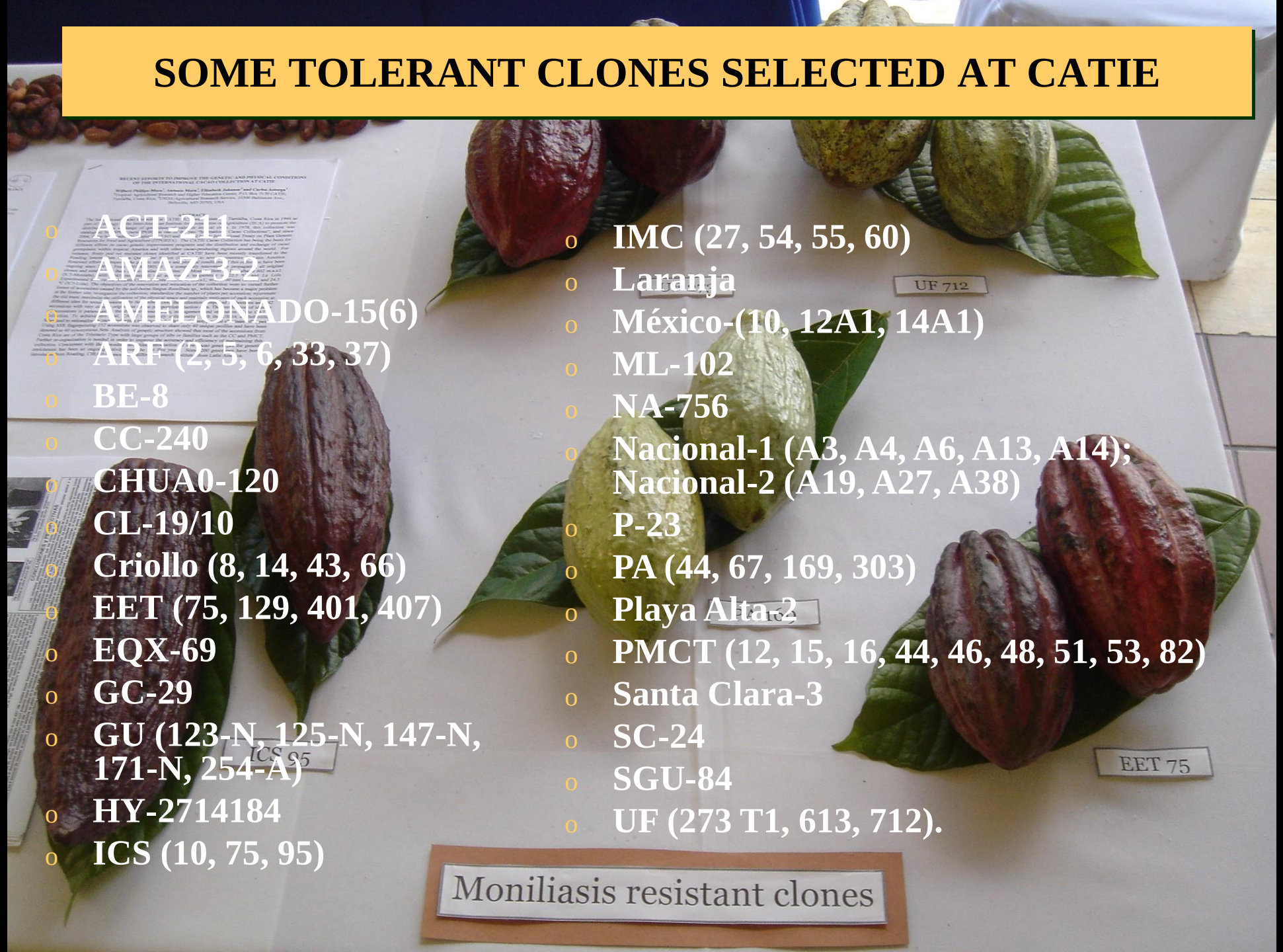
Duplicated in two contrasting sites

1260 genotypes from all over the world

ARTIFICIAL INOCULATION METHOD

SOME TOLERANT CLONES SELECTED AT CATIE

- ACT-211
- AMAZ-3-2
- AMELONADO-15(6)
- ARF (2, 5, 6, 33, 37)
- BE-8
- CC-240
- CHUA0-120
- CL-19/10
- Criollo (8, 14, 43, 66)
- EET (75, 129, 401, 407)
- EQX-69
- GC-29
- GU (123-N, 125-N, 147-N, 171-N, 254-A)
- HY-2714184
- ICS (10, 75, 95)
- IMC (27, 54, 55, 60)
- Laranja
- México-(10, 12A1, 14A1)
- ML-102
- NA-756
- Nacional-1 (A3, A4, A6, A13, A14); Nacional-2 (A19, A27, A38)
- P-23
- PA (44, 67, 169, 303)
- Playa Alta-2
- PMCT (12, 15, 16, 44, 46, 48, 51, 53, 82)
- Santa Clara-3
- SC-24
- SGU-84
- UF (273 T1, 613, 712).



FIFTY RESISTANT AND MODERATE RESISTANT CLONES

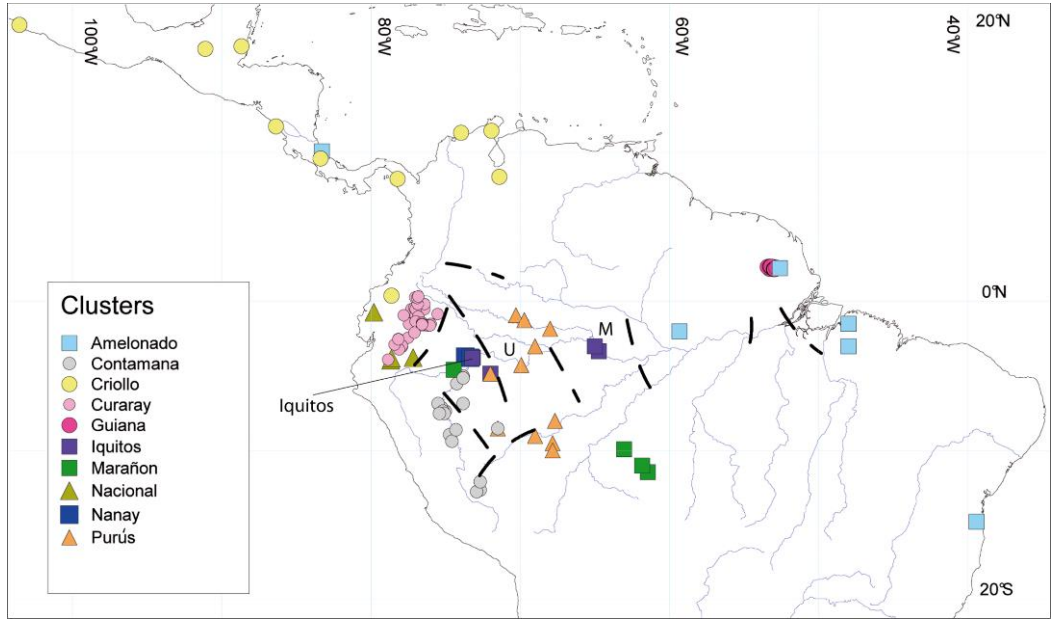
CATIE
Solutions for environment and development
Soluciones para el ambiente y desarrollo

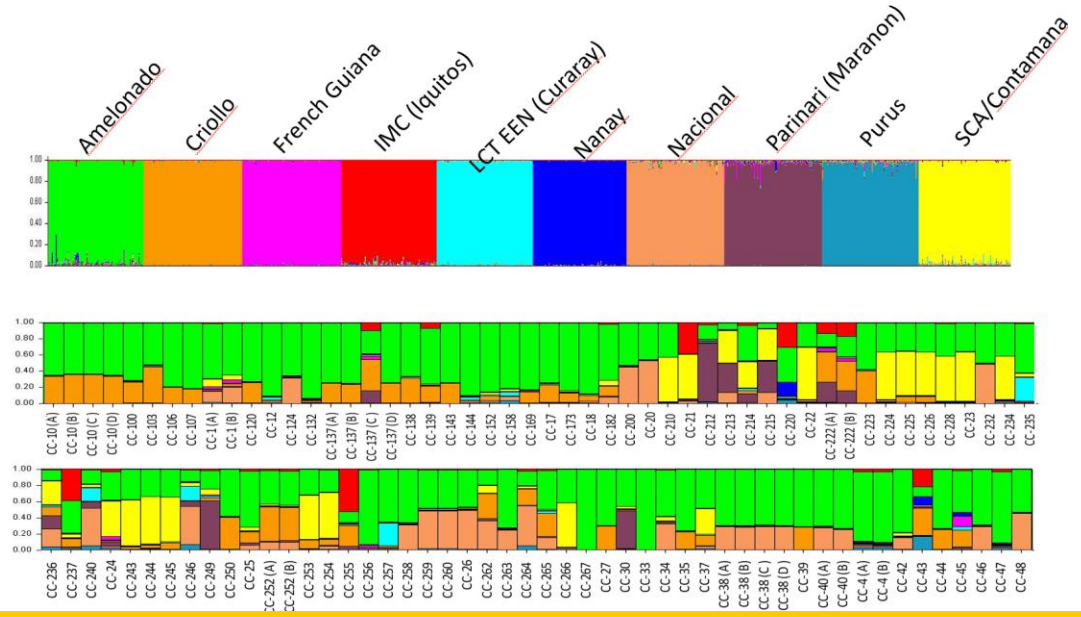
Clone	Genetic and/or Geographic origin
ELP-37A	River Elepoussing, French Guiana
CHUAO-120	Chuao, Venezuela
LCTEEN-37	Rio Anangu, Napo River, Ecuador
B7-A2	French Guiana
B-13/1 (RUQ348)	French Guiana
ELP-16A	River Elepoussing, French Guiana
ELP-20A	River Elepoussing, French Guiana
GU 139-A	French Guiana
GU 147-N	French Guiana
GU-185G	French Guiana
GU 249-H (RUQ228)	French Guiana
GU 285-B	French Guiana
GU 296-H	French Guiana
GU 310-P (RUQ815)	French Guiana
GU 355-N	French Guiana
AMAZ-3/2 (RUQ91)	AMAZ-3 Open, Amazonas River near Iquitos (Chalmers collection at INIAP, Ecuador)
IMC-60	Iquitos, Peru
PA-169	Parinari River, Perú
UF-712	United Fruit Co., Atlantic Coast of Costa Rica
Nacional-1 (A3)	Offspring of an open pollinated Nacional Clone
Nacional-2 (A26)	Offspring of an open pollinated Nacional Clone
Nacional-2 (A27)	Offspring of an open pollinated Nacional Clone
Nacional-3 (A38)	Offspring of an open pollinated Nacional Clone
RB-33/3 (RUQ40)	Rio Branco, Brazil
ARF-37	Catongo x POUND-12. Experimento Central, La Montaña, CATIE

Clone	Genetic and/or Geographic origin
HY-2714202	IMC-67 x TSAN-792. Trinidad
ICS-95 T1	Hacienda La Reconnaissance, North Range, Trinidad
UF-273 T1	United Fruit Co., Atlantic Coast of Costa Rica
ARF-33	POUND-7 x SCA-6. Experimento 14, Rep IV Árb 2. CATIE, Turrialba, CR
FHIA-330	UF-273 X P-23 (seeds provided by CATIE)
FHIA-707	UF-273 X PA-169 (seeds provided by CATIE)
CATIE-R4	UF-273 X PA-169
CATIE-R6	UF-273 X PA-169
ARF-2	F. Th. P. Árb Viejo, Finca Theobroma, Changuinola, Panamá
ARF-6	Hershey, Belmopán, Belice, 111195
EET-75	La Pretoria, Guayas, Ecuador
EET-233	Pichlingue, Los Ríos, Ecuador
EET-401	Selección Patología 7321. Pichilingue
EET-407	Selección Patología 7581. Pichilingue
EET-610	Pichlingue, Los Ríos, Ecuador
EQX-27 RUQ-857	Ecuador
GN-20	??
FHIA-577	FHIA, Honduras (seeds provided from CATIE)
ICS-10	Imperial College, Trinidad
IMC-45	Iquitos, Peru
Laranja	Bahía, Brasil
Pound-16/A (RUQ26)	Nanay River, Loreto, Perú
Pound-18 (RUQ874)	Amazonas River, Perú
VM-Z	??
Santa Clara-3	Upala, Costa Rica

Dr. Wilbert Phillips-Mora. Programa de Mejoramiento de Cacao, CATIE 7170, Turrialba, C.R.

GENETIC BACKGROUND AND PARENTAGE OF CACAO CLONES





Clone Name ↑	Miami Sample Number ↓	Classification ↓
AGU-22	TC-01170	Curaray
AGU-31	TC-01448	Curaray
AGU-8	TC-00476	Curaray
AGU17	TC-02953	Curaray
AGU5	TC-02952	Curaray
AM 1/57 [POU]	TC-04599	Iquitos
AMA-11	TC-01168	Iquitos
AMA-12	TC-00374	Iquitos
AMA-13	TC-01162	Iquitos
AMA-14	TC-01167	Iquitos
AMA-14	TC-00377	Iquitos
AMA-2	TC-01139	Iquitos
AMA-4	TC-01150	Iquitos
AMA-4 (ARBOL 2)	TC-00375	Iquitos
AMA-9	TC-00379	Iquitos
AMA10	TC-02955	Iquitos
AMA2	TC-02954	Iquitos
AMAZ 15 [CHA]	TC-04601	Iquitos
AMAZ 15/15 [CHA]	TC-04602	Iquitos
AMAZ 5/2 [CHA]	TC-04600	Iquitos
B3	TC-03071	Criollo
B48	TC-03072	Criollo
B7-A2	TC-02209	Guiana
B7-A6	TC-02214	Guiana
B7-B2	TC-02211	Guiana
B7-B3	TC-02212	Guiana
B7-B4	TC-02213	Guiana
B7-B5	TC-02210	Guiana
BE10-PL1	TC-02542	Amelonado
BE2-PL1	TC-02549	Amelonado
BE3-PL6	TC-02548	Amelonado

Geographic and Genetic origin of Resistant and Mod. Resistant clones against moniliasis.

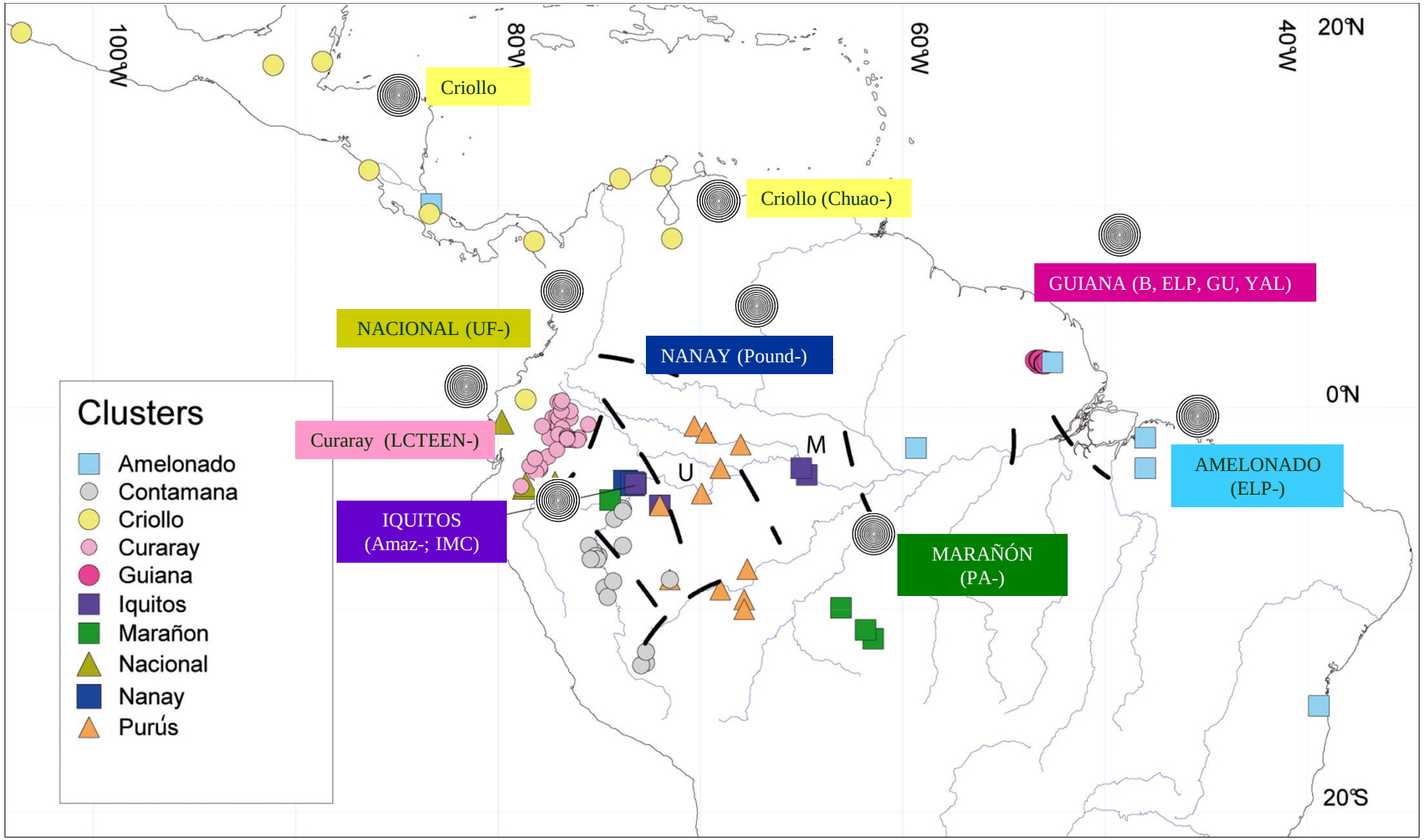
Pure ancestry

Clone	Country of origin	Genetic group 1/
ELP-37A	French Guiana	AMELONADO
CHUAO-120	Venezuela	CRIOLLO?
Criollo-8	Nicaragua	CRIOLLO?
LCTEEN-37	Ecuador	CURARAY
B7-A2	French Guiana	GUIANA
B-13/1 (RUQ348)	French Guiana	GUIANA
ELP-16A	French Guiana	GUIANA
ELP-20A	French Guiana	GUIANA
GU 139-A	French Guiana	GUIANA
GU 147-N	French Guiana	GUIANA
GU-185G	French Guiana	GUIANA
GU 249-H (RUQ228)	French Guiana	GUIANA
GU 285-B	French Guiana	GUIANA
GU 296-H	French Guiana	GUIANA
GU 310-P (RUQ815)	French Guiana	GUIANA
GU 355-N	French Guiana	GUIANA
AMAZ-3/2 (RUQ91)	Ecuador	IQUITOS
IMC-60	Peru	IQUITOS
PA-169	Perú	MARAÑON
UF-712	Ecuador	NACIONAL
Nacional-1 (A3)	Ecuador	NACIONAL?
Nacional-2 (A26)	Ecuador	NACIONAL?
Nacional-2 (A27)	Ecuador	NACIONAL?
Nacional-3 (A38)	Ecuador	NACIONAL?
RB-33/3 (RUQ40)	Brasil	PURUS

Hybrid

Clone	Country of origin	Genetic group 1/
ARF-37	Costa Rica	"Amelonado x Iquitos" hybrid
HY-2714202	Trinidad	"Iquitos x Uknown" hybrid
ICS-95 T1	Trinidad	"Criollo x Amelonado" hybrid
UF-273 T1	Costa Rica	"Nacional x Amelonado" hybrid
ARF-33	Costa Rica	"Nanay x Contamaná" hybrid
FHIA-330	Costa Rica	"(Nacional x Amelonado) x Unknown" hybrid
FHIA-707	Costa Rica	"(Nacional x Amelonado) x Marañon" hybrid
CATIE-R4	Costa Rica	"(Nacional x Amelonado) x Marañon" hybrid
CATIE-R6	Costa Rica	"(Nacional x Amelonado) x Marañon" hybrid
ARF-2	Panamá	??
ARF-6	Belice	??
EET-75	Ecuador	??
EET-233	Ecuador	??
EET-401	Ecuador	??
EET-407	Ecuador	??
EET-610	Ecuador	??
EQX-27 RUQ-857	Ecuador	??
GN-20	??	??
FHIA-577	Costa Rica	??
ICS-10	Trinidad	??
IMC-45	Peru	??
Laranja	Brasil	??
Pound-16/A (RUQ26)	Perú	??
Pound-18 (RUQ874)	Perú	??
VM-Z	??	??
Santa Clara-3	Costa Rica	??

RESISTANT GENES AGAINST MONILIASIS ARE SPREAD IN DIFFERENT GENETIC GROUPS AND COUNTRIES

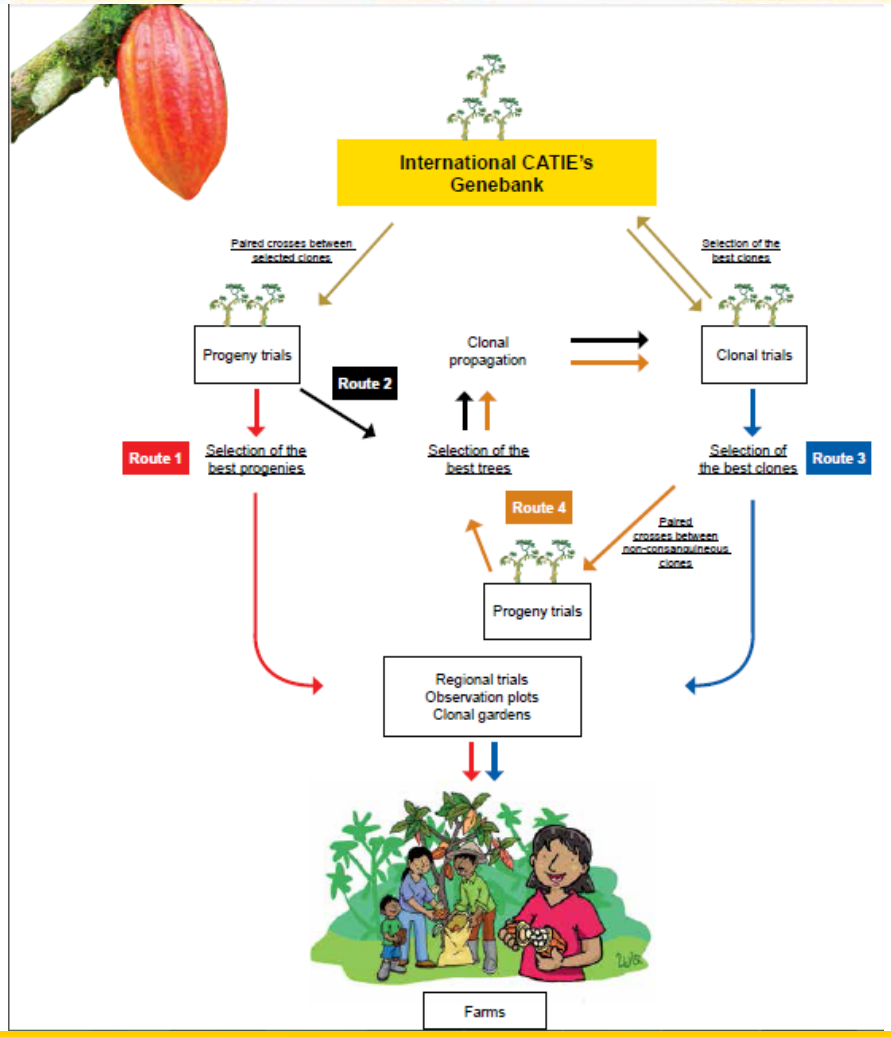


Remarkable facts

- ✓ **Resistance to moniliasis is widely spread in the complete known genetic diversity of cacao, and involves different countries and contrasting regions and environments.**
- ✓ **However, none resistance clone has been identified in the center of genetic diversity of *M. roreri* in Eastern Colombia (Phillips-Mora et al. 2007).**
- ✓ **The predominant presence of resistant genotypes in regions where the disease is not present suggest that non-specific R-genes are mostly responsible for moniliasis resistance in cacao.**
- ✓ **The presence of resistant genotypes in French Guiana suggests that an important selection pressure have led the emerging of resistant genotypes in this country, associated with organisms different to *M. roreri*, which is not present there.**
- ✓ **It can be speculated that the accumulation of R-genes would protect the plants against both, moniliasis and a series of endemic and foreign pathogens.**

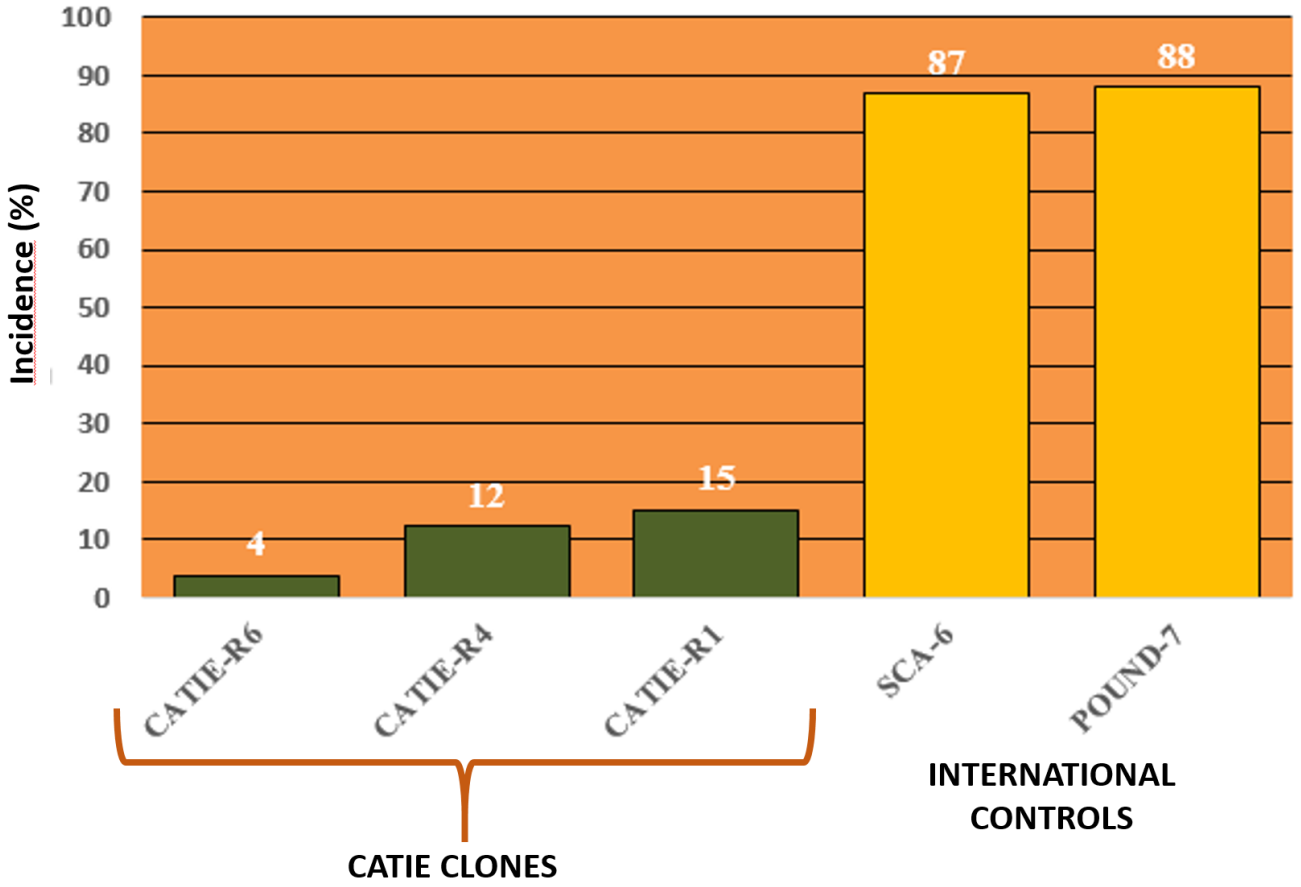
2. PRODUCTION/RELEASE OF CROSSES ACCUMULATING FAVOURABLE GENES

THE CACAO BREEDING PROGRAM AT CATIE



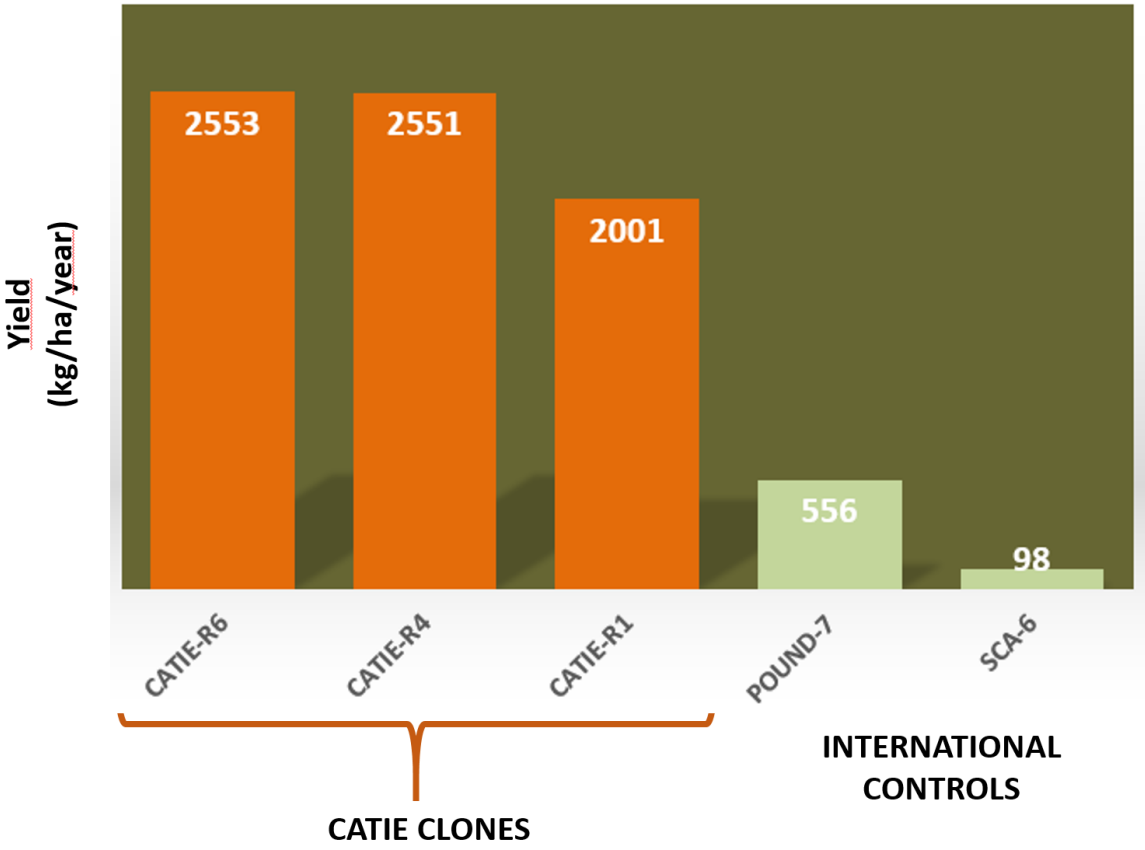
- ✓ **CATIE´s Breeding Program applies a holistic approach to enhance simultaneously both, cacao performance and durability of resistance.**
- ✓ **The research was initiated 22 years ago but was intensified recently as:**
  - ✓ more resistant materials were identified.
  - ✓ more information on the genetic background and parentage of the materials became available.

Moniliasis incidence in L6 (Avg last 10 years of data)



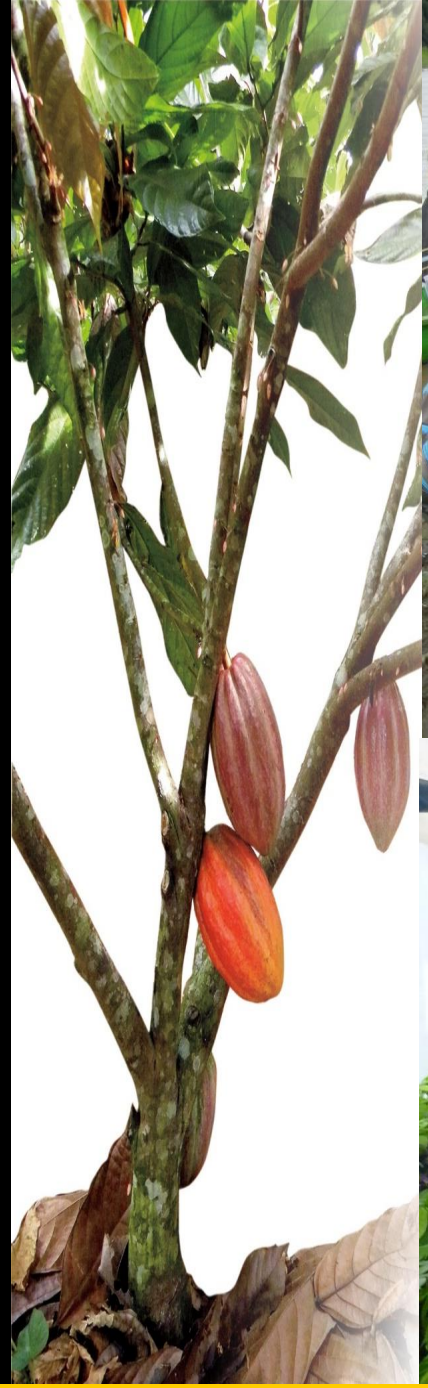
Yield (kg/ha/year) in L6

Avg of the last 10 years (July 2005 to June 2015)



CLONES RELEASED BY CATIE FOR FARMER USE IN CENTRAL AMERICA AND MEXICO

CATIE CLONES ARE PRESENT IN 10 COUNTRIES



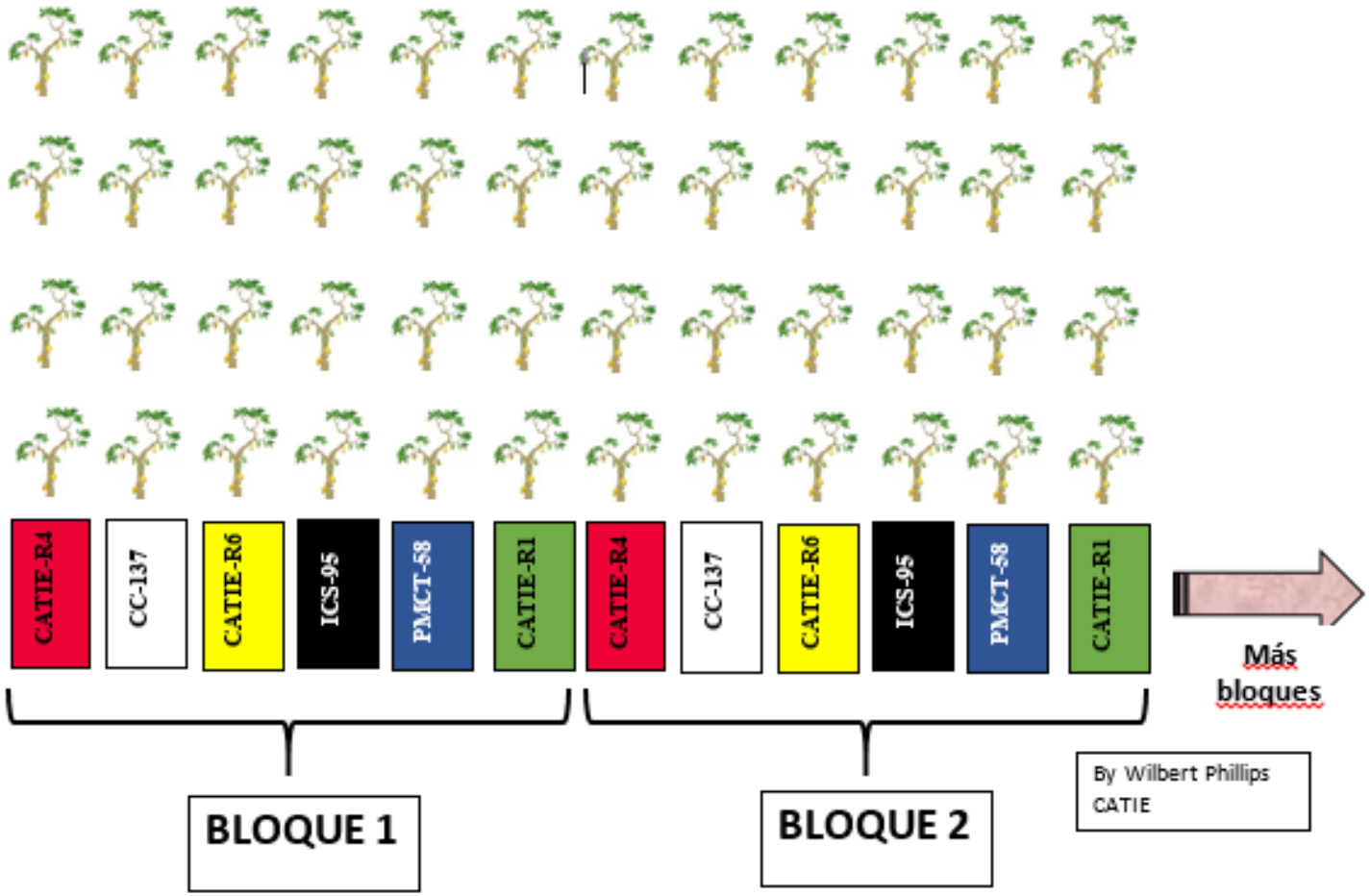
Deployment of CATIE´s varieties in Central America and Mexico

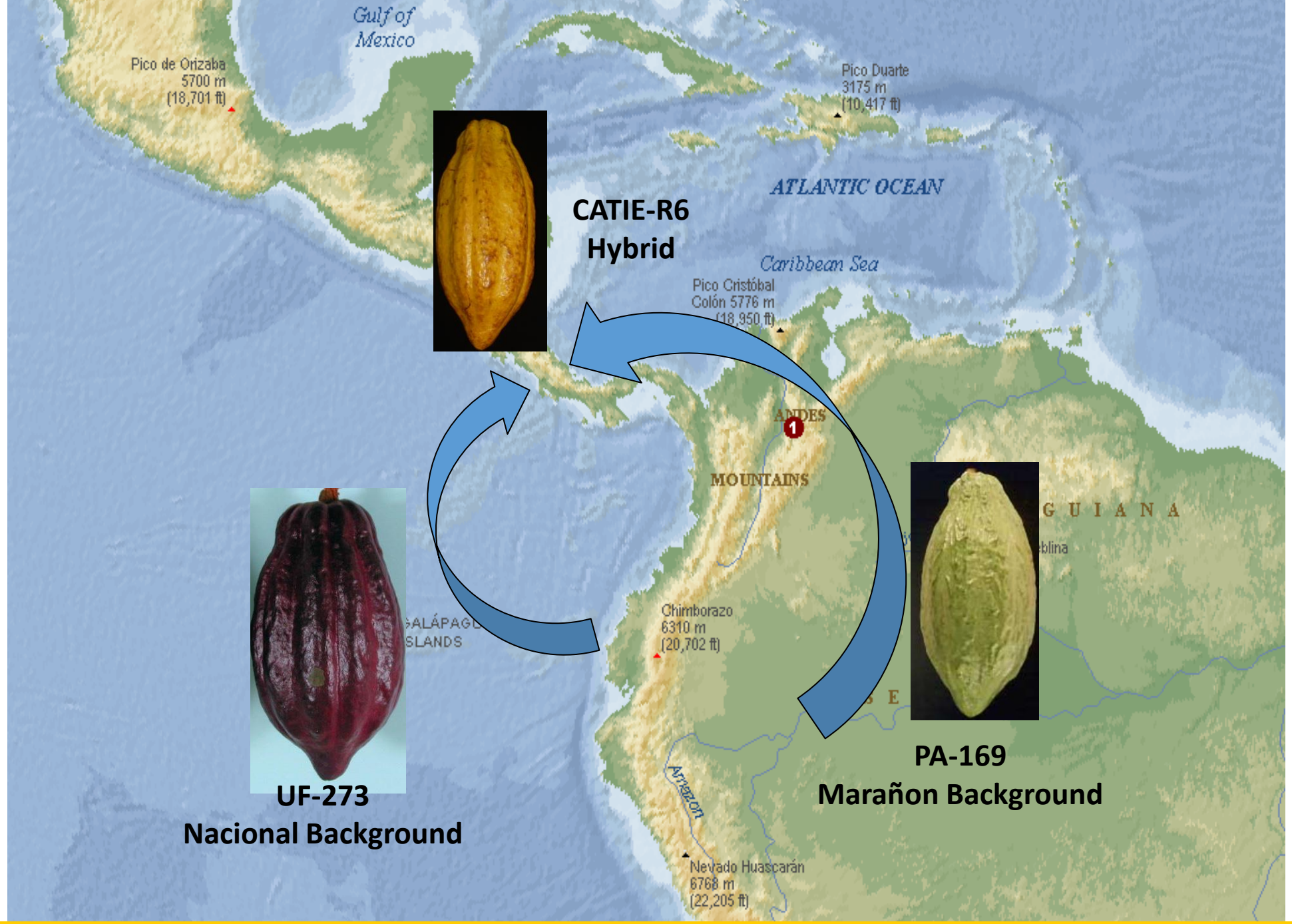
Dr. Wilbert Phillips-Mora. Programa de Mejoramiento de Cacao, CATIE 7170, Turrialba, C.R.

DEPLOYMENT STRATEGY: mixture of cultivars

PLANTING DESIGN OF CATIE´s VARIETIES

Minimizes infections of moniliasis disease and fosters the exchange of pollen among inter-compatibles clones



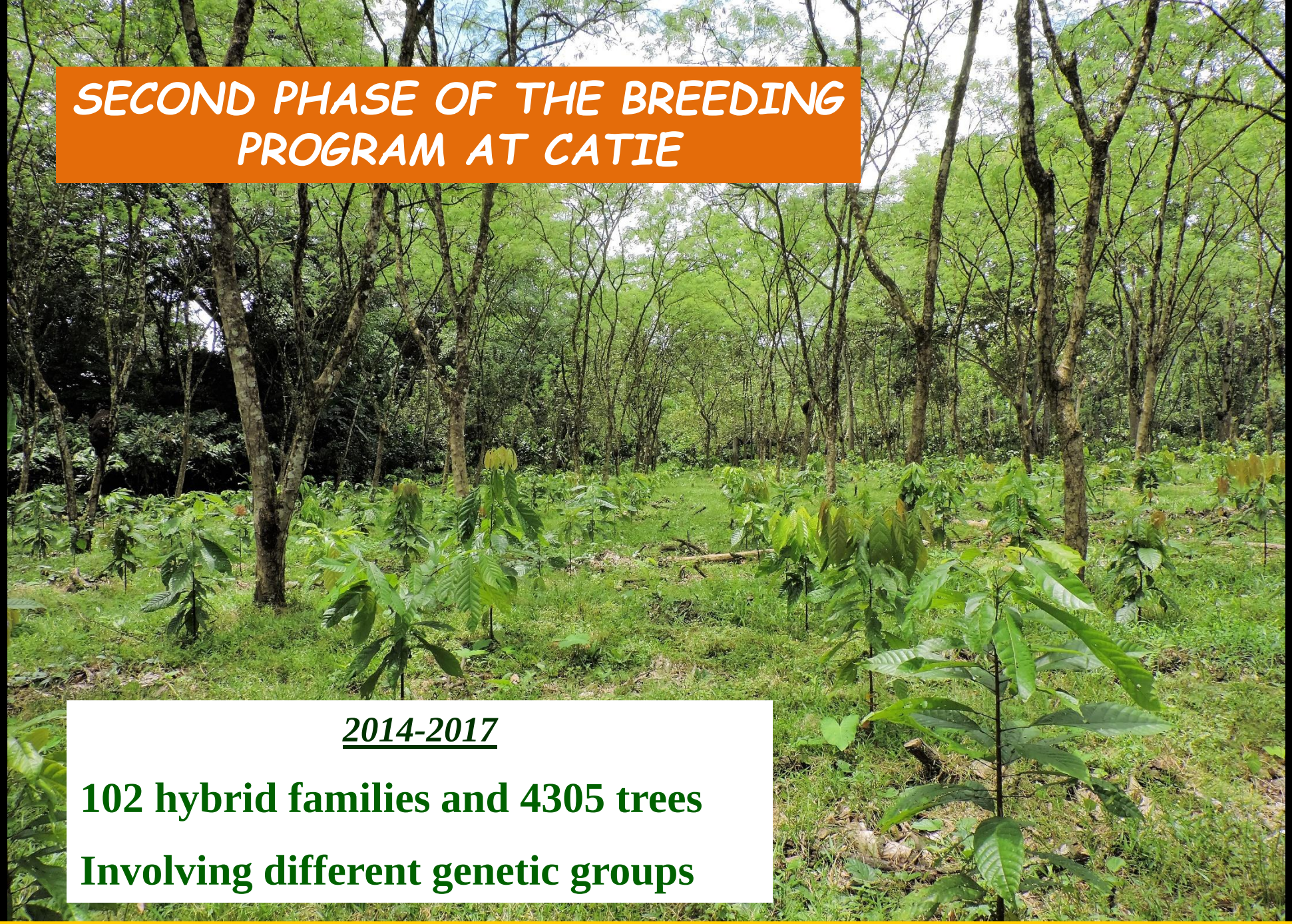

Gulf of Mexico
Pico de Orizaba
5700 m
(18,701 ft)
Pico Duarte
3175 m
(10,417 ft)
ATLANTIC OCEAN
Caribbean Sea
Pico Cristóbal
Colón 5776 m
(18,950 ft)
ANDES
MOUNTAINS
GUIANA
Chimborazo
6310 m
(20,702 ft)
Nevado Huascarán
6768 m
(22,205 ft)
CATIE-R6
Hybrid
UF-273
Nacional Background
PA-169
Marañon Background

Participation of clones in the conformation of crosses tested at CATIE

The main sources of resistance in the first phases of the breeding program came from the Nacional, Marañón and Criollo genetic groups

CLON	PARENTAGE	PRESENCE IN THE CROSSES
UF-273	66% Nacional 33% Amelonado	42%
PA-169	100% Marañon	11%
CC-137	73% Amelonado 24% Criollo	10%
UF-712	100% Nacional	10%
ARF-22, ARF-37, CC-124, CC-252, EET-75, ICS-95		< 5 each

SECOND PHASE OF THE BREEDING PROGRAM AT CATIE



2014-2017

102 hybrid families and 4305 trees

Involving different genetic groups

CCN-51 X CATIE-R6

Dr. Wilbert Phillips-Mora. Programa de Mejoramiento de Cacao, CATIE 7170, Turrialba, C.R.

Moniliasis: a substantial threat to cacao cultivation worldwide

- ✓ Planting materials
- ✓ Parents for breeding

CATIE
Solutions for environment and development
Soluciones para el ambiente y desarrollo

The cacao breeding team