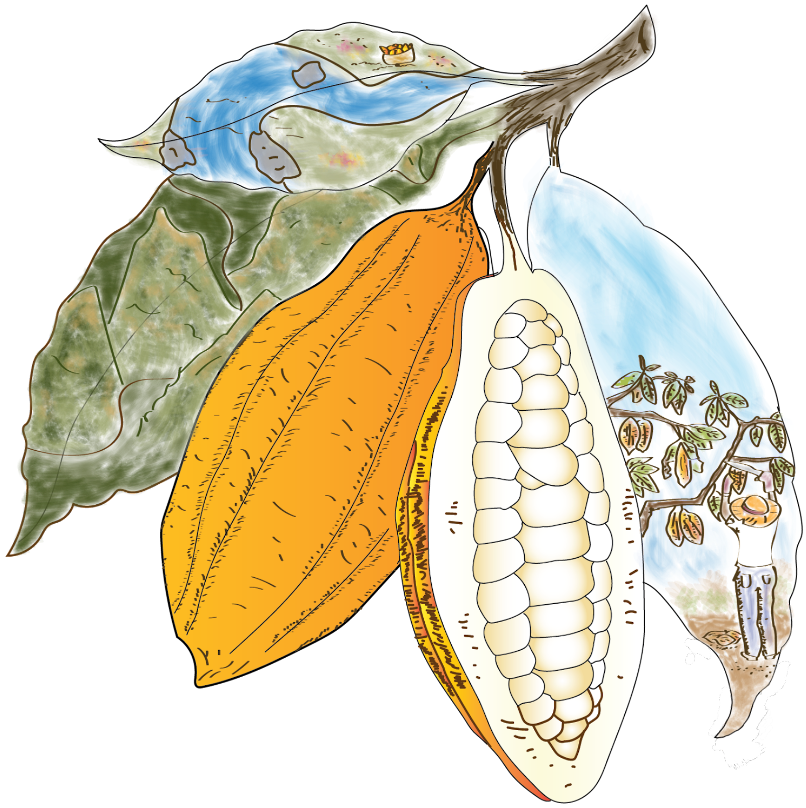

Review of Cacao Explorations and Germplasm Movements

by

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PREFACE

The Heirloom Cacao Preservation (HCP) Fund (www.hcpcacao.org) was founded in 2012 as an initiative of the Fine Chocolate Industry Association. Its mission is to discover, identify and preserve fine flavor heirloom cacao for the preservation of biological diversity and empowerment of farming communities. HCP was recently awarded a grant to review where cacao discovery expeditions have taken place and to determine locations of cacao genetic clusters that are (a) unique, (b) vital, (c) heretofore unrecognized or (d) under threat of extinction. The overarching aim is to indicate places for future expeditions and consolidate existing information on previous cacao discoveries and expeditions.

A literature review of historical and contemporary documents on cacao genetics and discovery efforts and a survey of key experts were undertaken to outline where cacao discovery expeditions have taken place and where future collections should be focused.

Cacao is an important tree crop affecting the livelihoods of millions of farming families in tropical and sub-tropical countries worldwide. This review is intended to help conserve cacao genetic diversity by identifying places for *in situ* collection and germplasm collection for *ex situ* gene banks. The review should also facilitate the identification of new HCP designations. To achieve this goal a team of seven persons collaborated to collate and extract relevant information from varied sources inclusive of gray literature. Complementary information was obtained from a germplasm questionnaire that was delivered online to cacao experts worldwide. Suggested future collection expeditions are based on the advice of these experts in conjunction with the literature analysis and represent a unified best approach to source cacao germplasm. Collectors, conservation specialists, scientists and students will find this review useful as a first and expert guide into cacao germplasm exploration.

EXECUTIVE SUMMARY

The available cacao literature was surveyed to obtain clarity in planning cacao collecting expeditions. In addition, expert feedback was sought to complement the published information and to get focused opinion on gaps in collecting cacao germplasm.

There is an increasing attempt to establish a best picture of the national genetic diversity by genotyping selected cultivars from breeding trials, collections within country and from farm accessions. These attempts should be encouraged as unique combinations of genetic profiles are often present especially in farmers' fields that have not been supplanted by improved cultivars.

There is a limited range of cacao genetic diversity as out-of-the-Amazon due to the limited number of introductions using few budsticks or seedlings in the early years, followed by distribution of seeds or otherwise from these few introduced plants, and the reliance on few cultivars for particular traits. Nevertheless as an outcrossing species with a unique incompatibility system, the majority of the genetic diversity is held among individuals rather than among populations. This means that the risk of loss of cacao is not as detrimental as it seems. An accession or cultivar lost can be made up for by the presence of other individuals which together can provide the allelic information carried by the lost accession. The most reasonable route is to ensure that national collections are made in each country so that the range of genetic diversity can be safely duplicated within national collections. In this way each country can have a replica of the germplasm movement that made its rich cacao history. This is particularly important for countries out of the Amazon Basin that have unique combinations of genetic profiles from the old stock. Relic material or landraces, especially those that have existed for at least 100 years, are good choices for genetic stock adapted to that country's climate. Given the threat of climate change, it is a wise decision to collect and genotype relic material to safeguard this cacao genetic history.

Collections within South and Central America were highly favored in feedback from the focus group of cacao experts. However, specificity of areas was generally lacking and instead main areas were indicated or entire countries. A systematic exploration of all the rivers within all the river basins or watershed areas in South and Central America is needed. This will help in circumscribing genetic diversity into the best possible sets of subsets of genotype pools. Collecting germplasm is but one part; the germplasm needs to be characterized at the DNA level and trait level. Indigenous communities can leverage newly found cacao by having the accessions genotyped to show their individual uniqueness as fingerprinted accessions and their ancestral composition. Having this information will help to craft a unique story in attracting the high end of the cacao industry be it organic cacao, single origin, single farm or single variety chocolates.

The sensory profiles of new cultivars even within populations that are not considered fine or flavor cacao (Criollo, Nacional and their hybrids especially with Amelonado, Contamana and Iquitos groups) offer great marketing opportunities and a unique perspective in finding cultivar profiles rather than a generic profile from a bulked set of unknown cultivars.

The need to collect cacao germplasm from hitherto unsurveyed areas remains as relevant now as in the early years of cacao explorations.

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LIST OF ABBREVIATIONS AND ACRONYMS

Short form	Expanded form
ACIAR	Australian Centre for International Agricultural Research
AD	Anno Domini
BC	before Christ
BCE	before the common (or current) era
CATAS	Chinese Academy of Tropical Agricultural Sciences
CATIE	Centro Agronomico Tropical de Investigación y Enseñanza, Costa Rica
CCAT	Centro de Cacao de Aroma Tenguel, Ecuador
CCI	Cocoa and Coconut Institute
CCN 51	Castro Colecion Naranjal 51
CCRI	Cocoa and Coconut Research Institute
CEPLAC	Executive Commission for Planning Cacao Culture, Brazil
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France
CNB	Cacao Nacional Boliviano
CORPOICA	Cocoa Germplasm Bank of Colombian Corporation of Agricultural Research
cpDNA	Chloroplast DNA
CRIG	Cocoa Research Institute of Ghana
CRIN	Cocoa Research Institute of Nigeria
DNA	Deoxyribonucleic acid
DR	Djati Roenggo
DRC	Democratic Republic of Congo
EBC	Caquetá Botanical Expedition
EET	Estacion Experimental Tropical (Ecuador)
ELP	Euleupousing River Basin (clones)
ERJOH	The Cacao Genetic Resources Station "José Haroldo", Brazil
ESCO Kivu	Edmond Schluter et Compagnie in North Kivu, Democratic Republic of Congo
ESTEX-OP	Experimental Station in Ouro Preto, Brazil

Short form	Expanded form
GU	Guiana
HCP	Heirloom Cacao Preservation Fund
ICA	Colombian Agriculture Institute
ICCO	International Cocoa Organization
ICGD	International Cocoa Germplasm Database
ICGT	International Cocoa Genebank, Trinidad
ICQC	International Cocoa Quarantine Centre
ICS	Imperial College Selection
INEGI	National Institute of Statistics and Geography
INERA	Institut National pour l'Etude e la Recherche Agronomiques, Democratic Republic of Congo
INIAP	Ecuadorian Agricultural Research Center
INIFAP	Instituto Nacional de Investigaciones Forestales, Agricolas, y Pecuarias, Mexico
INTA	National Institute of Agriculture and Technology, Nicaragua
IRAD	Institute for Agricultural Research for Development
KER	Kérindioutou River Basin
KWC	Kaliwining Experimental Garden
LCT	Local Clone Trial
OYA	Oyapok River Basin
RAPD	randomly amplified polymorphic DNA
RFLP	restriction fragment length polymorphism
SALF	Santa Ana-La Florida
SHRS	Subtropical Horticultural Research Station
SNA	Sabor Nacional Arriba
SNP	Single nucleotide polymorphism
TARS	Tropical Agriculture Research Station
TSH	Trinidad Select Hybrids
UF	United Fruit
VARTC	Vanuatu Agricultural Research and Technical Centre
VSD	Vascular Streak Dieback

Short form	Expanded form
WACRI	West African Cocoa Research Institute
XTBG	Xishuangbanna Tropical Botanical Garden
YAL	Yaloupi River Basin

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INTRODUCTION

Cacao, the chocolate tree, is a neotropical understory tree from which cocoa products are obtained. The market report ("Latest Study on Cocoa and Chocolate Market 2019–2029") from Trusted Business Insights according to Lindell (2020) estimated the global cocoa and chocolate market was worth US$43.13 billion in 2017 and would reach US$67.22 billion by the end of 2025. Cacao is among the top 10 agricultural commodities in the world (Utro et al. 2012) and is the only member of its genus to be cultivated on a large scale outside of its center of origin (Hebbar et al. 2011). It is estimated that the production of sustainable cocoa provides for the livelihood of 40 to 50 million people globally with about 5 million farming households depending on cacao as a cash crop (Houston and Wyer 2012). The crop is grown in tropical and subtropical regions. Temperature and rainfall are the main climatic concerns that limit the cacao growing regions, with best growth within 8º north and south of the equator (Nair 2010). Excluding England, with its cacao germplasm at Kew Gardens and in the International Cocoa Quarantine Centre (ICQC) at the University of Reading, a current total of 60 countries have cacao for production or as germplasm (Table 1, Fig. 1). Yet all of these genetic resources are a direct and indirect result of germplasm movement from, and within, Latin America and the Caribbean. Cacao is indigenous to the Amazon basin (Pound 1938; Cheesman 1944; Motamayor et al. 2002; Motamayor and Lanaud 2002; Bartley 2005). The wide geographical area of the natural populations of cacao underscores the simple observation that not all the areas with relic or undiscovered cacao have been explored. The current study seeks to position the current cacao genetic resources of countries and identify geographical areas that are worth visiting to obtain and conserve valuable cacao germplasm.

Table 1 Countries that contain cacao germplasm

Geographical area	Countries	Number
North America	USA (as state of Hawaii), Mexico	2
Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama	7
South America	Bolivia, Brazil, Colombia, Ecuador, French Guiana, Guyana, Peru, Suriname, Venezuela	9
Caribbean	Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Haiti, Jamaica, Martinique, Puerto Rico, St. Lucia, St. Vincent and the Grenadines, Trinidad and Tobago	12
Africa	Cameroon, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon, Ghana, Guinea, Ivory Coast, Liberia, Madagascar, Nigeria, Sao Tomé et Principe, Sierra Leone, Tanzania, Togo, Uganda	16
Asia	Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Philippines, Sri Lanka, Thailand, Vietnam	11
Oceania	Australia, Fiji, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Vanuatu	7

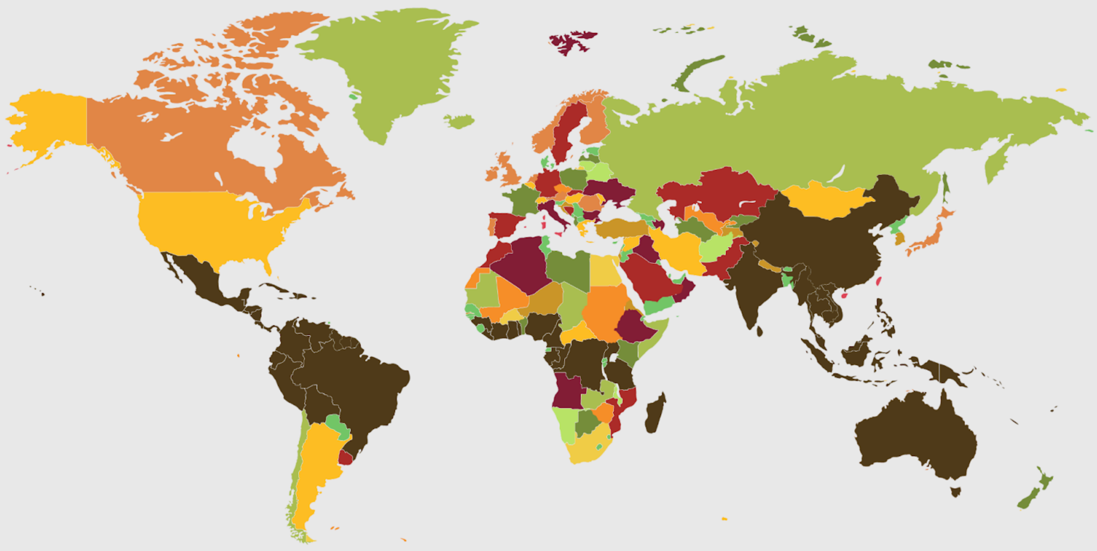


Figure 1
Countries with cocoa germplasm dispayed in brown.
Adapted from ICCO (2016-2020a).

INDUSTRY CLASSIFICATION

The cacao industry traditionally recognizes three varieties — Criollo, Forastero and Trinitario — based on fruit and seed morphology (Toxopeus 1985a). Cacao is also classed as bulk (ordinary) or as "fine or flavor" based on the flavor profile from the processed beans (ICCO 2016–2020b). In general, fine or flavor cacao is obtained from Criollo and Trinitario varieties, although exceptions are known to exist (ICCO 2016–2020b). An overview map of the distribution of these three broad cacao types is provided in Fig. 2.

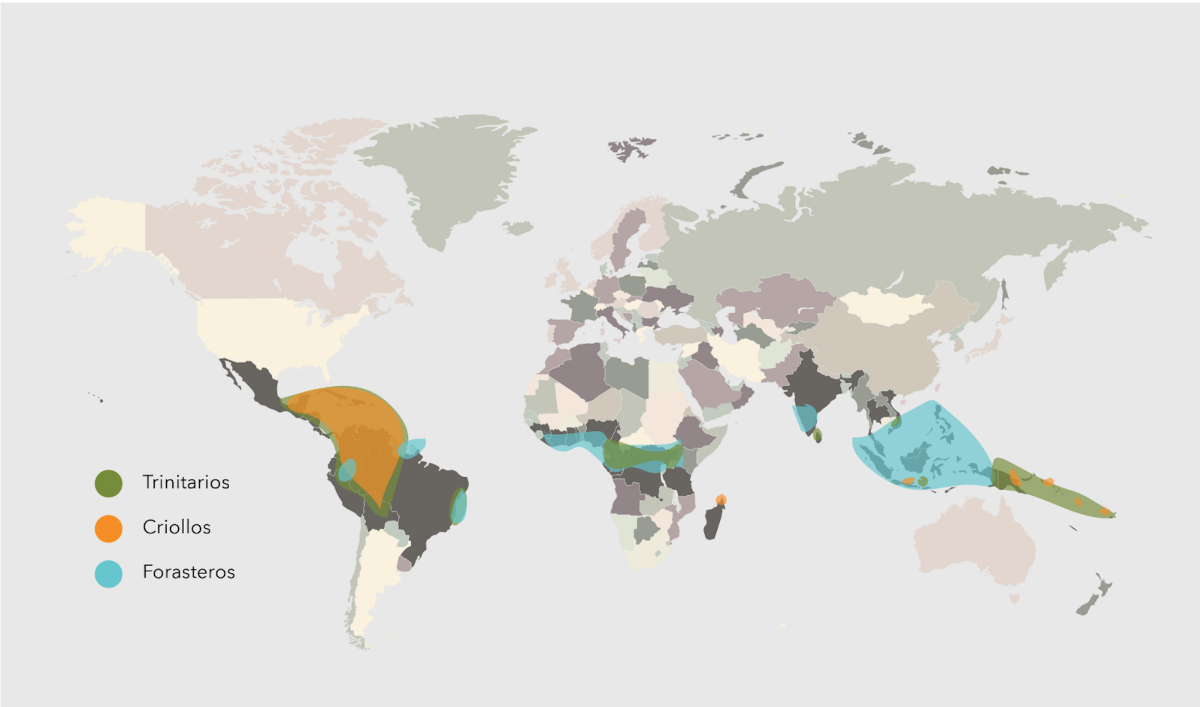


Figure 2
Schematic global distribution of Criollo, Forastero and Trinitario cacao.
Adapted from ICCO (2016-2020b).

BOTANY

Cacao is a cauliflorous evergreen dicot tree whose flowers are perfect (both fertile male and female parts in the same flower) and insect-pollinated. Several thousand flowers can be produced (Toxopeus 1985a) but only a small percentage of these will set fruit and be carried to maturity. Aside from the cropping system used, light intensity, and nutritional status of the plant for its carrying capacity, fruit setting is determined by a set of compatibility genes. Cacao has a special incompatibility system (Knights and Rogers 1953, 1955; Cope 1958, 1962; Lanaud et al. 2017). The outcome of this incompatibility system is the general tendency for cross-compatibility rather than self-compatibility. A cacao variety may therefore be able to pollinate itself, a few other varieties or many other varieties depending on the maternal and paternal complex of compatibility genes.

Cacao fruits have a range of colors and varying morphologies based on shape, size, basal constriction, apex form, ridging and rugosity (Engels et al. 1980; Bekele 1991; Bekele and Butler 2000). Fruit forms like Amelonado (oval, melon-shaped), Calabacillo (rounded, calabash-shaped), Angoleta (cylindrical with tapered ends) and Cundeamor (cylindrical with apex at tapered end) have also been used to describe varieties.

A cacao fruit can have between 30 and 60 seeds, although fruits with as few as 11 filled seeds have been encountered in the cacao germplasm managed by the Cocoa Research Centre of The University of the West Indies on its St. Augustine campus, Trinidad. In addition to its outcrossing nature, cacao has large fleshy seeds that readily germinate and are prone to desiccation (recalcitrant). The combination of its outcrossing nature and its recalcitrant seeds means that cacao germplasm must be conserved either in the places where cacao is found (farmers' fields, forested areas), in managed field collections of living trees, or in tissue culture banks. The former is *in situ* and the latter two *ex situ* conservation. The technological and electrical requirements for a tissue culture system limit its widespread application and instead cacao germplasm is more commonly managed in national and universal field collections (Motilal 2018). Newly found cacao can therefore be conserved either *in situ* in protected areas or on-farm or *ex situ* in national or universal gene banks.

Cacao seeds can be ovate to cylindrical with varying lengths, widths and thicknesses. As cacao is a dicotyledonous plant, cacao seeds have two cotyledons (fleshy seed leaves used up during early seedling growth), which is a result of the combination of maternal and paternal genes. Purple or brown cotyledons are present in many varieties, especially in bulk cacao. However, mottled seeds of varying colors tending toward those with all white cotyledons can also be found. White cotyledons are found in some anthocyanin-mutant varieties like CATONGO and ALMEDIA. However, the fine or flavor Criollo variety also has white cotyledons and depending on the paternal contributions all the seeds in a fruit can have white cotyledons.

ORIGIN AND DISTRIBUTION

The scientific name for cacao is Theobroma cacao L., indicating that it belongs to the genus Theobroma. This group belongs to the tribe Theobromeae of the Malvaceae family (Whitlock and Baum 1999; Whitlock et al. 2001; Silva and Figueira 2005). The Malvaceae is a well-known family with about 4,225 species including cotton, hibiscus, ochro, kola nut and durian as its members (Berry 2015). Theobroma encompasses 22 species (Cuatrecasas 1964) with a fairly tight gene pool (Fig. 3). Evidence gathered from herbarium collections indicates that northwestern South America (Fig. 4) is the most Theobromeae-rich region, with 26 species of Theobromeae being found in Colombia (Richardson et al. 2015).

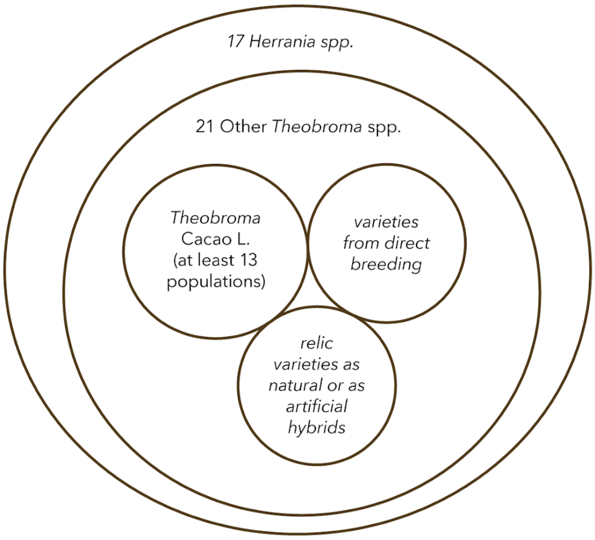


Figure 3 Genetic resources of the cacao genus *Theobroma*
Obtained from Motilal (2018)

Diversification of the Theobroma genus occurred from between 11.6 and 14.9 million years ago coincident with the Andean uplift, with T. cacao diverging from its most recent common ancestor between 7.7 and 12.9 million years ago in the mid- to late-Miocene period (Richardson et al. 2015). These authors suggested that this was ample time to generate significant within-species genetic diversity. Thomas et al. (2015) found that cacao was widely distributed across the western Amazon prior to the last glacial maximum (c. 21,000 years ago).

The center of origin and diversity of cacao is in the Amazon. Khoury et al. (n.d.) illustrated that the center of diversity for cacao was in Brazil in tropical South America. Cheesman (1944) suggested the primary center of origin and diversity was in the Upper Amazon of South America. He proposed a 400-km radius in the vicinity of the rivers Napo, Caquetá and Putumayo that would incorporate areas from the adjacent countries of Brazil, Colombia, Ecuador and Peru (Fig. 4). Bartley (2005) preferred the Peruvian Amazon as the center of diversity for cacao. Nieves-Orduña et al. (2021) supported northwestern Amazonia (Peru and Ecuador) as the center of diversity based on chloroplast microsatellite markers.

Since cacao seeds are recalcitrant, relatively heavy and without a tough outer seed coat, the seeds are not dispersed by wind or water and are prone to decomposition. The cacao fruits themselves do not naturally abscise from the plant. Instead, after fruit ripening, further senescence and necrosis occur, killing off the living tissue. The fruit remains attached for an indeterminate length of time until mechanical factors result in breakage of the dead stalk from the tree. Natural fruit abscission and subsequent spread by water is therefore excluded. Predation of fruits can cause seeds to fall or be thrown to the ground, where, if they are not eaten by foraging ground animals, they can germinate and establish as new seedling trees. Such accidental animal dispersal may not account for long-range dispersal, although Knapp (1920) stated without referencing that monkeys "often carry the beans many miles." Zarate et al. (2014) found that mean seed dispersal (13 plant species) in the rainforest of Mexico was 86 m by black howler monkeys. Canale et al. (2016) estimated a median dispersal distance of 300 to 360 m by capuchin monkeys in the northern Atlantic Forest of Brazil. In Guinea, chimpanzees dispersed cacao seeds 407 m on average from cacao plantations (Hockings et al. 2017). Thus the presence of cacao in Central America and in some areas of the Amazon may be a result of human-mediated dispersal. Nieves-Orduña et al. (2021) found two widespread chloroplast microsatellite profiles across the Amazon Basin, supporting the long-distance human-mediated seed dispersal from west to east in Amazonia.

Figure 4
Latin America and the Caribbean

EARLIEST USE

Cacao pulp, either raw or fermented, may have been the first form in which the cacao plant was used by humans (Bartley 2005; Henderson et al. 2007; Clement et al. 2010). A suggested timeline taken from Ozturk and Young (2017) is provided in Fig. 5. Alcoholic cacao beverages may have been the first cacao products to reach Mesoamerica from South America (Vail 2009; Clement et al. 2010). Trade and tribal contact would have spread the use of beans and pulp throughout the region (Henderson et al. 2007; Young 2007; Vail 2009; Clement et al. 2010; Chaves-López et al. 2014).

People of the Valdivia culture and their successors travelled by boat or raft along the coasts from their west Ecuadorian home to Peru and Middle America since 2200 BC and to southern Mexico since 1450 BC (Wolters 1999; Ogata 2002). Wolters (1999) suggested that living cacao plants were shipped from South to Middle America via this Pacific sea route since wild cacao trees and primitive varieties are absent between Ecuador and Guatemala.

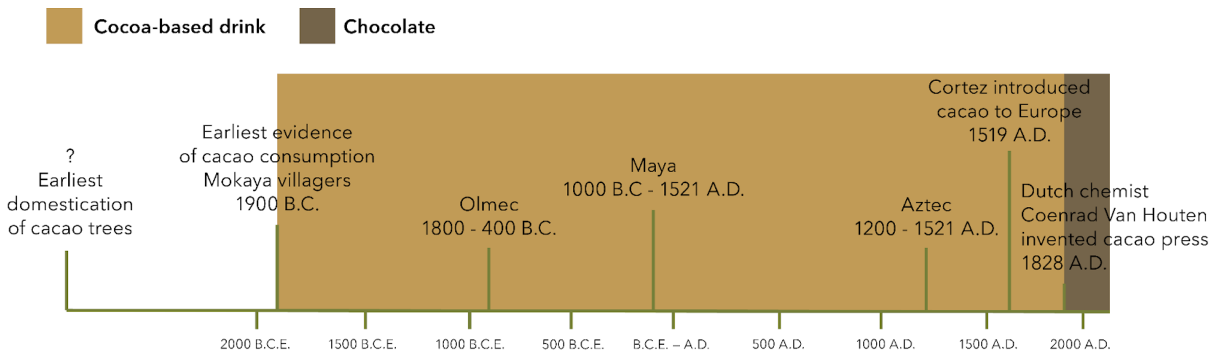


Figure 5
Cocoa used by indigenous tribes along the Mesoamerican timeline
Data obtained from Ozturk and Young (2017).

The earliest Mesoamerican cacao consumption is attributed to the Mokaya from 1900 to 1500 BCE (Powis et al. 2007; Fig. 5) with pre-Olmec people in the Gulf Coast area consuming cacao-based drinks by 1750 BCE (Powis et al. 2007). Later, between 1800 and 400 BCE, the Olmec civilization, centered around San Lorenzo (Figs. 6, 7), showed evidence of consuming cacao beverages (Powis et al. 2007, 2011). The spread of cacao among the indigenous and traditional Mesoamerican communities is attributed to the Olmecs, whose word for cacao, kakawa, became widespread (Coe and Coe 1996; Kaufman and Justeson 2007). By 1350 BCE cacao use and importance had spread to highland peoples of Mexico (Coe and Coe 2007). By 600 BCE the Mayans were using cacao beverages (Hurst et al. 2002; Powis et al. 2002) and by 700 AD they had cacao drinks made from the roasted and ground cacao beans, water and chile (Vail 2009; Powis et al. 2011; Ozturk and Young 2017). During the 14th through 16th centuries, the Aztecs (Fig. 6) adopted the use and importance of cacao from the Maya. Various uses include as currency (seeds); in medicine (bark and leaves), food, and pulp drinks either fresh or fermented; and in ceremonies and mortuary and residential contexts (Coe and Coe 1996, 2007; Powis et al. 2011; Christopher 2013; Casas et al. 2016; Zarrillo et al. 2018).

Apart from the signature alkaloid theobromine, archaeological artifacts and iconography have been used to substantiate the use of cacao in Mesoamerica and the southwestern U.S. in pre-Columbian times (Gómez-Pompa et al. 1990; Hurst et al. 2002; Powis et al. 2002; Henderson et al. 2007; Crown and Hurst 2009; Grivetti and Shapiro 2009; Stuart 2009; Powis et al. 2011; Coe and Coe 2013). These works led to the belief that the earliest domestication occurred in Central America. However, recent work by Zarrillo et al. (2018) incorporating evidence from distinctive *Theobroma* starch grains, theobromine and ancient deoxyribonucleic acid (DNA) at the Santa Ana-La Florida (SALF, Fig. 7) site in southeast Ecuador gave the earliest known use thus far at about 5,300 years ago.

Figure 6
Principal sites of Mesoamerican civilization
Data obtained from Encyclopedia Britannica

Bartley (2005) believes that indigenous tribes in South America would not have needed to domesticate cacao as it was present naturally throughout the jungle. Furthermore, the greatest genetic diversity of cacao is found in the Upper Amazon (Motamayor et al. 2002, 2008; Motamayor and Lanaud 2003; Loor Solorzano et al. 2012; Thomas et al. 2012), supporting Cheesman (1944) and Bartley (2005). Zarrillo et al. (2018) believe that earliest use and domestication is coincident with the region of greatest genetic diversity. Hence, these authors suggest that domestication of cacao started in the Upper Amazon.

DIVERSITY, CLIMATE CHANGE, AND DEFORESTATION

Climate change is expected to affect plants due to changes in carbon dioxide levels, warming and changes in the pattern and duration of rainfall and drought (IPCC 2018). Climatic changes may also change the risks and impacts of pests and diseases in cacao (Cilas and Bastide 2020). Lahive et al. (2019) in their review showed that cacao tree physiology is influenced by climatic variables. Restrepo et al. (2017) found a high significant correlation with flowering and precipitation, water balance and number of hours of photosynthetically active radiation. Schroth et al. (2016) suggested that climate change could cause a significant decrease in areas suitable for cacao cultivation in West Africa. The impact of climate change on human settlement, relocation and land use should not be underestimated and may lead to deforestation.

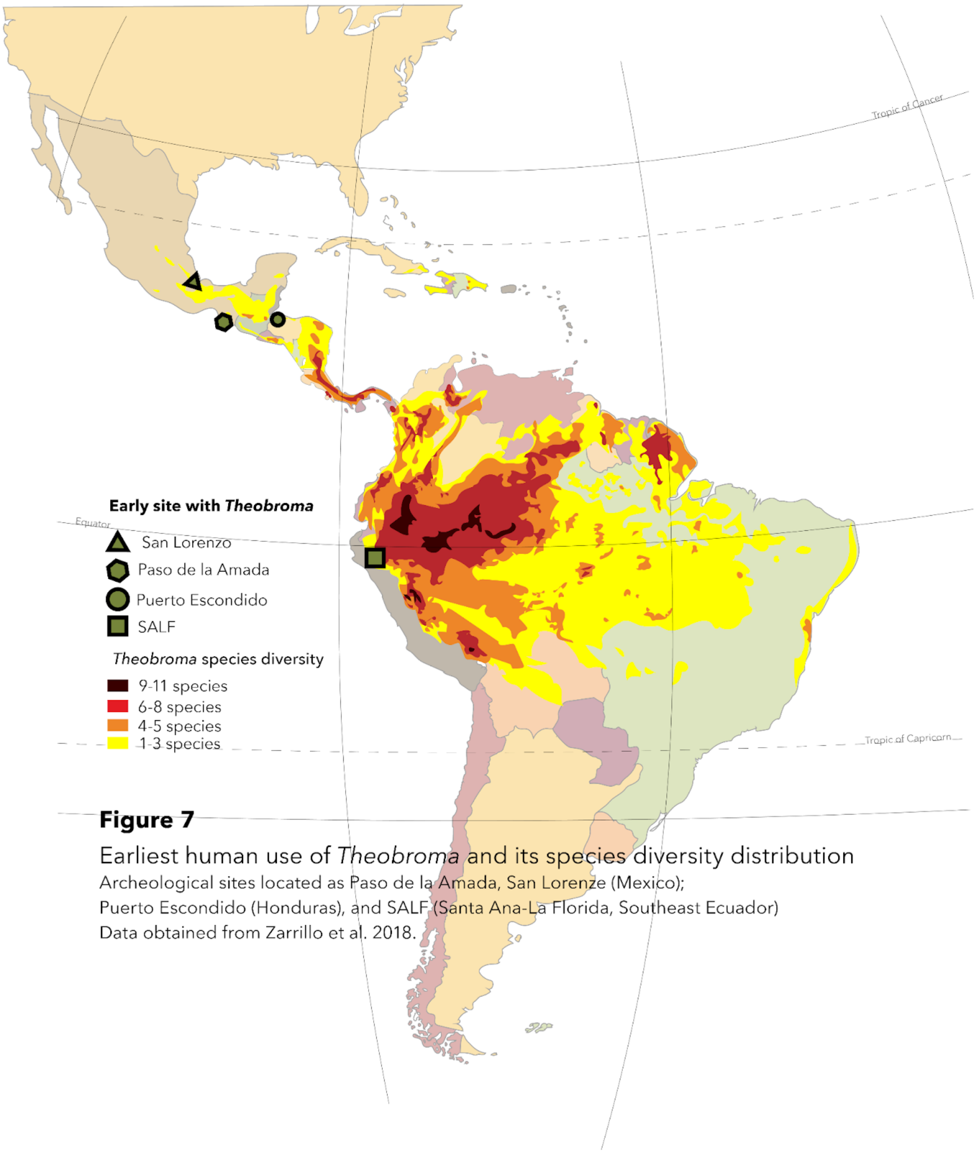


Figure 7

Earliest human use of *Theobroma* and its species diversity distribution

Archeological sites located as Paso de la Amada, San Lorenze (Mexico);
Puerto Escondido (Honduras), and SALF (Santa Ana-La Florida, Southeast Ecuador)
Data obtained from Zarrillo et al. 2018.

Deforestation in Latin America between 2002 and 2017 accounted for two-thirds of the total forest loss in the tropics and subtropics, with most of the loss coming from the Brazilian Amazon (Hancock and McCarthy 2021). Saatchi et al. (2001) referenced deforestation estimates of 88% to 99% of the Atlantic rainforest in southern Bahia. Recent losses in the Brazilian Amazon have been estimated at 11,088 square kilometers during the period from August 2019 through July 2020 (Phillips 2020a) and at 1,157 square kilometers from January 2021 through April 2021 (Spring 2021). Large-scale oil palm and cacao plantations in Peru have destroyed old-growth forests and impacted climate change by releasing substantial amounts of greenhouse gases (Hufstader 2021). Estimates of forest loss in Latin America from Global Forest Watch are provided in Table 2.

Table 2 Forest loss in selected Latin American countries

Country	Natural forest cover in 2010 (Mha)	Loss of natural forest cover in 2020 (kha)	Loss of natural forest cover over 2002– 2020 (Mha)
Belize	1.74	26.5	0.127
Bolivia	62.7	430	3.02
Brazil	492	3.20	26.2
Colombia	81.4	320	1.66
Costa Rica	3.78	7.34	0.0262
Ecuador	19.1	48.2	0.193
El Salvador	0.922	2.21	0.00138
French Guiana	8.16	4.29	0.0518
Guatemala	6.94	97.5	0.519
Guyana	19.1	15.8	0.135
Honduras	7.22	91.2	0.398
Mexico	49.8	295	0.662
Nicaragua	7.62	111	0.513
Panama	5.54	27.3	0.0784
Peru	78.7	278	2.16
Suriname	14.0	15.1	0.133
Venezuela	57.3	139	0.533

Data obtained from Global Forest Watch (https://www.globalforestwatch.org/dashboards/global/)

Thomas et al. (2012) suggested that glaciation cooling and drying restricted the distribution of cacao to isolated refugia centers of different vegetation types, several of which were located at the foot of the Andes. Future modeling of habitat suitability suggested that priority areas for germplasm collection were at the margins or expansion areas of these refugia. Two specifically mentioned areas were the Peruvian Madre de Dios department and the Amazonian region around Iquitos. These areas of high genetic diversity and best likelihood to sustain cacao populations are shown in Fig. 8. Deforestation is therefore antagonistic for *in situ* conservation and cacao explorations. Protecting relic types, finding new spots of old populations, finding new additions to the population pools, and finding new populations are all jeopardized by the continued scale of deforestation.

GENETIC ANCESTRY

The industry classification of cacao into Criollo, Forastero and Trinitario is convenient but downplays the genetic diversity that is present. Other traditional groups include Amelonado, Nacional and Refractario. Zarrillo et al. (2018) indicated that Criollo, Nacional and Amelonado were cultivated in Mexico (about 3,900 years), Ecuador (Province of Zamora Chinchipe; about 500 years) and Brazil (about 300 years) respectively. The Amelonado cacao has had several varietal names applied due to the fruit characteristics: Indio, Amelonado, Calabacillo, Matina, Común, Catongo and Pará (Bartley 2005; Van Hall 1932). The Matina variety was so named after it was introduced from Martinique into the Matina region of Costa Rica on its Atlantic Coast (Bartley 2005). The Matina variety is also known as "Ceylan" or "Sanchez" or "Costa Rica" (Soria 1970). The Común and Pará types are cultivated in the Bahia and Pará regions of Brazil respectively (Soria 1970; Bartley 2005). Other Amelonado types include Naranja. Criollo-related varieties include "Lagarto" or "Pentagona;" "Criollo type," and "Criollo de Nicaragua" or "Cacao Real" (Soria 1970). The former is distinctive with five prominent ridges on the red fruit wall along with the usually thin and warty fruit wall and curved tapered apex (Soria 1970; Toxopeus 1985a; Bartley 2005).

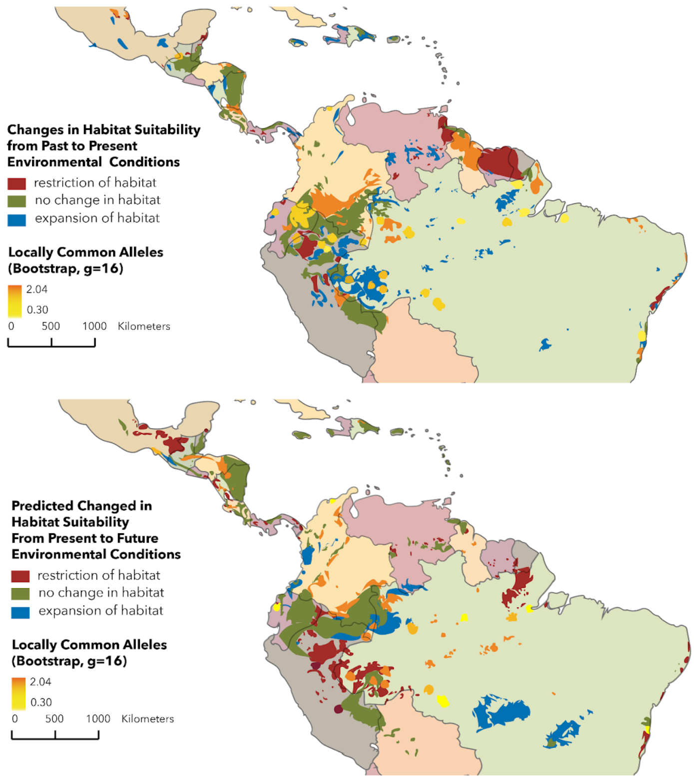


Figure 8
Current (top) and future (bottom) habitat suitability for cacao in Latin America and the Caribbean.
Obtained from Thomas et al. (2012). The highest genetic diversity and locally common alleles is in the Peruvian Amazon. Green areas in South America on the top of the diagram were recommended by Thomas et al. (2012) as interesting areas to collect.

Currently there are 10 accepted population groups or genetic clusters in cacao: Amelonado, Contamana, Criollo, Curaray, Guiana, Iquitos, Marañon, Nacional, Nanay and Purús (Motamayor et al. 2008; Fig. 9). This study was based primarily on samples collected from germplasm collections. A new genetic cluster was possible from germplasm collected in Beni, Bolivia (Zhang et al. 2012). Also, Osorío-Guarín et al. (2017) reportedly found two new Colombian groups, although the finding was limited by the inability of these workers to allocate the reference samples to the 10 known genetic groups. Chuncho cacao in Cusco, Peru, may be another new genetic cluster, although it was closely related to samples from Beni in Bolivia, Ucayali in Peru (Contamana population), and Madre de Dios in Peru (Céspedes Del Pozo et al. 2017). There is, therefore, scope for finding new genetic diversity of conserved cacao. The search must be focused in geographical areas that are within the center of genetic diversity, that have relic or landrace populations and/or that have not yet been explored.

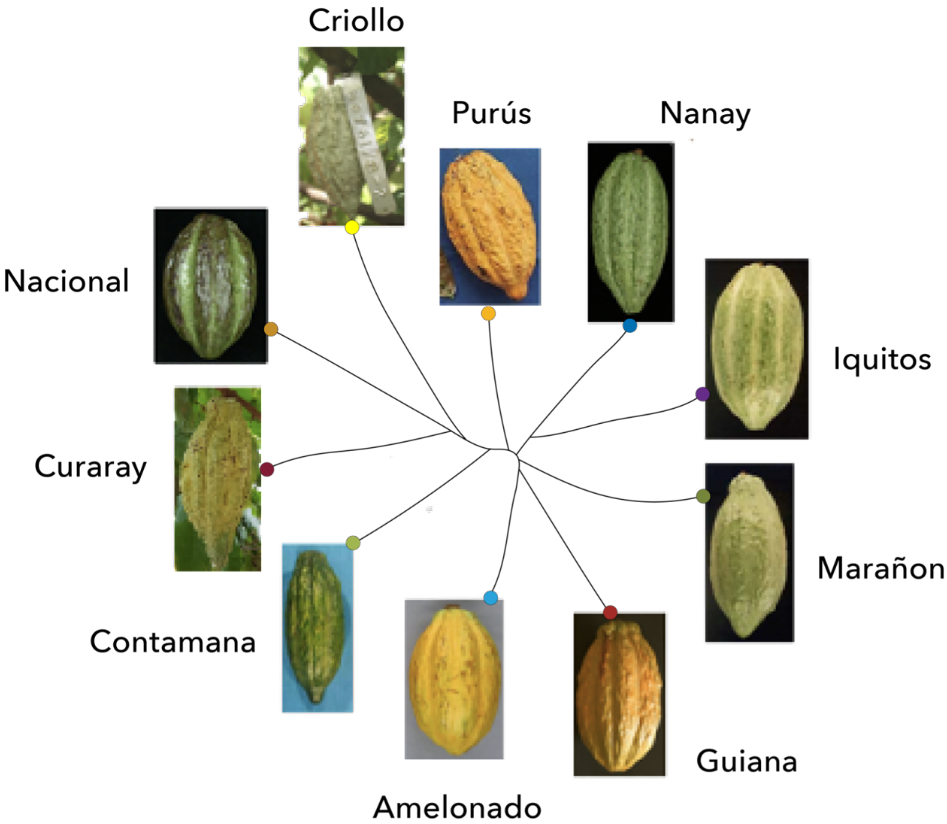


Figure 9
The 10 genetic clusters (populations of cacao described by Motamayor et al. [2008]).
An example of an accession in each cluster is provided. Fruit pictures are from the International Cocoa Germplasm Database except for Curaray Criollo (courtesy Lambert Motilal).

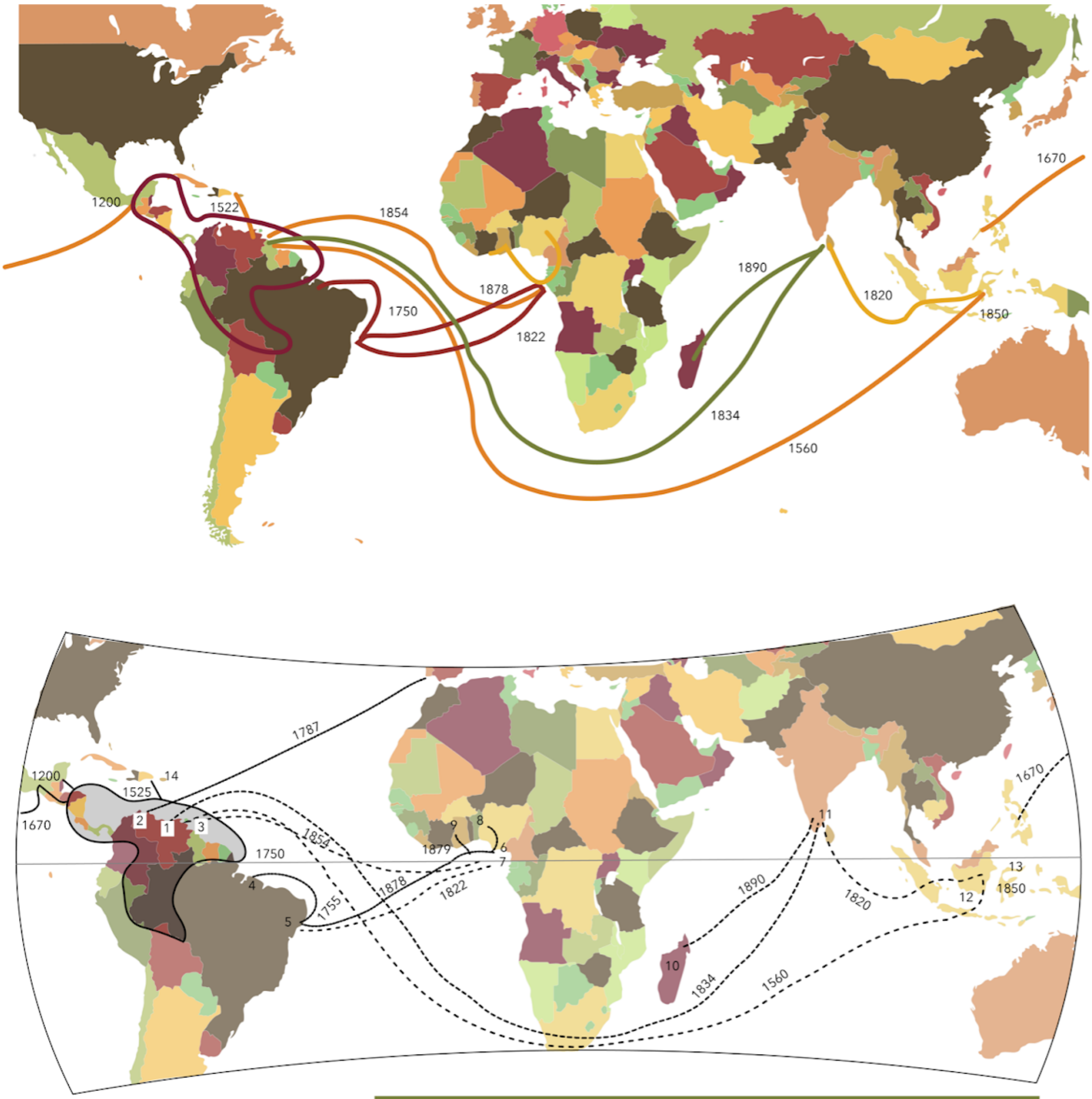
The names of three traditional cacao varieties (Amelonado, Criollo and Nacional) were used for their population names. Criollo, Guiana, Nanay, Amelonado and Marañon have the lowest (in ascending order) genetic diversity (Thomas et al. 2012). Criollo is thought to originate in Central America or Mexico, although many modern Criollos now exist in Colombia and Venezuela (Lachenaud and Motamayor 2017). This variety is considered to have fruits with a thin cortex (fruit wall, husk), plump/round seeds that are white or lightly pigmented, and unpigmented flowers except for pink staminodes (Soria 1970).

The Trinitario varieties are hybrids of Criollo, Amelonado and Upper Amazon varieties (Johnson et al. 2009; Motilal et al. 2010; Yang et al. 2013). The Refractario germplasm originated in Ecuador out of a mass field screening program for resistance to witches' broom disease (Pound 1938, 1943; Bartley 2001). This Ecuadorian group is genetically distinctive (Zhang et al. 2008) with two main groups, each with two subgroups (Motilal et al. 2012). Refractario germplasm was derived from Nacional (Zhang et al. 2008) and contains Nacional-Amelonado hybrids (Lambert Motilal, personal communication).

HISTORIC GERMPLASM TRANSFERS

Outside of South America, cacao is an introduced crop. It was introduced either thousands of years ago, as for Central America, or hundreds of years ago, as for all other cacao-growing countries. Amerindian sea navigation reportedly played a major role in the dissemination of cacao in the Americas along the Pacific coast (Ogata 2002). Due to the New World exploration by the Old World powers in the seafaring days, cacao was moved around by the British, Dutch, Portuguese and Spanish travelers according to the time of ownership and countries that were colonized. Repeated waves of germplasm transfer would have occurred due to a variety of factors, including the need to replace plants or to set up new plantations, preference for particular varieties, and convenience in moving among locations. This germplasm base represents the foundation for later cacao genetic diversity as the descendants of these relic plants may have been present in old estates intermingling with more recent acquired plants. Propagation by seed as would have likely occurred in earliest times may have therefore captured some of the relic genetic ancestry that would have survived neglect, natural disasters and age.

Criollo cacao is the ancient variety preferred by the Aztecs and Mayans and was later adopted by the colonial powers for establishing early plantations. The pure Nacional cacao was limited primarily to its Ecuadorian home. Hybrids of Criollo and Nacional with Amelonado instead of the pure cultivars were likely to be moved within and among regions. The Amelonado variety was transported out of South America, most often reported as from Brazil, to the Caribbean, Central America and Africa (Bartley 2005). Historic germplasm transfers from 1200 to 1890 were depicted by Cilas and Bastide (2020; Fig. 10). Early reviews of germplasm transfers inclusive of germplasm collections are available (Wood and Lass 1985; Wood 1991; Lockwood and End 1993; Bartley 2005) and were recently reviewed by Zhang et al. (2011a) and Zhang and Motilal (2016). The earliest out-of-America movements were said to be from Caracas, Venezuela, to Celebes (now Sulawesi, Indonesia) in 1560 and from Acapulco, Mexico, to the Philippines in 1614 or 1670 (Wood 1991 and references therein). However, Wood (1991) indicates that the sources used did not provide details as to how their dates were obtained. Given the seafaring conditions at the time, it is unlikely that cacao seeds in fruits or cacao seedlings could have survived the length of a voyage and been successfully established.



Symbol	Nationality
···········	Spanish
- - - - - -	British
———	Mayas
···········	Portuguese
· · · · · ·	Dutch

1 Caracas
2 Maracaibo
3 Trinidad
4 Para, Brazil
5 Bahia, Brazil
6 Fernando Po (now Bioko)
7 Sao Tome
8 Nigeria
9 Cote d'Ivoire
10 Madagascar
11 Ceylon (now Sri Lanka)
12 Java, Indonesia
13 Celebes (now Sulawesi), Indonesia
14 Dominican Republic

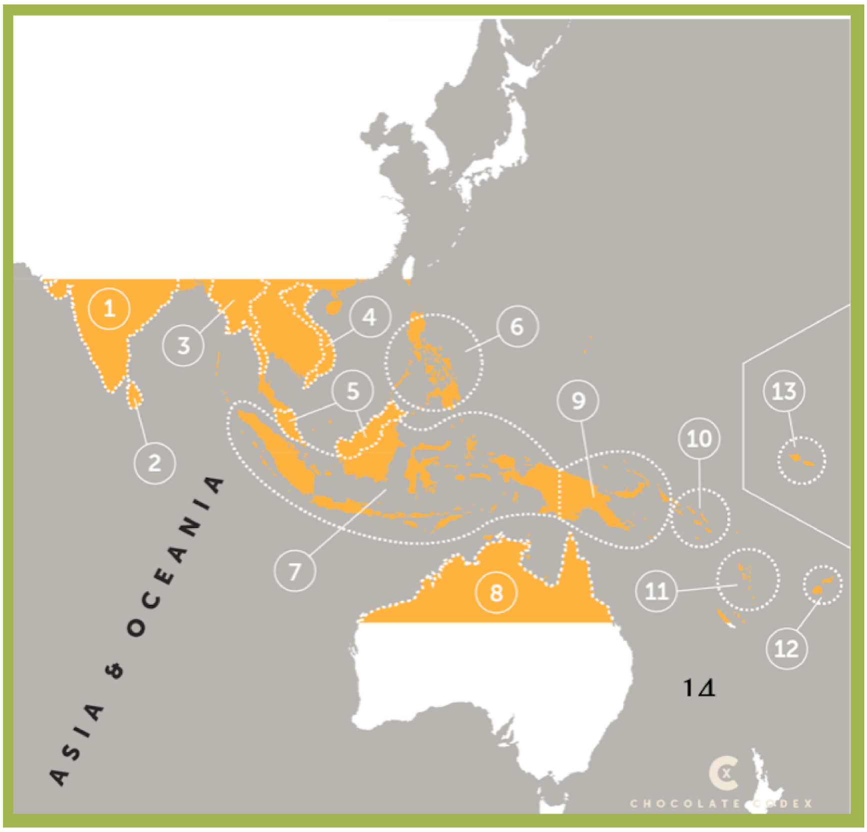
Figure 10
Historic movements of cacao within Latin America and the Caribbean (LAC) and from LAC to Africa, Asia and Oceania. Top: Obtained from Cilas and Bastide (2020). Bottom: Main movements during 1200-1879 from Nosti Nova (1953) cited in Wood (1991)

COUNTRY PROFILES

Germplasm transfers and collection expeditions are provided for each country that has grown cacao or continues to grow cacao for production. The University of Reading in England with its International Cocoa Quarantine Centre is excluded. Profiles are presented from Oceania, Asia, Africa, Caribbean, North America, Central America and finally South America, from where it all started.

OCEANIA

The Pacific islands and Australia (Fig. 11) represent some of the earliest long-range oceanic and most recent germplasm transfers. Cacao on the small Pacific islands has been sought for its fine flavors and unique qualities (PHAMA n.d.). Indeed, Dillon et al. (2020) suggest that the fine flavor, unusual genetic resources and novel "single origin" branding make the Pacific islands and north Australian cacao competitive in the high-value, low-volume markets.



1 India
2 Sri Lanka
3 Myanmar
4 Vietnam
5 Malaysia
6 Philippines
7 Indonesia
8 Australia
9 Papua New Guinea
10 Solomon Islands
11 Vanuatu
12 Fiji
13 Samoa
14 New Caledonia

Figure 11

Cacao growing regions in Asia and Oceania

Modified from Chocolate Codex (http://chocolatecodex.com/portfolio/countries-of-origin/).

Note: China is not listed

AUSTRALIA

Overview

Australia (#8 in Fig. 11) is the continent in the Pacific Ocean located north of Antarctica, northwest of New Zealand and south of Indonesia and Papua New Guinea. Although absent from World Population Review's 2022 list of 59 cocoa producing countries, Australia is listed in the Chocolate Codex. Australia exported US$82,600 in cocoa beans in 2020, making it the 74th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/aus).

Historical Introductions

Australia has the most recent germplasm transfer in the South Pacific. Cacao in this continent is grown near Darwin in the Northern Territory, in North Queensland, and in northwest Western Australia (Northern Territory Government of Australia 2021). Previous reviews of the potential for cocoa in Australia (Urquhart and Stephens 1960; Cull 1973; Watson 1987, and Watson 1992) suggest that production is feasible and that the crop has potential in North Queensland. A range of introductions of primarily Trinitario germplasm occurred from Papua New Guinea from the 1960s to the 1980s (Y Diczbalis and N Dillon, pers. comm.). With the closure of the Department of Primary Industries – Queensland Kamerunga Research Station near Cairns, the bulk of material found its way into private hands (Y Diczbalis and N Dillon, pers. comm.). In 1999 cocoa trees were growing on private properties in North Queensland from Tully to Daintree, although none were commercially cultivated (Y Diczbalis and N Dillon, pers. comm.)

Recent Cultivation

Reporting on a comprehensive set of trials funded by the Australian government, Cadbury, and State Departments of Agriculture, "Producing Cocoa in Northern Australia" (Diczbalis et al. 2010) reports that cocoa is currently only grown commercially on a small scale in the wet tropics of northern Queensland. The planting material is based on imported seeds from five hybrid lines from the Cocoa and Coconut Research Institute (CCRI) in Papua New Guinea and 11 clones imported from ICQC from 1999 to 2001 (Diczbalis et al. 2010). The 11 clones were composed of a natural hybrid Imperial College Selection (ICS) that developed in Trinidad (ICS 1) and 10 primary germplasm cultivars (AMAZ 15/15, EET 399, IMC 67, NA 33, PA 300, POUND 4/A, POUND 4/B, SCA 6, SCA 11 and SCA 19) that were collected in the Amazon (Diczbalis et al. 2010).These clones are expected to have Nacional/Amelonado or Nacional/Amelonado/Iquitos, Curaray/Nanay/Iquitos or Amelonado/Curaray/Nacional, Amelonado/Criollo, Iquitos, Nanay, Marañon, Iquitos (the two POUND 4 accessions) and Contamana (latter three SCA accessions) respectively pending identity analysis (Lambert Motilal, pers. comm.). From January to April 2007 some 20,200 seeds from four hybrids from Stewart Research Station (Madang), Cocoa and Coconut Institute (CCI) of Papua New Guinea, were introduced into North Queensland (Diczbalis 2013). In November 2009, 1,700 seedlings of an Indian cocoa hybrid were introduced to the Innisfail site (Diczbalis 2013). In 2012, the Australian Chocolate Co. imported and planted out over 1,000 hybrid seeds from Papua New Guinea in the Mission Beach region (Diczbalis 2013). In 2013, 4,000 SG2 hybrid seeds were imported from the CCI of Papua New Guinea by Mackay Estates for planting south of Tully (Diczbalis 2013).

Sixteen selections (including PNG 44 and PNG 56) are being evaluated in a first-stage selection trial and include two of the 11 international clones imported from ICQC which were recovered following Tropical Cyclone Larry in 2006, which are labeled as ICS 1 and the Contamana clone POUND 4/A (Y Diczbalis and N Dillon, pers. comm.).

Genetic Studies

The cultivar PNG 44 is a hybrid of 38% Amelonado, 19% Criollo, 25% Nanay, 14% Iquitos, and 4% Nacional, while the cultivar PNG 56 is a hybrid of 53% Parinari, 45% Nanay, and 1% Amelonado and Iquitos (Y Diczbalis and N Dillon, pers. comm.).

Highlighted Cultivars

Current work funded by the Australian Centre for International Agricultural Research (ACIAR) and the Department of Agriculture and Fisheries – Queensland is based on the use of PNG 44 and PNG 56 in a production trial (Y Diczbalis and N Dillon, pers. comm.).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Australia were selected in the best 50 of the International Cocoa Awards in 2017 (one batch), 2019 (one batch) and 2021 (one batch), with one winner each for 2017 and 2021. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch from Mission Beach, Queensland, had strong cocoa; moderate roast, bitterness; low acidity, astringency, and sweet, brown fruit, floral, spice, woody, nutty flavors (CoEx 2019). The winning entry in the best 50 of the International Cocoa Awards 2021, from 78 Mountainview Drive, Shannonvale, Mossman, Far North Queensland, was given the following flavor profile description: "Medium brown colour. Soft, creamy mouth melt. Moderate chocolate notes emerge along with mild fruit acidity and fresh fruit notes balanced with bitterness and astringency, spice (licorice, pepper), browned fruit (raisin), herbal, dark wood. Blended aftertaste." (CoEx 2021).

Recommended Collection

The 16 selections that are being evaluated should be conserved. The oldest remaining trees and the best performers in all cacao areas, including Innisfail and Mission Beach, should be collected.

FIJI

Overview

Fiji is an archipelago country (#12 in Fig. 11) of more than 300 islands in the South Pacific Ocean located northeast of New Zealand and Australia. The two major islands are Viti Levu and Vanua Levu. Fiji produced 12 metric tons of cocoa in 2021, ranking 57th out of 59 cocoa producing countries (World Population Review 2022). It is listed in the Chocolate Codex. Fiji exported US$50,700 in cocoa beans in 2020, making it the 77th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/fji). Amelonado cocoa is reportedly the most common type in Fiji (Clarke n.d.).

Historical Introductions

The early history of cocoa in Fiji began in Suva on the island of Viti Levu in the late 1790s with the introduction of approximately 50 trees from the best varieties from South America and West Indies, reported to be Amelonado and "Sangre Toro," a Criollo type (Vinning 2017). In 1880 the British introduced Trinitario cocoa from Ceylon (now Sri Lanka) and Trinidad into Fiji (Cook 1982; Martin 1987; Golikova 2016; Cacao Fiji 2021). Cook (1982) also indicated that Criollo and Venezuelan Amelonado (Forastero) from Trinidad; cocoa from India, Singapore, Java and Samoa; and clonal material from Papua New Guinea, Western Samoa and Grenada were variously introduced. In 1882, seven or eight Trinidad cacao varieties, which included Cundamar, Verdilico, Mixed Forastero, Longpointed Forastero, Sangre Toro, Forastero and Fine-grooved Prolific Yellow, were imported (ltr from Des Voeux 1882; Tomohito Zukoshi, pers. comm.). Fiji Times in 1888 said that about 800 seedlings were distributed all across Fiji but were overtaken by the jungle (Tomohito Zukoshi, pers. comm.). From the 1950s to the 1960s, the cocoa area was expanded using seeds from the remaining plants of the 1880–1930 Trinitario plants, but these were susceptible to stem canker and black pod disease (Martin 1987).

Recent Cultivation

The government of Fiji tried many revitalization efforts for introducing the best adaptable seedlings from its pre-independence of 1950 to post-independence 1986 from Papua New Guinea via W. Samoa and USDA Miami Quarantine Station to Naduruloulou Research Station in Suva (Tomohito Zukoshi, pers. comm.). The modern industry started in the 1960s when the government made efforts to establish Amelonado cacao as a smallholder crop to be interplanted with coconut (Martin 1987; Cacao Fiji 2021). Martin (1988) stated that the government policy since 1965 was to plant only Amelonado material introduced in 1958 from Sabah, Malaysia. In 1958 seeds of West African Amelonado imported from Malaya (currently Peninsular Malaysia) were planted at Waimaro on Viti Levu Island (Vernon and Sundaram 1972). In 1963, seed from Waimaro was sent to Wainigata on Vanua Levu Island and the majority was interplanted with open-pollinated seed from NA 32 (Vernon and Sundaram 1972). Variety trials since 1971 have included hybrids from SCA 6, SCA 12, ICS 39, ICS 40, ICS 60, ICS 89 and GS 29 (Vernon and Sundaram 1972). A revitalization of the industry started in 2014 (Cacao Fiji 2021) with apparently the existing cacao crop on the islands. Fijian Amelonado and ICS stocks have been crossed to obtain hybrid seedlings (Tomohito Zukoshi, pers. comm.).

Genetic Studies

Sampling of cocoa genetics in farmers' fields (≈180 samples) by the Pacific Community and Ministry of Agriculture (MOA) funded by ACIAR suggests that Amelonado genetics predominates; however, there are many instances of Trinitario seedlings and seedlings high in Nanay, Nacional, Parinari and Guiana, which are likely to be remnants of early introductions (Y Diczbalis and N Dillon, pers. comm.).

Highlighted Cultivars

The research stations at Naduruloulou and Wainigata have an extensive collection of imported clones, particularly from PNG. Interest is growing in the collection and testing of seedling selections from farmer orchards, which have fine flavor genetic credentials (Y Diczbalis and N Dillon, pers. comm.).

Flavor Quality

Over the period from 2010 to 2021, a batch of chocolate sample from Fiji was selected for the best 50 International Cocoa Awards in 2019 and secured a win. The chocolate was made from a Trinitario cacao batch (Wainigata cultivar) from Cakaudrove, Vanua Levu, and had strong cocoa; moderate roast, bitterness, astringency; and low acidity, sweet, fresh fruit, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees at the research stations of Naduruloulou and Wainigata, in farmers' fields, and in forest regrowth should be collected and conserved.

NEW CALEDONIA

New Caledonia (#14 in Fig. 11) is an archipelago of about 10 islands and various islets in the southwest Pacific Ocean south of Vanuatu and east of Australia. New Caledonia was not included on World Population Review's 2022 list of 59 cocoa producing countries. However, it is listed in the Chocolate Codex, and cacao trees were alive in 2014 in New Caledonia (Harris 2014). The country reportedly exports around US$968 in cocoa beans, making it the 103rd largest exporter in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/ncl). A chocolate factory owned by the French company Bisochoc was present in 2016 (Radio New Zealand 2016). The oldest trees and the best-performing trees should be collected and conserved.

PAPUA NEW GUINEA

Overview

Papua New Guinea (#9 in Fig. 11) is composed of the eastern part of the island of New Guinea and associated offshore islands in Melanesia in the southwestern Pacific Ocean. Papua New Guinea produced 44,504 metric tons of cocoa in 2021, ranking 11th out of 59 cocoa producing countries (World Population Review 2022). The country exported US$87.4 million in cocoa beans in 2020 making it the 13th largest exporter of cocoa beans worldwide (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/png).

Historical Introductions

Trinitario cacao from Samoa (Clarke n.d.; Efron 1996) was reportedly introduced in the 1890s to Papua New Guinea by German missionaries and traders (Clarke n.d.; Cook 1982). In 1889, cocoa from Samoa was introduced to Gorima in the Madang District by Richard Parkinson (Vinning et al. 2017). Antony et al. (1988) suggest that it was around 1905 that cacao was introduced from Samoa, Sri Lanka and Java by the German settlers. Early spread was by the activities of the New Guinea Kompagnie and migrant workers among Bougainville Island, New Guinea, Samoa, Solomon Islands and Vanuatu (Vinning et al. 2017). The introduced germplasm material originated in Trinidad and Venezuela (Efron 1996). Germplasm from Venezuela, likely Trinitario, was introduced until 1907 (Vinning et al. 2017). Criollo cacao was reportedly present in the Botanic Gardens in Rabaul until the Second World War (Keane et al. 2017; Vinning et al. 2017) and was probably derived from Java Criollo (Keane et al. 2017). Later, Trinitario cacao (Djati Roengo clones) from Java, Indonesia, was introduced in 1932 (Efron 1996; Keane et al. 2017; Vinning et al. 2017). Most cacao plantations, especially experimental plantings, were destroyed as a result of World War II but 10 trees were protected and developed by F. C. Henderson and later became the Keravat (K) clones (Keane et al. 2017; Vinning et al. 2017). In 1948 and 1949, fruits from promising trees were used for seeds for progeny trials at Keravat (Antony et al. 1988). The KA (Keravat Asalingi) clones were selected from the Asalingi Plantation, Bainings region in East New Britain (Keane et al. 2017; Vinning et al. 2017). The "Java Red" Criollo type from Indonesia may have contributed to the Trinitario cocoa types (the K and KA clones) that were selected and tested at Keravat and widely planted in Papua New Guinea after the Second World War (Bridgland 1960, cited in Keane 2017). Upper Amazonian cacao was brought in the early 1960s from Trinidad (Efron 1996; Vinning et al. 2017) and again in 1972 to restart the breeding program after the effects of vascular streak dieback (VSD) caused by Oncobasidium theobromae (Efron 1996). The Upper Amazonian material of 1962–1964 was composed of the progeny of several crosses of clones amongst the Nanay, Parinari, Scavina and Iquitos groups, and the matured selected trees became the Amazonian parents (KEE clones) of the "hybrid" cocoa seedlings released in the 1980s (Keane et al. 2017). Germplasm from Puerto Rico and Ghana was introduced in the early 1970s, and germplasm from Kew Gardens, the University of Reading, and USDA Miami started in 1975 (Keane et al. 2017). To incorporate resistance to black pod, ICS clones and Amelonado material from Malaysia via the Solomon Islands were made in the mid-1980s (Keane et al. 2017).

Collections

Collection of budwood from the old Trinitario material began in 1995 and some of these clones ("Old Trinitarios" or "OT" clones) gave very high yields (Keane et al. 2017).

Recent Cultivation

All 14 provinces have suitable land for cacao cultivation, with proven areas being the coastal areas of East New Britain, Bougainville, New Ireland, Oro, Madang, and West and East Sepik (Yinil et al. 2017). Successful cultivation at elevations of 1,400 masl is recorded in Karamui Valley, Simbu Province (Yinil et al. 2017). Until 1980, most of the surviving cacao was Trinitario seedlings derived from open pollination from the early plantings in East New Britain (Vinning et al. 2017). In 1986, the CCRI initiated a breeding program and collected seeds from naturally set fruit from the surviving trees for progeny trials. The Papua New Guinea breeding program sought to emphasize yield potential, butter fat content, reduced shell percentage, and resistance to vascular streak dieback and black pod rot, while flavor appeared to be of lesser consideration (Efron 1996). The polycross SG hybrids came out of the breeding program and were based on Amazonian and Trinitario parents (Efron 1996). Three Amazonian parent clones (KEE2, KEE5 and KEE52) were crossed in all combinations with three Trinitario parent clones (KA2-101, KA5-201, K20 or K24-102) and the progenies selected mainly for VSD resistance and yield became the parents of the SG1 hybrids (Keane et al. 2017). Improved hybrid seed gardens were established during 1982–1987, and the new hybrid seed (SG2 seed produced in Seed Garden 2) was released in 1988 (Keane et al. 2017; Antony et al. 1988). Most of the cocoa grown on farms consisted of SG1 or SG2 hybrid seedlings that replaced the old Trinitario cocoa (Vinning et al. 2017). Planting is currently from hybrid seeds of known parents or from clones of four or five known mother trees grafted onto seedling rootstock of SG1 or SG2 hybrids (Marfu et al. 2017a).

Highlighted Cultivars

The KA2-101 cultivar is highly resistant to the dieback disease (now known as VSD) that started in 1961, and the parents of the SG1 hybrids (e.g. KA2-101, KA5-201) were very susceptible to black pod (Keane et al. 2017). In contrast, the K82 cultivar has a high level of resistance to black pod but is susceptible to VSD (Keane et al. 2017).

In 1982, "SG1 Hybrid" seed derived from parents selected for high yield, good cocoa quality and especially for resistance to VSD was released (Keane et al. 2017; Vinning et al. 2017). Later, in 1988, the "SG2 Hybrid" seed derived from parents with some resistance to black pod was released (Vinning et al. 2017). Both hybrids were, however, very fast-growing, requiring heavy pruning, and had variable yields (Keane et al. 2017; Vinning et al. 2017). New hybrid clones selected from the progeny of crosses between KEE and recently introduced clones include AK56-1-4 (KEE 43 × SIAL 93), AK57-1-9 (KEE 43 × Pound 5/C), 16-2/3 (C) (KEE 42 × K 82) and 73-14/1 (C) (KEE 12 × K 24-102) as high-yielding cultivars (Keane et al. 2017).

In 2003 and 2013, the first series of hybrid clones (HC1-B and HC1-S) and the second series (HC2-B and HC2-S) were released respectively, where the big (B) and small (S) vigor selections were generated for different farm sizes (Marfu et al. 2017b). These hybrid clones have a low pod value (15–25); acceptable bean mass (> 1 g); high butterfat content (≥ 55%); resistance to black pod and VSD; and tolerance to cocoa pod borer (Marfu et al. 2017b). Cultivars TA 102, TA 103 and TA 104 of the HC1-B series have large beans with 1.5–1.6 g dry mass while cultivars CCI-B1, CCI-B2, CCI-B3, CCI-B4 and CCI-B5 of the HC2-B series are all self-compatible (Marfu et al. 2017b). Cultivars CCI-S1, CCI-S2, CCI-S3, CCI-S4 and CCI-S5 of the HC2-S series are all self-compatible (Marfu et al. 2017b).

Flavor Quality

The cocoa in the late 1930s was reportedly very similar to that of fine flavor Trinitario cocoa from Java, Sri Lanka and the West Indies (see Keane et al. 2017; Vinning et al. 2017). Papua New Guinea is a 70% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b).

Over the period from 2010 to 2021, chocolate samples from Papua New Guinea were selected for the best 50 International Cocoa Awards in 2010 (three batches), 2011 (four batches), 2015 (one batch), 2017 (two batches), 2019 (two batches) and 2021 (two batches) with 2, 1, 1, 0, 0 and 2 wins respectively.

In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario/Forastero cacao batch from Solita Cocoa Farm, Kundiawa Town, Karamui District, Simbu Province, had strong cocoa; moderate roast, bitterness, astringency and brown fruit; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019). Another chocolate made from a Trinitario/Forastero cacao batch from Poro village, Vanimo, Aitape Lumi District, Sandaun Province, Momase Region, had strong cocoa; moderate roast, bitterness and astringency; and low acidity, sweet, fresh fruit, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from Kopure Village, Oro Bay, Popondeta, Ijivitari District, Momase Region, was given the following flavor profile description: "Rich dark color. Flavor emerges gradually with a moderate cocoa and browned, fermented/cooked fruit note. Center taste displays earthy/mushroom and mild herbal notes. Spice notes present along with an umami character. Bitterness and astringency are present in the aftertaste." (CoEx 2021). Another winning entry in 2021, from Dpi/Aciar Project, C/O-Abg-Dpi, P.O Box 322, Buka Town, North Bougainville, was given the following flavor profile description: "Medium brown color. Cooked fruit aroma. Smooth mouth melt with chocolate/cooked fruit notes dominant in the flavor with mild caramel and trace nut notes. Center taste presents mild herbal, earthy, and woody notes. Low bitterness and astringency throughout. Complex and harmonious with a long finish." (CoEx 2021).

Recommended Collection

The oldest trees on the island should be conserved as well as the cultivars or a representative set of the diversity that led to the winning entries in the cocoa awards. This includes germplasm from Solita Cocoa Farm, Poro Village, Kopure Village and Buka Town.

SAMOA

Overview

Samoa (#13 in Fig. 11) is in the South Pacific Ocean and is composed of four main islands and several smaller islands. Samoa is to the northeast of Tonga and Fiji and west of American Samoa. Samoa produced 479 metric tons of cocoa in 2021, ranking 38th out of 59 cocoa producing countries (World Population Review 2022). Samoa exported US$163,000 in cocoa beans in 2020, making it the 65th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/wsm). Samoa, due to the popular consumption of "Koko Samoa," utilizes the bulk of its production nationally (Y Diczbalis and N Dillon, pers. comm.).

Historical Introductions

There are conflicting reports on the introduction of cacao to Samoa. Vinning (2017) asserts that the traders JC Godeffory and Sohn who ran trading vessels between Chile and Samoa from the 1850s were the likely introduction conduit. Cacao was reportedly introduced in the 1890s to Samoa by German missionaries and traders (Clarke n.d.). Van Hall (1914) indicated that the original introductions were of a pure Criollo type similar to Java Criollo and "Ceylon" Old Red types. Historic cacao varieties were mostly Trinitario-type material from Trinidad and Venezuela, brought through Java in Indonesia, Ceylon (Sri Lanka) and Cameroon (Efron 1996). However, Cook (1982) indicated that it was Criollo cacao from Java and Ceylon.

Recent Cultivation

In the late 1970s cocoa exports declined due in part to poor planting material, pests and diseases (Frederick 2015). Replanting with Amelonado cacao started in 1983 (Frederick 2015), but in the early 1990s cyclones destroyed most of the cocoa plantations (Malua 2003). Droughts, excessive rain or wind, and recent cyclonic damage in 2012 also occurred, but stands of Trinitario trees are still present (Frederick 2015).

Genetic Studies

Sampling of 185 trees across cocoa orchards on the islands of Savai'i and Upolu indicate that the cocoa population in Samoa did not have pure Criollo trees but was Trinitario with high contribution from Criollo lineage (only 10% of samples having <30% Criollo ancestry) (Y Diczbalis and N Dillon, pers. comm.).

Flavor Quality

The industry, with assistance from the Scientific Research Organization of Samoa and the Ministry of Agriculture and Fisheries and funded by ACIAR, is focused on collecting and evaluating selections of cocoa for the production of fine flavor cocoa as part of developing an origin bean export market (Y Diczbalis and N Dillon, pers. comm.). The Trinitario and Criollo varieties grown in Samoa are said to have high quality and fine flavor (PHAMA n.d.). Knapp (1920) indicates that the Criollo in Samoa had plump, sweet beans with the cinnamon "break."

Over the period from 2010 to 2021, a chocolate sample from Samoa was selected for the best 50 International Cocoa Awards (CoEx) in 2017 but did not secure a win.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

SOLOMON ISLANDS

Overview

The Solomon Islands (#10 in Fig. 11) is an archipelago of over 900 islands, with the six largest being Choiseul, Santa Isabel, New Georgia, Malaita, Makira and the largest, Guadalcanal. The Solomon Islands produced 4,940 metric tons of cocoa in 2021, ranking 27th out of 59 cocoa producing countries according to World Population Review. The Solomon Islands exported US$8.02 million in cocoa beans in 2020, making it the 32nd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/slb).

Historical Introductions

Cocoa was reportedly introduced in the 1880s to the Solomon Islands by the British (Clarke n.d.). Charles Woodford, the first British Residential Commissioner, reported cocoa plantings at Ugi in Makira Province, and there is strong evidence that returning indentured laborers from Samoa and Fiji brought back seed, most likely from Trinitario stock, and skills to establish cocoa orchards (Vinning 2017). McGregor (2006) indicated that prior establishment efforts were unsuccessful because the Trinitario varieties were susceptible to black pod disease. More recent introductions occurred in the 1950s (Hivu 2013), likely 1958 in Aimela, Malaita (CLIP 2010), to make the industry a significant one (McGregor 2006). An Amelonado variety imported from Fiji and Kerevat (northeast area in island of New Britain of Papua New Guinea) was the basis for selecting a black pod-resistant, high-yielding variety suited to the islands (McGregor 2006; AusAid 2010 cited in Hivu 2013).

Recent Cultivation

The cocoa industry expanded in the 1980s with hybrids from Papua New Guinea (McGregor 2006). Cacao is now grown in all provinces except for Rennell and Bellona with Guadalcanal, Malaita and Makira being the top three producers (McGregor 2006). Yet cacao is not grown systematically but with minimal husbandry (Fallon and Herr 2011). Amelonado cocoa is reportedly the most suitable variety for the Solomon Islands (CLIP 2010). Yet Amelonado, Criollo and Trinitario varieties are reportedly present in Guadalcanal, Makira and Western Province (CocoaNect 2018).

Genetic Studies

Extensive sampling of cocoa across the main cocoa-producing provinces of the Solomon Islands by the Ministry of Agriculture and Livestock for genetic attribution analysis indicates that the Amelonado attribution predominates; however, there are many instances of seedlings sampled where Criollo, Nacional, Parinari and Nanay contribute to the genetic complex of Solomon Islands cocoa (Toramo et al. 2019; Dillon et al. 2020).

Flavor Quality

Cocoa from the Solomon Islands has a sensory profile with high chocolate, low acidity, low bitterness, nutty, honey, caramel, toffee, dried fruit (prune) and green olive notes (CocoaNect 2018). Over the period from 2010 to 2021, chocolate samples from Solomon Islands were selected for the best 50 International Cocoa Awards in 2011 (one batch) and 2015 (one batch), with a win in 2015 (CoEx).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

VANUATU

Overview

Vanuatu (previously New Hebrides; #11 in Fig. 11) is a Y-shaped archipelago comprising about 80 islands in the South Pacific Ocean. Vanuatu is northeast of New Caledonia, east of Australia, southeast of Solomon Islands and west of Fiji. Vanuatu produced 1,813 metric tons of cocoa in 2021, ranking 31st out of 59 cocoa producing countries (World Population Review 2022). Vanuatu exported US$3.78 million in cocoa beans in 2020, making it the 39th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/vut).

Historical Introductions

Similar to Samoa, Vanuatu reportedly has the oldest cocoa industry in the South Pacific, dating back to the late 19th century, when cocoa was established as a plantation crop on Santo (McGregor et al. 2009). Cocoa was reportedly introduced in the 1890s to Vanuatu by German missionaries and traders (Clarke n.d.) and was being exported by 1914 (Prothero 1920). The plantation of Lambubu Bay (Malekula island) obtained two varieties (Sabah and Amelonado) from Malaysia (Pellegrin and Nandris 1991).

Recent Cultivation

Amelonado cocoa is reportedly the most common type in Vanuatu (Clarke n.d.). The modern industry was revitalized in the 1950s and 1960s with subsequent development being concentrated in three provinces (Sanma, Penama and Malampa), with the island of Malekula in Malampa Province providing about 70% of the total production (McGregor et al. 2009). The Réunies du Vanuatu plantation in Malekula reportedly planted Amelonado since 1980 (Pellegrin and Nandris 1991). Two hundred seedlings from the farm of Moli and Monique on Malo island were reportedly distributed to other farmers on Malo (Sainovski 2017). Agroforestry systems include cacao and coconut with or without canarium, and cacao, sandalwood and sweet potato (or other short-term crop) are present (Harrison et al. 2016).

Genetic Studies

Extensive genetic sampling across Vanuatu cocoa production areas led by Alternative Communities Trade in Vanuatu in conjunction with Vanuatu Agricultural Research and Technical Centre (VARTC) and the Department of Agricultural Development and funded by the Australian Centre for International Agricultural Research (ACIAR) has sampled more than 400 grower seedlings (Y Diczbalis and N Dillon, pers. comm.). Although they are predominantly Amelonado in nature, there are considerable examples of Trinitario selections and selections high in Nanay, Parinari, Criollo, Nacional, Contamana and Iquitos (Y Diczbalis and N Dillon, pers. comm.). VARTC also houses a considerable international clonal selection, established during French colonization by Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD). The collection houses a "Fine Flavor" collection with a high Criollo attribution including Porcelana, KA 5/201, ICS 95, Fanofo and R10.

Flavor Quality

With careful selection and yield evaluation a Vanuatu "origin" cocoa is achievable (Y Diczbalis and N Dillon, pers. comm.). Exports of organic cocoa started in 2006 and single-origin chocolate was expected in 2010 (McGregor et al. 2009; FAO 2010). Improving quality by improving fermentation, improving bean-drying practices and avoiding smoke tainting is expected to help niche markets (Lloyd 2014; Edwards 2014; INDaily 2017). Cacao submitted from the farm of Moli and Monique on Malo island to Cocoa of Excellence 2017 was among the top 50 samples (Sainovski n.d., 2017). Over the period from 2010 to 2021, two chocolate batches from Vanuatu were selected for the best 50 International Cocoa Awards in 2017 but did not secure a win (CoEx).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

ASIA

According to Cilas and Bastide (2020), cacao plantations were established in Southeast Asia by the end of the 16th and 17th centuries, and more so from the 19th century onward. Cacao was taken to Asia mainly from Venezuela, Trinidad and Brazil (Wood 1991), and these were likely to be Criollo, Trinitario and Amelonado varieties respectively (Motamayor et al. 2003).

CAMBODIA

Overview

Cambodia (Fig. 12) was not included on World Population Review's 2022 list of 59 cocoa-producing countries and was omitted from the Chocolate Codex. Cambodia exported US$6,770 in cocoa beans in 2020, making it the 94th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/khm).

Figure 12
Cambodia in peninsular Southeast Asia
Map extracted 14 December 2021 © from google.com/maps.
Map 2021 AfriGys (Pty) Ltd GeoBasis-De/BKG (©2009) INEGI.

Recent Cultivation

Cacao in Cambodia started recently (about 1999) with a few trees along the borders with Thailand and Vietnam (Dame Cacao 2021a). In 2014, KamKav Farm (Mondolkiri Province, Eastern Cambodia) planted several thousand cacao trees sourced as seeds from four varieties in Vietnam that were reportedly suitable for the soil conditions (Dame Cacao 2021a). The types were said to be Forastero but all seedlings died in the 2015 drought and the process was restarted in 2016 (Stef Lambert interview in McCormick 2015). Currently at least 19 varieties as hybrids of Trinitario and Forastero are thought to be present on KamKav Farm according to Dr. A. Eskes (www.pinterest.com/pin/471048442285610529/).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. A representative set of the trees on KamKav Farm should be collected and conserved.

CHINA

Overview

China (Fig. 12) was not included on World Population Review's list of 59 cocoa-producing countries and was omitted from the Chocolate Codex. China exported US$43,900 in 2020 in cocoa beans, making it the 78th largest exporter of cocoa beans in the world (https://oec.world/en/profile/bilateral-product/cocoa-beans/reporter/chn).

Historical Introductions

Cacao was introduced to China in 1954 from Indonesia, and the first 28 seeds from a single Trinitario tree were planted on a state farm in Xinglong, Hainan Island (Zhu 2003 cited in Wang et al. 2020). The 1950s saw additional introductions from Indonesia and Malaysia. These imported varieties were described as Cundeamor, Angoleta, Amelonado, Calabacillo and Trinitario (Zhu 2003 cited in Wang et al. 2020). Since the 1960s, germplasm has also been introduced from Vietnam, Thailand, Malaysia, Indonesia, Cameroon, Ecuador and Brazil (Qin et al. 2014; Li et al. 2019).

Collections

Two cacao repositories exist in mainland China. The Chinese National Cacao Repository, hosted by the Chinese Academy of Tropical Agricultural Sciences (CATAS), is in Wanning City, in the Hainan Province. The collection maintains more than 300 cacao accessions, presumably with diverse genetic backgrounds (Li et al. 2019). The second is hosted by the Chinese Academy of Sciences and is located at the Xishuangbanna Tropical Botanical Garden (XTBG) in Mengla County, Yunnan province, with 170 accessions (Wang et al. 2020).

Genetic Studies

A set of 91 single-nucleotide polymorphism markers (SNPs) was used to assess 88 XTBG samples (Wang et al. 2020). These samples had Amelonado, Contamana, Criollo, Iquitos, Marañon, Nacional and Nanay ancestries but existed predominantly as Amelonado hybrids with Iquitos, Criollo and Marañon ancestry (Wang et al. 2020).

Highlighted Cultivars

Crop genetic improvement, carried out by the Spice and Beverage Crop Research Institute of CATAS, has led to the release of a new variety, Reyinf No. 4 (Qin et al. 2014). Li et al. (2021) assessed six varieties of Hainan cacao and recommended two of these based on plant growth potential, yield and quality for continued production.

Flavor Quality

The total polyphenolic and flavonoid content of Hainan cocoa beans was higher than or equal to that of the cocoa beans from Papua New Guinea and Indonesia (Gu et al. 2013). Nevertheless, China's submission of cocoa beans from Hainan was selected among the 50 best entries in Bioversity International's 2021 Cocoa of Excellence competition (Hayford 2021). The first submission to the Cocoa of Excellence was in 2021 from Dalu Town, Qionghai, Hainan, and it secured a win in the best 50 International Cocoa Awards for 2021. It was given the following flavor profile description: "Medium light brown color with slight yellow hues. Bright immediate fruit acidity and fresh fruit notes (berry, red currant, citrus, pineapple) and sweet caramel/panela notes define this unique sample. Chocolate note is mild and in the background. Mild spice joins the lingering finish with a blended complexity." (CoEx 2021).

Recommended Collection

The sampled trees used to enter into the cocoa awards should be prioritized for duplicate collection. Both the Chinese National Cacao Repository and the XTBG collections should be completely fingerprinted to identify all the unique plants and their ancestral profiles. Plants with potential for desirable flavor profiles should be identified, propagated and established in clonal plots to verify the sensory profiles in pulp, liquor and chocolate.

INDIA

Overview

India (#1 in Fig. 11; Fig. 13) is bordered on the north by China, Nepal and Bhutan; on the east by Bangladesh and Myanmar; on the south by the Indian Ocean, and on the west by Pakistan. India produced 19,000 metric tons of cocoa in 2021, ranking 16th out of 59 cocoa producing countries (World Population Review 2022). India exported US$405,000 in cocoa beans in 2020, making it the 59th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/ind). Over the entire country, South India has the most suitable climate for cocoa.

Historical Introductions

Cacao was first introduced into India in 1798 in the Tirunelveli district of the old Madras state as Criollo types (Ratnam 1961 cited in Malhotra and Apshara 2017). The introductions made in the early 20th century included presumably Criollos and Forasteros from unknown sources (Thondaiman et al. 2013). Between 1930 and 1935, Criollo trees were planted at the Kallar and Burliar Fruit Stations in the Nilgiri Hills in the southern Indian state of Tamil Nadu (Lass and Wood 1971; Malhotra and Apshara 2017). Cocoa trees can also be found in various towns along the Malabar coast (Fig. 13), which stretches on the southwestern edges of Kerala and Mysore (Lass and Wood 1971). Around 1930, all the Forastero plants were reportedly removed, leaving the Criollo trees (Thondaiman et al. 2013). After 1965, Forastero cacao was introduced for planting in the two other southern states of Mysore and Kerala but was banned from being planted in Tamil Nadu (Lass and Wood 1971). This Forastero cacao was from selected cacao trees in Malaysia (Thondaiman et al. 2013). Subsequently introductions were made from Cocoa Research Institute of Ghana and Kew Botanical Garden of United Kingdom in the 1970s, and then from 1990 from the International Cocoa Quarantine Centre at the University of Reading, United Kingdom (Thondaiman et al. 2013).

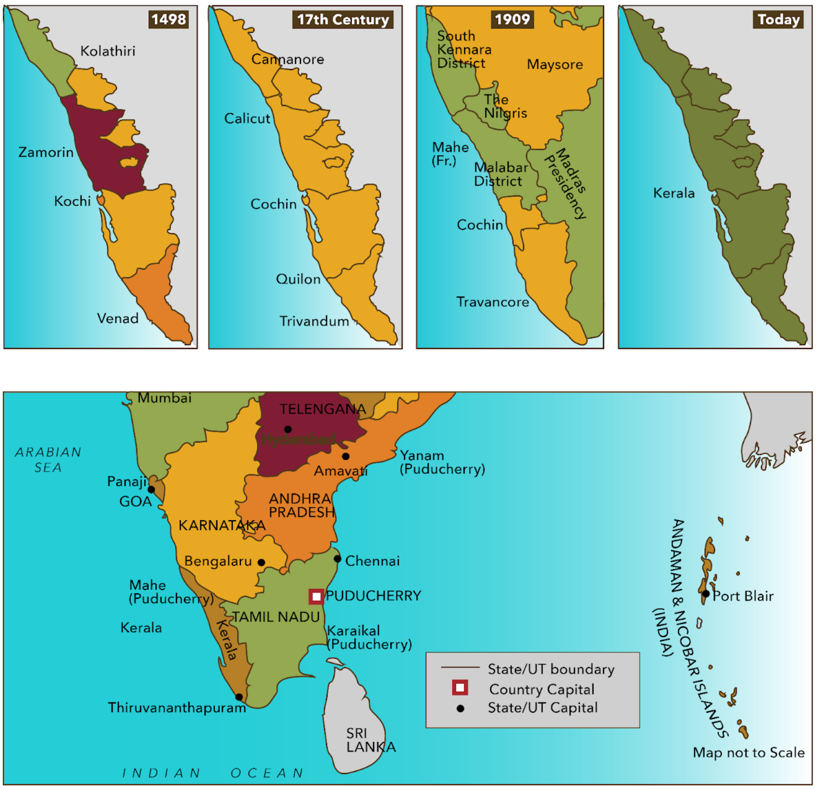


Figure 13
Southern states in India with cacao plantations.
Data obtained from https://www.zum.de/whkmla/region/india/xmalabar.html
Bottom - the four southernmost states.
Data obtained from https://www.mapsofindia.com/

Recent Cultivation

Commercial cacao cultivation started in the 1970s (Peter and Chandramohanan 2011) and predominantly in the four most southern states (Fig. 13; Kerala, Andhra Pradesh, Tamil Nadu and Karnataka) from Forastero, Trinitario and Criollo varieties (Thondaiman et al. 2013). The germplasm at Central Plantations Crops Research Institute Regional Station Vittal was based on introductions from Malaysia (1970; seedlings), Nigeria (1975; seedlings), Kew Gardens (1981, 1983; clones), Ghana (1986, 1991, 1996; clones) and locally from Wyanad, Kerala (1988; seedlings/clones) and Kallar (1988; seedlings) (Bhat et al. 2005).

Genetic Studies

Cacao in Tamil Nadu, mainly cultivated in the coconut plantations of Pollachi in Coimbatore district, was assessed and 27 potential elite trees were identified (Karthikkumar and Jansirani 2014). These 27 trees were distributed over eight clusters based on microsatellite markers (Thondaiman et al. 2013), but the ancestry or type varieties were not provided. Bhat et al. (2005) indicated that the cacao types at the Central Plantations Crops Research Institute Regional Station Vittal were mainly from Malaysian and Nigerian estates derived from Amelonado, C, EET, ICS, IMC, NA, PA, RIM and UF varieties.

Highlighted Cultivars

Drought-tolerant clones (NC 23, NC 29, NC 31, NC 39 and NC 42) and best dry bean yield performers (I-56 × II-67, I-14 × II-67, I-56 × III-105, I-14 × NC 42/94, II-67 × NC 29/66, II-67 × NC 42/94, NC 45/22) were identified by Bhat et al. (2005).

Flavor Quality

Over the period from 2010 to 2021, a chocolate batch from India in 2017 was selected for the best 50 International Cocoa Awards (CoEx) and secured a win.

Recommend Collection

Oldest possible trees in the four states should be collected and conserved. The drought-tolerant clones and the best performers should be propagated and maintained in duplicate collections.

INDONESIA

Overview

Indonesia (#7 in Fig. 11; Fig. 14) is located between the Indian and Pacific oceans with Australia on its south and Southeast Asia to the north. Indonesia is composed of over 17,000 islands, including Sumatra, Java, Sulawesi (previously Celebes) and parts of Borneo and New Guinea. Rapid cocoa expansion in the 1980s and 1990s made Indonesia the world's third largest exporter of raw beans by the end of the 20th century (Neilson 2007). Sulawesi is the largest cacao-producing region in Indonesia, contributing to 70–80% of this production.
Indonesia produced 659,776 metric tons of cocoa in 2021, ranking 3rd out of 59 cocoa producing countries (World Population Review 2022). The Chocolate Codex describes Indonesia as the 2nd top cocoa producing country in the world, but the year of assessment was not provided. In 2020, Indonesia exported US$97.2 million in cocoa beans, making it the 12th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/idn).

Historical Introductions

Van Hall (1914) indicated that the first introduction was in 1560 into Sulawesi. Further, the 1560 introduction into Indonesia was said to be from Venezuela (Van Hall 1913 cited in Susilo et al. 2013). These authors also indicate that Criollo from Caracas, Venezuela, was introduced to Sulawesi. Cacao in Sulawesi expanded along the coast in 1974 and 1975 at Tarailu (south Mamuju), and in 1976 and 1977 at Mala Mala and Lapai (north Kolaka) with material from Sabah, northern Borneo (Ruf et al. 1996). Subsequently seed planting material was also sourced from Noting and Palopo (Luwu) and sold to farmers along the coast (Ruf et al. 1996).

Figure 14
Map of Indonesian Archipelago
Data obtained from https://www.worldatlas.com/maps/indonesia

Criollo from Mexico was reportedly introduced into Java in 1560 by the Spaniards (Cook 1982). Van Hall (1914) also indicated that the initial cacao cultivated in Java was all descended from a few trees or one tree imported as early as the 16th century. The Dutch East India Co. brought cacao probably from the Philippines into West Java during the 1770s (Frasch 2014; Clarence-Smith 2000). The Java Criollo was said to be generally deep red or rarely yellow in color, the former being similar if not identical to the red-fruited Venezuelan Criollo (Van Hall 1914). However, this same author also indicated that the Porcelaine variety of Criollo with smooth fruit and shallow furrows resembling the Amelonado variety but with thin fruit walls and plump white seeds was found in the Criollo plantations of Java before the introduction of Forastero types. In Java, about 1880, when coffee cultivation declined, the coffee fields were replanted with cocoa (Van Hall 1914). Cook (1982) narrated the development of the Indonesian natural hybrids out of a lucky introduction. Apparently in 1888 a planter named Mr. MacGillavry, in an attempt to revive his estate, requested two Criollo plants from Venezuela but only one survived the journey. This proved to be a Forastero with Cundeamor fruits. The plant hybridized with the remaining Java Criollo to give disease-resistant and high-quality cacao known as the Djati Roenggo or DR clones but had poor resistance to pests and diseases such as VSD (Susilo et al. 2011). Cook (1982) indicated that the Agriculture Department brought seeds from Nicaragua of other Criollo-Forastero hybrids that were also disease-resistant and of high quality. Knapp (1920) stated that the Criollo in Java had plump, sweet beans with the cinnamon break and beautiful clean shells. Breeding from bulk varieties started in the 1950s in response to the need for greater resilience (Susilo et al. 2011).

Recent Cultivation

Cacao production regions (Sulawesi, Sumatra, Nusa Tenggara, Java, Kalimantan, Maluku, and Irian Jaya) are located in the lowland wet temperate zone of Indonesia (Lukman et al. 2014). Sulawesi is the major producing region, with Central Sulawesi, South Sulawesi, and Southeast Sulawesi as the top three producing provinces (Moriarty et al. 2014). Most cacao trees were planted in the 1980s and 1990s and were of a Criollo variety selected from Malaysia for high fat content rather than flavor (Moriarty et al. 2014). After the tsunami of 2004, cacao cultivation was developed in Aceh (northern tip of Sumatra in western Indonesia) with centers in East Aceh, East South Aceh, North Aceh, Bireuen, Pidie Jaya and Pidie districts (Irfan et al. 2018). In the Pidie district, the Keumala, Titeue, Glumpang Tiga, Padang Tiji and Tangse sub-districts were primarily responsible for production. However, the province of Aceh had the lowest output of cocoa in Indonesia, and to overcome this low productivity, rehabilitation and rejuvenation of farms started in 2009 with clones that appeared high-yielding and disease-resistant (Lukman et al. 2014). Farmers from North Sumatra started to use new Upper Amazon Forastero hybrids introduced from Malaysia in the mid-1970s (Mawardi et al. 1995). Further experimentation gave rise to superior varieties resistant to black pod and vascular streak dieback (VSD; Susilo et al. 2011). The local Java Criollo population declined because of the introduction of this newer material. However, the Java Criollo, still widely known as a fine flavor variety ("Java A"), was used for breeding. The DR 1, DR 2 and DR 38 varieties were released in 1948 (Susilo et al. 2011; Fig. 15).

Figure 15 Examples of fruits from DR accessions
From left to right: DR 1, DR 2, DR 38, and DRC 16 (Adapted from Susilo et. al 2011)

Later in 1997, DRC 16 was released for its superior resistance to pod rot (Susilo et al. 2011), followed by ICCRI 01 (released 2005) and PNT 16 (released 2010), both selected from a population of Java A clones in Penataran Plantation, East Java (Devy et al. 2018). Cacao intensification is becoming common with a tendency toward full-sun farming system (Julian Witjaksono 2016).

Genetic Studies

Susilo et al. (2011) studied 84 Java cacao accessions (67 fine; 17 bulk) inclusive of DR 1, DR 2, DR 38 and DRC 16 cultivars with 114 alleles from 15 microsatellite markers. Java cacao was found grouped into three clusters: Trinitario parentage (including the DR clones), KWC (Kaliwining Experimental Garden) clones and Amelonado (Susilo et al. 2011). Few accessions exhibited Criollo ancestry, with the PNT 23 accession being the closest to the Criollo 22 cultivar (Susilo et al. 2011). Furthermore, parentage analysis demonstrated that the DR clones came from at least two crosses (Susilo et al. 2011). Java Criollo was not a pure Criollo and instead varieties from the Ocumare region in Venezuela, the Catongo Blanco cultivar and the Para cultivar could be putative parents (Susilo et al 2011). This is in opposition to Van Hall (1914). However, the Criollo samples used in the study are not red-fruited like that described by Van Hall (1914) and it is likely than an introgressed Criollo was instead first moved into Java. It is suggestive that the two putative parental varieties from Venezuela (OC 61 ad OC 77; Susilo et al. 2011) are both Amelonado/Criollo hybrids (Motilal, pers. comm., data not shown).

Susilo et al. (2013), using 98 alleles from 15 microsatellite markers, investigated 25 clones resistant to cocoa pod borer and found that there were some outliers from the general Trinitario and Forastero groupings. However, the latter was represented by type samples from only the Contamana, Guiana, Iquitos and Marañon populations, and an ancestry analysis was not conducted. Hence the genetic background of the outlier samples or those in the Trinitario and Forastero groupings could not be ascertained. Nevertheless, high Criollo ancestry could be allocated to one accession (ICCRI 02) due to its proximity to the full Criollo cultivar Criollo 22 (Susilo et al. 2013). Examination of the phylogram in Susilo et al. (2013) suggests a Contamana background and Iquitos background for at least one accession each and Amelonado/Criollo ancestry in 12 accessions. Devy et al. (2018), using a specific transcription factor, showed that the fine cacao accessions PNT 16, ICCRI 01 and DRC 16 were grouped together while being separated from the bulk ICCRI 03 and PA 191 accessions. Lukman et al. (2014), using SNPs, showed that 80 farmed cacao cultivars from Aceh Region of Sumatra island were mostly of Marañon and Trinitario (Amelonado/Criollo) ancestry with lower contributions from either

Nanay, Iquitos or Contamana/Morona ancestry. Likewise, Dinarti et al. (2015), using microsatellite markers, showed that 53 farmed cacao cultivars were mostly Marañon and Trinitario (Amelonado/Criollo) ancestry. Furthermore, at a minimum threshold of 10%, about seven, 11 and 15 accessions had Contamana/Morona, Iquitos and Nanay ancestry respectively. Rubiyo et al. (2015) examined eight local genotypes and four released varieties (Sulawesi 1, Sulawesi 2, ICCRI 03 and ICCRI 04) from Kolaka, southeast Sulawesi, with 14 microsatellite markers. The 12 varieties were distinct from each other yet clustered into three groups, with Sulawesi 1 grouping with ICCRI 04, but Sulawesi 2 and ICCRI 03 being in separate clades.

Highlighted Cultivars

McMahon et al. (2018) indicated that the varieties ICCR I03, KW 617 and PBC 123 have good resistance to VSD while M 04, Pan R, TR01 and Husbitori were susceptible. Promising bean quality characteristics (low bean count and shell content, and high fat content) were, however, present in the VSD-susceptible varieties (McMahon et al. 2018). Resistance to cocoa pod borer is present in the cultivars ARDACIAR 10 and KW 397 (NA 33) (Susilo et al. 2013). High-yielding clones include KW 30 (ICCRI 03) and KW 48 (ICCRI 04), KW 162 (Sulawesi 01) (Susilo et al. 2013). The accessions PNT 16, ICCRI 01 and DRC 16 were said to be fine flavor (Devy et al. 2018). Two of these, ICCR 01 and DRC 16, were shown to be in Trinitario assemblage.

Flavor Quality

Indonesia is a 10% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Irfan et al. (2018) stated that the Pidie District of Aceh exported its cacao product to the U.S. as unfermented beans which had low quality because of high moisture content. Similarly, Fibrianto et al. (2021) suggest that farmers sell unprocessed cacao because they want to sell quickly. About 90–95% of Indonesian beans are unfermented but they are used in the manufacturing industry to blend with fermented beans (Moriarty et al. 2014). Sensory profiles reveal low acceptability with acid, bitter and astringent notes coupled with a low cocoa flavor (Rahmat et al. 2018).

Over the period from 2010 to 2021, chocolate samples from Indonesia were selected for the best 50 International Cocoa Awards in 2015 (one batch), 2017 (one batch), 2019 (one batch) and 2021 (one batch), with one win each in 2015 and 2021. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Forastero cacao batch (MCC 01, MCC 02, SUL 1 cultivars) from Manoriwawo, Soppeng, South Sulawesi, had strong cocoa; moderate roast, bitterness, astringency and floral; and low acidity, sweet, fresh fruit, brown fruit, spice, woody and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Award 2021 from Jl. Rajawali No 44, Surabaya, Krembangan, Surabaya, East Java, was given the following flavor profile description: "Very light yellowish-brown color with soft mouth melt. Caramel and panela plus fresh nuts dominate the flavor profile along with a gentle velvety astringency. Chocolate note is mild and joined by mild fresh dark and yellow fruits along with a pleasant white raisin character. Long caramel/nut finish." (CoEx 2021).

Recommend Collection

All cacao accessions identified as fine cocoa (e.g. PNT 16, ICCRI 01 and DRC 16) with maximal resistance to cocoa pod borer (e.g. ARDACIAR 10 and KW 397) and with high Criollo ancestry (ICCRI02 and PNT23) should be conserved with high safety duplication. The population of Java A clones in Penataran Plantation, East Java (Devy et al. 2018), should be assessed for cultivars with Criollo and Nacional ancestry. High Criollo or high Nacional ancestry cultivars should be conserved. All plantations should be surveyed for oldest germplasm, and the most promising of these should be conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

LAOS

Laos is the only landlocked country in southeast Asia. It is surrounded by China, Myanmar and Vietnam to the north, Vietnam to the east, Cambodia to the south and Thailand to the west (Fig. 16).

Figure 16 Location of Laos in Southeast Asia
Map adapted from MapsinWorld.com

Laos was not listed either by the World Population Review on its 2022 list of 59 cocoa producing countries or by the Chocolate Codex. In 2015, Laos exported US$9 in cocoa beans (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/lao).

Recommended Collection

The cacao germplasm throughout Laos should be screened to determine the oldest trees, the best-performing trees and unique genetic identities, and the best coverage of these trees should be collected and conserved.

MALAYSIA

Overview

Malaysia consists of Peninsular Malaysia in Southeast Asia separated by the South China Sea from its counterpart of East Malaysia in Borneo (#5 in Fig. 11, Fig. 17). Peninsular Malayasia is adjacent to Sumatra of Indonesia. Malaysia produced 1,029 metric tons of cocoa in 2021, ranking 33rd out of 59 cocoa producing countries (World Population Review 2022). In 2020, Malaysia exported US$242 million in cocoa beans, making it the 6th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/mys).

Figure 17
Location of Malaysia
Data adapted from https://www.worldatlas.com/maps/malaysia

Historical Introductions

The earliest movement into Malaysia was said to be in 1600 (Lani 1982 cited in Rahman 1990). Cacao was introduced into Peninsular Malaysia by the Dutch in the 1700s (Thong et al. 1992; Kaur 1995). Hunter (1902, cited in Thong et al. 1992) reported that by 1802 a few experimental trees were thriving in Penang. Chong and Phua (1993) reported that cacao was in Malaysia before 1890 and that the earliest introductions were of unknown genetic origin planted as ornamentals from Sipitang, located on the West Coast, to Tawau. Cacao was first intentionally imported for agriculture in 1895 as Criollos from Ceylon, followed by Ceylonese Forasteros and then Forasteros from Malaya, Celebes and the Philippines (Chong and Phua, 1993). In 1923 some Forastero and Nicaraguan varieties from Sri Lanka were imported (Bunting and Milsum 1931, cited in Thong et al. 1992). Cacao seeds from Sri Lanka were brought in 1928 to north Perak (Rosenquist 1950, cited in Thong et al. 1992). In 1934 a test plot of Trinitario cacao was established in an agricultural station at Serdang from a Sri Lankan tree (Faulkner and Milsum

1938, cited in Thong et al. 1992). Seedlings that died were reportedly replaced by seedlings from two Forastero fruits obtained from Sri Lanka (Rosenquist 1950, cited in Thong et al. 1992). Seeds from the best-yielding Trinitario trees at Serdang were used in 1937 to establish other experimental plots at agricultural stations at Cheras, Selangor and Kuala Lipis and Temerloh, Pahang (Faulkner and Milsum 1938; Hartley 1949; both cited in Thong et al. 1992). It is believed that multiple introductions occurred around 1937 and included material from Java, Indonesia, to Kampongs on the Perak River; from Borneo (Sabah) to Beranang, Selangor; and from Medan, Indonesia, to Dusun Tua, Selangor (Thong et al. 1992).

In 1946, Trinitario fruits were imported from Sri Lanka from which 15,000 seedlings were grown and distributed for trials (Hartley 1949 cited in Thong et al. 1992). In 1948, "cocoa planting materials" were imported from, but not limited to, the West Indies, West Africa, Sri Lanka, and Java (Thompson 1950 cited in Thong et al. 1992). In 1949, 200 fruits from the Botanic Gardens in Aburi, Ghana, were imported; 5,000 seedlings were raised (Thong et al. 1992) and 4,956 were distributed over Malaya, Sarawak, Sabah and Singapore, with Malaya receiving 3,649 seedlings (Thompson 1950 cited in Thong et al. 1992).

Chong and Phua (1993) reported that in 1950 a few thousand Amelonado-type seedlings from Ghana were obtained and planted at what later became the Agricultural Research Centre in Tuaran. Cook (1982) also indicated that Amelonado from Africa and Nanay cacao were brought into Malaysia. Also in 1950, 80 best Criollo trees were selected from Negri Sembilan, Malacca, Johore, Perak, Penang and Province Wellesley, Kedah and Perlis (Anon 1950 cited in Thong et al. 1992). In 1950/1951, germplasm was brought in from Indonesia (seeds from open-pollinated fruits from seven best clones at Bogor), West Africa (seeds from 10 West African Cocoa Research Institute (WACRI) clones and some ICS clones), Papua New Guinea (seeds from five selected Keravat clones), Samoa (25 seeds from the original LAFI 7 clone) and Amelonado cacao from Sulawesi (Haddon 1961 cited in Thong et al. 1992). In 1953, "a good collection of ICS clones from Trinidad" was planted at the Agricultural Research Station, Jerangau (Arasu and Phang 1972 cited in Thong et al. 1992). In 1955, eight Upper Amazon Forastero clones from the Nanay, Parinari and Scavina series (Nanay, Marañon, and Contamana populations respectively) were imported into Peninsular Malaysia (Malaya) from South America (Arasu and Phang 1972 cited in Thong et al. 1992). In 1956 the Amelonado and the Upper Amazon Forastero clones from Malaya were introduced into Sabah (Thong et al. 1992; Kaur 1995). Based on the good growth of the latter, a further 200 Upper Amazon clones from the Pound collection were imported during 1958–1961 from South America (Thong et al. 1992). Around 40 imported clones had been collected by 1958, which included ICS clones, Indonesia Selection, West Africa Selection, New Guinea Keravat and Upper Amazon clones; Paranari and Nanay clones came shortly thereafter (Chong and Phua, 1993; Tay et al. 1993).

Recent Cultivation

In the mid-1960s the Sabah hybrid was developed at the Quoin Research Station with superior yield and disease tolerance (Rahman 1990). Extensive planting of cacao in smallholdings occurred in the late 1960s and into the early 1970s, especially as an intercrop with coconut (Rahman 1990). Rapid development of the industry occurred in the 1970s and 1980s with Sabah having plantation owners but Sarawak having smallholders (Khazanah Research Institute 2016). Between 1969 and 1991 several introductions from Brazil, Costa Rica, Papua New Guinea, Miami and Puerto Rico occurred (Thong et al. 1992). Following an outbreak of the cocoa pod borer in 1980, screening for resistant clones identified PA 7, Mocorongo, NA 137 and PA 30 as highly resilient. Chong and Phua (1993) reported that there are about 500 introduced clones with at least 1,500 clones derived from the former. Some hybrids have been released as "Sabah Mixed Hybrids" for commercial planting as a result of Malaysia's breeding program (Chong and Phua 1993). The Malaysian Commercial Clones (53 clones in Class I–IV) were selected for good agronomic characteristics for farmers (Johnsiul and Yazik 2019).

Genetic Studies

Johnsiul and Awang (2019) conducted a small study on five Class I commercial clones and demonstrated that three of these contained mislabeled trees. Johnsiul and Yazik (2019) assessed replicates of 13 Class II clones (total 78 trees) with 990 alleles from 11 microsatellite markers. High diversity and high heterozygosity were obtained over 47 unique samples. This demonstrated a high level of mislabeling among the 13 expected clones but must be weighed against the inordinately high number of alleles at each microsatellite marker. The ancestry plot of Johnsiul and Yazik (2019) revealed a high to exclusive Amelonado background with few individuals with accessory Criollo (four; 5–30%), Contamana (10), Nanay (one) and Guiana (five) contributions.

Highlighted Cultivars

Yield potential and VSD incidence of 38 commercial clones allowed for the identification of three high-yielders (KKM 2, DESA 1, PBC 123), three VSD-resistant clones (QH 1176, KKM 25, QH 37) and five VSD-susceptible clones (PBC 130, MCBC 3, MCBC 5, MCBC 7 and PBC 140) at Bagan Datuk (Yazik et al. 2019). The cultivar PBC 123 is widely planted with good resistance to VSD, good yield potential (7.72 fruits per tree) and average dry bean mass of 1.15 g (Aizat et al. 2019). Evaluation of 20 new clones at a farmer's plot
in Tebakang, Serian, Sarawak, identified promising clones as good as or better than PBC 123 for VSD resistance (BTKU-A03 to BTKU-A09 inclusive) and with nearly twice the fruit yield per tree (BTKU: A03, A04, A05, A07, A12 and A14) (Aizat et al. 2019).

Flavor Quality

Figueira et al. (1999) demonstrated that flavor profiles from different genotypes grown at BAL plantations, Sdn Bhd, Malaysia, were repeatably consistent and different from each other, indicating a strong genetic contribution to flavor. Further, the accessions AMELONADO, PA 137 and SPA 9 reportedly had medium-high cocoa flavor with medium astringency and bitterness while the accessions CC 10, CC 11 and UF 168 had low-medium cocoa flavor with medium-high astringency and bitterness in both Brazil and Malaysia (Figueira et al. 1999). However, a wide range was reported for cocoa flavor for PA 137 in both countries. Quality is reportedly inconsistent as the farmgate price is driven by volume and many smallholder farmers neglect fermentation and drying (Khazanah Research Institute 2016).

Over the period from 2010 to 2021, chocolate samples from Malaysia were selected for the best 50 International Cocoa Awards in 2010 (three batches), 2011 (two batches), 2013 (four batches), 2017 (two batches) and 2021 (two batches), with 0, 1, 2, 1 and 2 wins respectively.

In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch (Malaysian Commercial Clones) from Peti Surat 30 Jln Sungai Dulang, 36307 Sungai Sumun, Perak, had moderate cocoa, roast, bitterness, astringency, acidity, sweet, fresh fruit and brown fruit flavors, and low acidity, floral, spice, woody and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Kampung Goshen P/S 195, Kota Marudu, Kota Marudu, Sabah, was given the following flavor profile description: "Reddish-brown color. Moderate chocolate note blends with browned fruit (dates, dark raisins) — uniform throughout. Mild fresh fruit acidity supports mild citrus, dark, yellow and tropical fruit notes. Mild spice notes and trace nut / nut skins appear later. Balanced bitterness and astringency. Complex, balanced, bright." (CoEx 2021). Another winning sample in 2021, from No. 132 Jalan Besar, 18400 Temangan, Machang, Kelantan, was given the flavor profile description: "Dark brown color. Early flavour is one of dried and browned fruits (dried apricot) with mild fresh fruit acidity and moderate chocolate note. Tobacco leaves / spice notes appear in center taste along with dried herbal notes. Finish presents a slightly high bitterness and astringency." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

MYANMAR

Overview

Myanmar (formerly Burma) is in southeast Asia and is bordered on the northwest by Bangladesh and India, on the northeast by China, on the east by Laos, and on the southeast by Thailand (#3 in Fig. 11; Fig 18). Myanmar was not included in World Population Review's 2022 list of 59 cocoa producing countries. In 2020, Myanmar exported US$50 in cocoa beans, making it the 113th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/mmr). In 2019, chocolate exports brought in US$210,000 (www.selinawamucii.com/insights/market/myanmar/chocolate/).

Historical Introductions

Reportedly there was an unsuccessful government experiment on cacao in the 1970s or 1980s and pockets of cacao trees exist in the secondary forest (Lovett 2017). Three such pockets were found: near Taungoo (Karen State), near Thaton Township (once home to an ancient Mon Kingdom), and in Kalein Aung village (about 90 kilometers north of Tanintharyi Region's capital, Dawei). Plantations in the former and latter started in 2003 (cacaoauthority.com/chocolate/myanmar-dark-chocolate/).

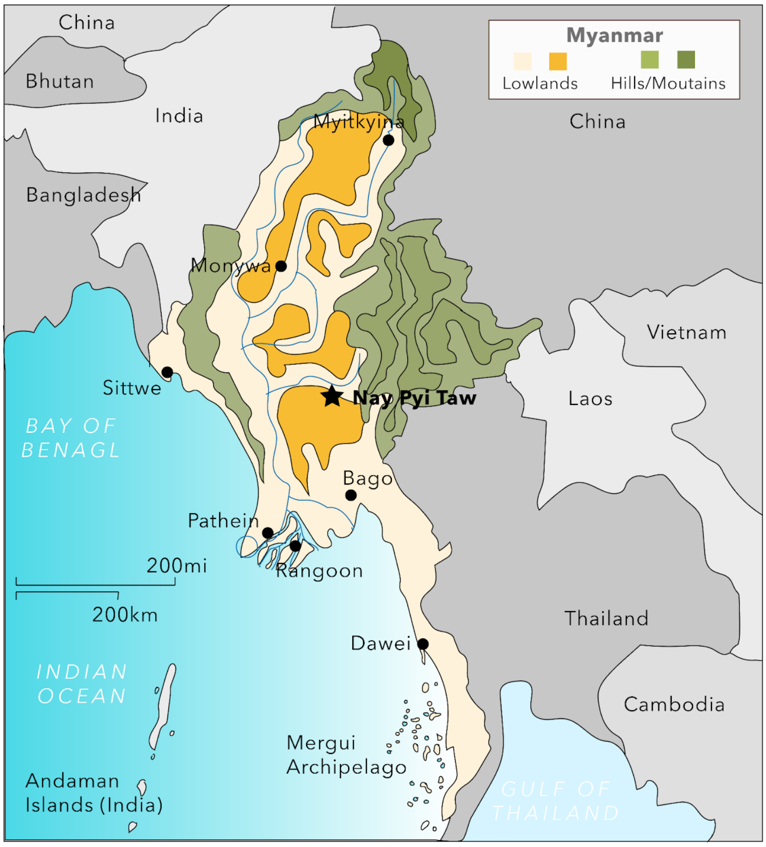


Figure 18
Map of Myanmar (previously Burma).
Adapted from https://www.worldatlas.com/maps/myanmar

Recent Cultivation

Lovett (2017) indicates that organic cacao farming occurs on a 125-acre plantation with 400,000 cacao trees. The farmers use four cacao varieties chosen from a batch of 15 types of seeds that comes from a government laboratory on the South Pacific island nation of Vanuatu (Lovett 2017). Contrawise, cacao in the Thanintharyi Region, which covers the long narrow southern part of the country on the Kra Isthmus, was said to be based on Trinitario, hybrid and Criollo varieties (es-la.facebook.com/natcoffeecom/posts/myanmars-cocoa-can-be-found-in-thaninthary-region-covering-the-long-narrow-south/2767013309993912/).

Flavor Quality

Myanmar chocolate has a strong chocolatey flavor that is reinforced further and joined by earthy sensations mixed with woody notes (cacaoauthority.com/chocolate/myanmar-dark-chocolate/). Over the period from 2010 to 2021, a chocolate batch from Myanmar was selected for the best 50 International Cocoa Awards in 2019 but did not secure a win; the chocolate, made from a Trinitario cacao batch from Kalei Aung, Dawei, Tanintharyi, had strong cocoa; moderate roast, bitterness and astringency; and low acidity, sweet, fresh fruit, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

PHILIPPINES

Overview

The Philippines (#6 in Fig. 11; Figs 12, 19) is an archipelago in the western Pacific Ocean consisting of about 7,640 islands found northeast of Malaysia and east of peninsular southeast Asia.

Figure 19
Map of the Philippines archipelago
Adapted from https://www.worldatlas.com/maps/philippines

Philippines produced 7,009 metric tons of cocoa in 2021, ranking 24th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Philippines exported US$17.7 million in cocoa beans, making it the 28th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/phl).

Historical Introductions

The Spanish introduced cacao as a commercial crop to the Philippines in the 1660s (Frasch 2014). Cook (1982) indicated that Criollo from Mexico was introduced to the Philippines in 1860 by the Spaniards. Frasch (2014) supported the connection of the Philippines to Central America since, at the time, they were part of the Spanish Empire, governed by the Viceroy of Mexico, and had the transportation link of the annual Manila Galleon.

Recent Cultivation

Seedlings are distributed and/or sold to farmers, and the reference varieties are conserved at the University of Southern Mindanao-Genebank and Bureau of Plant Industry, Davao (Espino et al. 2017).

Genetic Studies

Espino et al. (2018) studied 50 accessions (13 varieties and seven Criollo clones) collected from 10 provinces in the country with 84 alleles from 15 microsatellite markers. Nine of these varieties were collected from more than one location. This study established that of the seven Criollo clones used only three appeared to be of high Criollo ancestry (Criollo Red, Criollo Green and Criollo 22). The other Criollo cultivars, including Criollo 21, were in three different clusters, with Criollo 21 being most similar to Criollo from New Leyte and Criollo from Quezon being in a sister group to ICS 40. This suggests that the differentially grouped Criollo cultivars are Criollo hybrids, especially since the true ICS 40 is mixed as 50% Criollo/49% Amelonado (Lambert Motilal, pers. comm). Furthermore, Criollo Red and Criollo Green were closer to each other than to Criollo 21, suggestive of differences within the Criollo complex and with distinction from at least a cultivar (Criollo 22) known to be 100% Criollo. Examination of the phylogenetic tree of Espino et al. (2018) shows clearly that all 13 varieties have misidentified samples, which means more genetic diversity but issues with varietal dissemination.

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Philippines were selected for the best 50 International Cocoa Awards in 2017 (one batch), 2019 (one batch) and 2021 (three batches) with 0, 1 and 3 wins respectively.

In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch (Karaan (old) Cacao, UF 18, BR 25 cultivars) from Kialaw, Malabog, Paquibato District, Davao City, had strong cocoa, moderate roast, bitterness, astringency, fresh fruit and brown fruit flavors; and low acidity, sweet, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from Talandang, Tugbok District, Davao City, Davao Region, was given the following flavor profile description: "Lighter colored, medium brown. Cooked fruit aroma, chocolate note, nuts, and sweet caramel that emerge smoothly and harmoniously in the flavor profile. Mild fresh fruit acidity and a complex of fresh fruit notes. Browned fruit is a cooked note. Finish is chocolate-caramel. Unique, complex." (CoEx 2021). Another 2021 winning entry, from Brgy. Atipuluan, Bago City, Negros Occidental, Region Vi, was given the flavor profile description: "Medium-light brown color. Mild, creamy mouth melt with chocolate note blended with sweet caramel, browned fruit (date, dark raisin), and nuts. Low bitterness and astringency. Mild fruit acidity and a complex of fresh fruit notes. Clean, sweet caramel/nut finish. Unique, balanced, harmonious, very mild." (CoEx

2021). The third winning entry in 2021, from Purok Cacao C., Barangay Sawata, San Isidro, Davao Del Norte, Davao Region, was given the following flavor profile description: "Medium brown color, reddish hues. Chocolate note emerges along with dried fruit (dried plum, dark raisin, trace apricot and prune), and a mild fruit acidity with fresh fruit undertones (berry, yellow fruits). Low bitterness and astringency. Clean, clear cocoa finish." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

SRI LANKA

Overview

Sri Lanka (previously Ceylon) is an island in the Indian Ocean located southeast of the southernmost tip of India (#2 in Fig. 11; Fig. 20). Sri Lanka produced 1,291 metric tons of cocoa in 2021, ranking 32nd out of 59 cocoa producing countries (World Population Review 2022). In 2020, Sri Lanka exported US$30,400 in cocoa beans, making it the 79th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/lka).

Sri Lanka was an important site of cacao cultivation in the late 19th century and was a waypoint for dissemination to Asia and the Philippines and across the Indian Ocean (Frasch 2014).

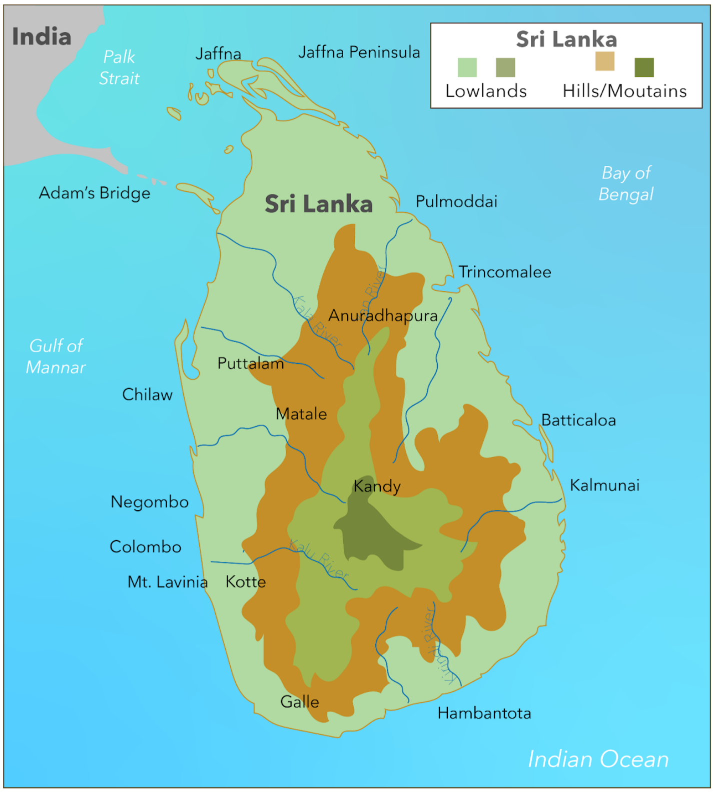


Figure 20
Map of Sri Lanka
Data adapted from https://www.worldatlas.com/maps/sri-lanka

Historical Introductions

Possibly the Dutch (in the 1770s) and certainly the English (in the 1830s) brought cacao into Sri Lanka (Frasch 2014). Van Hall (1914) indicated cacao was likely on the island before 1834 as there was cacao in the Botanic Gardens in 1819. Cocoa plants from Trinidad were said to be introduced around 1834–1835 (Frasch 2014; Van Hall 1914) and again in 1880 (Van Hall 1914). Knapp (1920) stated that it was in 1834 and that the plants had survived a voyage of 10,000 miles. Cook (1982) indicated that in 1834 the English brought an original Mexican strain of Criollo, known as "Old Red," from Trinidad. However, Van Hall (1914) suggests that it is more likely that this red-fruited variety was imported from Venezuela though Trinidad. The "Old Red" variety was also called "Caracas variety" and was the only cultivated variety until 1878, when Forastero was introduced (Van Hall 1914). It is also reported that Forastero types gave rise to all the types that were grown (Martin Report to Planters' Association 1892, cited by Hart 1900). During the 20th century, Matale, a district in the central highlands, was preferred for cacao plantations (Frasch 2014), and the first cacao plantation was established by the British in 1819 in Nalande, Matale (Attygalle 2020). Hart (1900) indicated that the Dutch cacao from Ceylon corresponded to the Criollo cocoa of Trinidad.

Recent Cultivation

Suitable growing conditions are found in the Central, North Western, Sabaragamuwa, Uva, Western and Southern provinces. Cacao can be grown in monoculture, or in an agroforestry system intercropped and underplanted in coconut and rubber plantations (Department of Export Agriculture 2021). The mixture of cacao/coffee/black pepper and the mixture of banana/coffee/cacao are the two main agroforestry systems with mature coconuts (Liyanage et al. 1984). Kandy, Wattegama, Matale and Dumbara Valley were traditional cultivation areas while Kundasale, Pallekelle, Mahaberiyatanna, Wariyapola, Bandarapola and Mariawatta estates reputedly produced good cocoa (Gunathilake n.d.). The main cocoa-growing districts are Matale, Kandy, Badulla Kurunegala, Kegalle and Monaragala (Department of Export Agriculture 2021). Although Criollo or high Criollo varieties were originally introduced into Sri Lanka (Hart 1900; Van Hall 1914; Cook 1982), most of the farmed cacao are crosses involving Trinitario, Forastero and Criollo, with two main hybrids (SCA 6 × ICS 6, NA 32 × ICS 1) and four main clones (W 6/457, W 5/5, WK 2 and WK7) (Department of Export Agriculture 2021). The varieties ICS 1, 'Amilando,' Millawana and F-Amerson (from Nigeria) are also present (Gunathilake n.d.). The SCA 6 and ICS 6 varieties are reportedly the best to grow in Sri Lanka (Dole 2012). Seeds are normally used for production of planting material, but grafted plants are also used, especially in multiplying high-yielding varieties (Department of Export Agriculture 2021). Farmers often use seed from their own or government-approved nursery (Gunathilake n.d.).

Flavor Quality

Knapp (1920) stated that the Criollo in Sri Lanka had plump, sweet beans with the "cinnamon break" and beautiful clean shells. However, he noted that inferior cacao was also produced.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

THAILAND

Overview

Thailand is in the middle of peninsular southeast Asia and is bordered on the north by Myanmar and Laos, on the east by Laos and Cambodia, on the south by Malaysia, and on the west by Myanmar (Fig. 21). Thailand produced 125 metric tons of cocoa in 2021, ranking 54th out of 59 producing countries (World Population Review 2022), but was not listed in the Chocolate Codex. In 2020, Thailand exported US$9,540 in cocoa beans, making it the 91st largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/tha).

Figure 21
Map of Thailand
Data adapted from https://www.worldatlas.com/maps/thailand

Historical Introductions

Cacao has been present in Thailand for over a century (Piankarn et al. 2021, Stevens 2021), imported in the early 20th century, most probably from Malaysia (KamKav Farm 2021, Stevens 2021). In 1952 the government started subsidizing cocoa cultivation to help expand production but by the late 1990s had declined considerably (Stevens 2021)

Recent Cultivation

Cacao cultivation is in northern and southern Thailand (Piankarn et al. 2021). The Chumphon collective group of farmers with 25,000 trees in southern Thailand is focusing on northern Thailand with intent to plant more than 150,000 trees in Chiangrai and Nan, close to Myanmar, at altitudes between 300 and 500 meters (KamKav Farm 2021). Nuttaya and Paniti Chunhasawatikul, in Mae Taeng, Chiang Mai, produce organic cacao and also source organic cocoa from the provinces of Chanthaburi, Prachuap Khiri Khan and Chumphon (Alimin 2021).

Highlighted Cultivars

The Chumphon #1 variety was developed by crossing PA 7 × NA 32 from Trinidad (Piankarn et al. 2021; Struik 2021) by Dr. Pon of Chumphon Horticultural Research Centre (KamKav Farm

2021; Struik 2021) and the hybrid was found to have high yields and a signature yellow color (Piankarn et al. 2021). This variety is mostly grown in Thailand (KamKav Farm 2021). The first cacao plant in Chiang Mai, northern Thailand, is named Coco Hohm Hybrid and was developed by breeding plants from Peru and the Philippines (Stuart 2017). The Coco Hohm Hybrid, officially known as IM 1, is said to take the hardiness genes from the Peruvian plants and the good yield and large beans from the Filipino plants (Stuart 2017). In contrast, Struik (2021) writes that IM 1 is a cross between a Criollo variety from Peru and a Forastero variety from the Philippines. Dr. Sanh La-Ongsri and his wife Kanokked La-Ongsri claim that "Our cacao breed [IM 1] is the first, and only fine coco producing breed in Thailand" (Stuart 2017). IM 1 is said to produce all year round and pod collections every fortnight can be scheduled (Stuart 2017).

Flavor Quality

Thailand chocolate was awarded one gold, two silver, and two bronze medals in the 2018 International Chocolate Awards (Piankarn et al. 2021). However, cacao in south Thailand is considered as bulk cocoa (Stuart 2017). Mark Rin Chocolate, a family-led cooperative of the La-Ongsris', produces a 75% chocolate, Siamaya Chocolate, that is strong but smooth, rich but peppery and with a few aromatic Thai notes (Stuart 2017). Nuttaya and Paniti Chunhasawatikul's Kad Kokoa chocolate company produces a Chiang Mai Dark 70% with honey aroma at the beginning, but at the end you may get the aroma of dried fruits (Alimin 2021). The Chunhasawatikuls note that cacao in the region has "the charming characteristics of local fruits, and ends up more fruity, more acidic, and floral" (Loh 2021). Indeed, several Thai chocolates have won several awards in 2018 and 2019 (Stevens 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

VIETNAM

Overview

Vietnam (#4 in Fig. 11) was not included on World Population Review's 2022 list of 59 cocoa producing countries. In 2020, Vietnam exported US$4.12 million in cocoa beans, making it the 37th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/vnm).

Historical Introductions

According to Stef Lambert, French missionaries tried to grow cacao in Vietnam at the end of the 19th century but were unsuccessful (McCormick 2018). It is also reported that cacao was introduced to Vietnam in the 1960s and planted in several areas (Ha and Shively 2005). However, the country from which it was obtained and whether the germplasm was brought in as seeds or clonal plants were not indicated. Introductions occurred again in 1980 with help from Russia and Cuba and then again in 2004 or 2005 when Cargill gave free seedlings to 12,000 smallholder farmers (McCormick 2018). The latter was successful, generating 21,000 ha of cacao farms (Stef Lambert interviewed by McCormick 2018).

Recent Cultivation

An estimated 5,147 smallholder farmers with cacao plantations in Ben Tre, Tien Giang, Ba Ria Vung Tau and Binh Phuoc, Dak Nong, Lam Dong and Dak Lak on 1,400 hectares received 90,000 cacao seedlings (Voorney 2015). The types of seedlings or the varietal bases were not indicated.

Genetic Studies

Five regions in Southern and Central Vietnam were selected for cacao genetic analysis using microsatellites by Everaert et al. (2017). A total of 75 (44 Vietnamese and 31 reference samples) were collected from Central and South Vietnam. Collections were made from the Dak Lak (Ea Kar district, Central Highlands), Dong Nai (Trang Bom district, Southeast regions), Ben Tre (Chau Thanh district, Mekong Delta), and Can Tho (Phong Dien district, Mekong Delta) regions of Vietnam. The Dong Nai samples included reference accessions from a germplasm collection, the Can Tho samples were from a Can Tho University cacao garden, and the other samples from local cacao farms. The results showed that the Vietnamese samples were either Trinitarios (Can Tho and Dak Lak) or hybrids of Forastero or Forastero with Trinitario (Ben Tre and Dong Tai). Later, Everaert et al. (2020) showed that 80 Vietnamese cacao cultivars of unknown origin using both microsatellite and SNP markers were distinct from each other occurring principally as Criollo/Trinitario hybrids (62.5%), with some Amelonado (8.75%), Nanay (7.5%), Marañon (2.25%) and Iquitos (1.25%). Priority cultivars were identified as TD2 (closely related to PA13, which is resistant to VSD), and TD55 and TD43, which are closely related to Criollo and Nacional respectively (Everaert et al. 2020).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Vietnam were selected for the best 50 International Cocoa Awards in 2013 (one batch), 2017 (one batch) and 2019 (two batches), with one win each in 2013 and 2019. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch (TD 1, TD 3, TD 5, TD 7, TD 8, TD 9, TD 10, TD 12) from

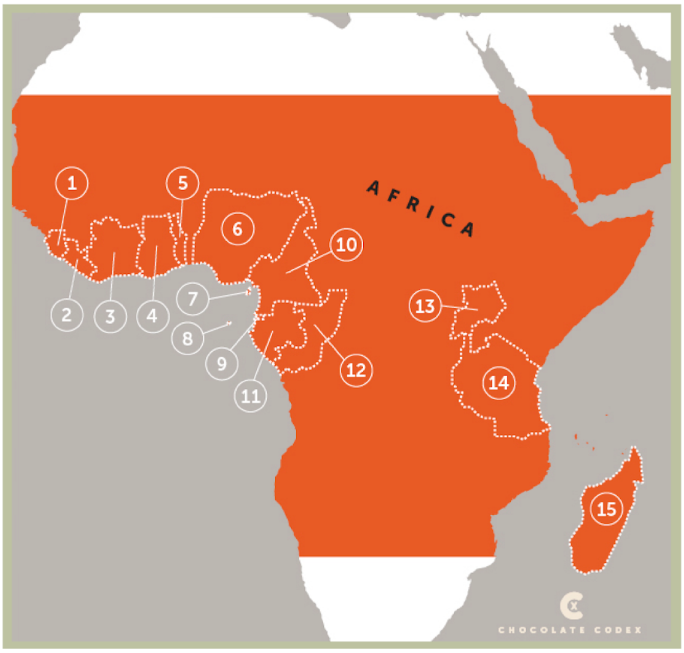
Số 67, Ấp Bình, Dưỡng Điềm, Châu Thành, Tiền Giang had strong cocoa; moderate roast, bitterness, astringency, acidity, fresh fruit and brown fruit; and low sweet, floral, spice, woody and nutty flavors (CoEx 2019). Another qualifying best-50 in 2019 was chocolate made from a Trinitario cacao batch (TD 3, TD 5, TD 6, TD 9, TD 12 cultivars) from Vĩnh An, Bình Giã, Châu Đức, Bà Rịa - Vũng Tàu, and had similar profile but with a stronger cocoa and fresh fruit flavor (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

AFRICA

Africa (Fig. 22) produces about 70% of the world cocoa as bulk cocoa from Forastero cocoa. The West African region accounts for about 72% of world cocoa production with about 96% being produced from smallholder farms (Aikpokpodion et al. 2009).



1 Sierra Leone
2. Liberia
3 Cote d'Ivoire
4. Ghana
5. Togo
6. Nigeria
7. Bioko (an island of Equatorial Guinea–formerly Fernando Pò
8. São Tomé and Príncipe
9. Equatorial Guinea
10: Cameroon
11. Gabon
12. Congo
13. Uganda
14. Tanzania
15. Madagascar

Figure 22 The cacao countries in the African region
Adapted from http://chocolatecodex.com/portfolio/countries-of-origin/

Criollo, Trinitario and Amelonado cacao germplasm was moved to Africa from Venezuela, Trinidad and Brazil respectively (Motamayor et al. 2003). Reviews of cacao movements into Africa are available (Toxopeus 1985b; Bartley 2005; Aikpokpodion et al. 2009; Aikpokpodion 2012). Cacao was cultivated in Africa first in Sao Tomé et Principe (1822) and then in Fernando Poo (now Bioko) and the Gold Coast (now Ghana) (Rodriguez 1924). West African cacao is said to be a mixture of Amelonado landraces and Upper Amazon hybrids (Aikpokpodion et al. 2009; Opoku et al. 2007). The Upper Amazon hybrids were derived from the IMC, NA, PA, POUND and SCA accession series (Abdul-Karimu et al. 2006). The Upper Amazon hybrids produce fruit all year, have shorter juvenile periods and have higher yields, while the Amelonado clones have high bean-to-pod volume ratio and are less susceptible to black pod disease (Aikpokpodion et al. 2009). The Guiana germplasm group (GU), collected from 1985 to 1995 from French Guiana, is known to be quite resistant to black pod rot and historically performs well in West Africa, with some progenies giving a dry bean yield as high as 3,000 kg/ha in Cote d'Ivoire (Aikpokpodion et al. 2009).

CAMEROON

Overview

Cameroon, formerly a German colony, is located in west-central Africa and is bordered by Nigeria, Chad, Central African Republic, Equatorial Guinea, Gabon and Congo. Cameroon (#10 in Fig. 22) produced 295,028 metric tons of cocoa in 2021, ranking 5th out of 59 producing countries (World Population Review 2022). Cameroon is the 5th top producing cocoa country in the world according to the Chocolate Codex. In 2020, Cameroon exported US$590 million in cocoa beans, making it the 4th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/cmr).

Historical Introductions

The first recorded planting reportedly occurred in 1876 with 13 plants (likely from Trinidad) in the Royal Botanic Gardens in the city of Limbé in southwestern Cameroon (Efombagn et al. 2008; Aikpokpodion 2012). In the early 1890s, the cacao trees in the Botanic Gardens at Victoria and the Bibundi plantation were exporting cocoa, with the latter having 44,500 cacao trees (Anon 1896). Varieties from Sao Tomé were also reportedly introduced in 1876 (Aikpokpodion 2012). Alternatively, the introduction occurred in 1892 by the Germans (Champaud 1966) from Sao Tomé and Principe (Nya Ngatchou 1981) or from Fernando Po (Efombagn et al. 2008). Another attribution is in 1886 in the Mount Fako region by the Germans (Andoh and Mbah 2018). A set of 322 plants including Forastero types was reportedly introduced probably in 1895 from Trinidad (Gosselin 1895 and Preuss 1901 both cited in Aikpokpodion 2012). In 1900, introductions of several types (Forastero, Criollo, Puerto-Cabello, Venezuela, Maracaibo, Guayaquil, La Guira, Soconusco, Suriname and Nueva Grenada from Colombia) by Preuss from Central America, South America and Trinidad occurred (Aikpokpodion 2012). The first plantations (approximately 11,000 ha) were on Mount Cameroon, followed successively by plantations near Douala, Kribi and Edea in Eastern Cameroon (Champaud 1966). Cultivation then proceeded easterly toward Ebolowa and Yaoundé and eventually reached Abong-Mbang and Batouri with much expansion in 1924 and 1925 in Cameroon under the French colonials (Champaud 1966).

Amelonado cacao was the first imported, followed by Trinitario types (Preuss 1901; Bartley 2005; Efombagn et al. 2008). Fruit from Upper Amazonian Forastero cacao that originated from Trinidad (T-clones) and was introduced to Ghana in 1944 (Toxopeus 1985b) was brought into West Cameroon (Efombagn et al. 2006). The traditional varieties that developed from the Amelonado and Trinitario types became known as “German Cocoa” (Efombagn et al. 2006). Trinitario population with red-fruited trees developed in West Cameroon, and Trinitario mixed with Amelonado from Fernando Poo in East Cameroon (Cook 1982, Wood 1991).

Recent Cultivation

By the early 1980s, cacao in Cameroon was mainly descended from Trinitario from Sao Tomé followed by Upper Amazon cacao (Nya Ngatchou 1981). Cacao is now grown mainly in the coastal zone and the Central, South and East regions in the country (Tankou 2016). There are over 200,000 cacao farms in Cameroon (Efombagn et al. 2006), with the major agroecological zones of cocoa production in the South and the Southwestern parts of the country along the Coastal Zone (Tankou 2016). The Central and South regions form the oldest production area in Cameroon (Michel et al. 2019). Seed gardens contain locally selected Trinitario types and Upper Amazon clones (Efombagn et al. 2006). Plant material is distributed in the form of cuttings (approximately 500,000 each year) (Champaud 1966). Farmers have, however, used seeds from their own or neighboring plantations as the main source of planting materials (Efombagn et al. 2008).

Jagoret et al. (2011) surveyed 1,171 farms in three areas (Bokito, Zima and Ngomedzap) of Central Cameroon. These farms practicing cacao agroforestry kept the age of the cacao trees lower with respect to the surrounding trees by replacing dead or senescent trees with seedlings (94% farmers). Senescent trees or unproductive trees were also cut back and allowed to regrow suckers by 53% of the surveyed farmers (Jagoret et al. 2011). These authors indicated that the maintenance of younger cocoa trees in old cocoa stands, the long-term steady cacao density and the long-term stabilized yields were important facets of the cacao growing model of Central Cameroon. This was in opposition to that of Côte d'Ivoire and Indonesia (Jagoret et al. 2011). These authors further indicated that in Central Cameroon the cacao tree stands are the main components of the complex agroforestry system with high agrobiodiversity (15 to 26 tree species per cacao agroforest) that mitigated the clearance of forests for new plantations. Michel et al. (2019) indicated that the old Amelonado variety is predominant in the Akongo (Nyong and So'o departments of South-Central Cameroon; 94%) and Mintom (Dja-et-Lobo department of South Cameroon; 79%) but was fairly represented in Obala (Lekié department of Central Cameroon; 65%) and scarce in the Talba (Mbam-et-Kim department of Central Cameroon; 26%) agroforestry regions. Hybrid varieties were present in the more recently planted sites of Mintom and Talba (Michel et al. 2019). In the four studied areas of Central and South Cameroon, the oldest farms were in Obala but had the highest percentage of renewed and young cocoa stands while Talba had the youngest cacao trees (Michel et al. 2019).

Jagoret et al. (2012) reported on the innovative approach of the cacao agroforestry system on grasslands in the forest-savannah interface in Cameroon. This soil-climate zone is considered unsuitable for cacao cultivation, but the afforested cacao grassland using an agro-successional strategy enabled the growth of viable cacao plantations with similar marketable cacao yields to that of nearby gallery agroforest and in forested areas in central and southern Cameroon (Jagoret et al. 2012).

Genetic Studies

Efombagn et al. (2006) assessed samples from major Cameroonian cacao-growing regions using 13 SSR primers. These included 194 on-farm accessions from the South Province (Dja-et-Lobo, Vallée-du-Ntem, Mvila); Center Province (Mefou-et-Akono, Lekié, Mbam-et-Inoubou, Mbam-et-Kim, Nyong-et-Mfoumou, Centre Nyong-et-So'o), and the East Province (Haut-Nyong, Lom-et-Djerem). The survey also included 71 breeders' accessions from IRAD (Institute for Agricultural Research for Development), Cameroon, which included Trinitario clones (SNK – Selection of Nkoemvone); F1 hybrid genotypes (SNK600 series), and Upper Amazon Forastero clones (UPA and T-clones) (Efombagn et al. 2006). The samples from the Center and South provinces grouped with the SNK600 hybrids that developed from a cross between local Trinitario and Upper Amazon genotypes. These two regions were similar but apart from the East province that was mainly grouped with the local SNK Trinitario, the T-clones and the other Upper Amazon clones (Efombagn et al. 2006). However, the authors indicated that there was a poor adoption of progenies from these T-clones.

Efombagn et al. (2008) using 12 microsatellites demonstrated that 400 farmer selections from Southern Cameroon were admixed mainly from Amelonado (48%), Upper Amazon Forastero (33%; Contamana, Iquitos, Marañon, Nanay) and Criollo (7%) ancestries. These authors suggest that the traditional Trinitario have nearly disappeared from farmers' fields due to hybridization in seed gardens and farmers' fields and the use of seeds from within and between neighboring estates as the main source of planting material. The SNK accessions were mainly Amelonado mixed with Criollo (Efombagn et al. 2008). Mfeck Eyenga et al. (2017), from a survey of 100 farmers in the Center Region, found that while the hybrids used on farms had increased yields in general, the yield increase was not sufficient to recommend the widespread use of these varieties.

Efombagn et al. (2009) examined 300 farm accessions across the Southern and Western regions for 17 traits from leaf, flower, fruit and seed and an unspecified number of microsatellite markers. In general, the Southern and Western regions were similar across all traits although the authors claim that these two regions could be differentiated on quantitative pod traits. However, examination of the means and standard errors showed that this was only noticeable for fruit width and fruit mass. The latter is known to be greatly affected by environmental conditions. Further, the authors claimed that the principal component analysis of the phenotypic diversity demonstrated a separation of the two regions. This was not observed in the actual figure, and overlap in all four quadrants was present. The microsatellite analysis also supported the non-separation of these two regions.

Highlighted Cultivars

Youbi et al. (2018) found that the variety SNK 413 had triple the yield of BAT 1, a local variety in the Center Region of Cameroon. This suggests that this SNK hybrid may be an elite cultivar among the general hybrids.

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Cameroon were selected in the best 50 International Cocoa Awards for 2010 (three batches), 2011 (three batches), 2013 (two batches), 2019 (one batch) and 2021 (one batch) with 1, 1, 0, 0 and 1 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a mixed but mainly Forastero cacao batch from Nkoldja, Meyomessala, Dja Et Lobo, Sud Region, had strong cocoa; moderate roast, bitterness and astringency; low acidity, fresh fruit, brown fruit, floral, spice and woody flavors; and an absence of nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Didipe, Nkondjock, Nkam, Littora, was given the following flavor profile description: "Clear chocolate aroma with direct chocolate flavour emerging quickly. Low and balanced bitterness and astringency. Overall smooth profile with lower levels of brown fruit (dates) and dried fruits and a clear dark wood background note." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

CONGO

Congo (#12 in Fig. 22) produced 4,000 metric tons of cocoa in 2021, ranking 28th out of 59 producing countries (World Population Review 2022). In 2020, Congo exported US$42.9 million in cocoa beans, making it the 16th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/cog). Congo, formerly a French colony, is located on the western coast of Central Africa and is bordered by Gabon, Cameroon, Central African Republic, Democratic Republic of Congo (DRC) and the Angolan exclave of Cabinda. Nieburg (2017) summarized this country's cocoa history, stating that the crop was introduced in the late 19th century, when the country was the private colony of Belgium's King Leopold II. During the 1920s and 1930s, after DRC became a Belgian colony, organized cocoa plantations began, with plantings of around 20,000 ha along the Congo River.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

DEMOCRATIC REPUBLIC OF CONGO

Overview

The DRC produced 3,758 metric tons of cocoa in 2021, ranking 29th out of 59 cocoa producing countries (World Population Review 2022). In 2020, DRC exported US$80.6 million in cocoa beans, making it the 14th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/cod). A former Belgian colony, the DRC is in central Africa and shares borders with Sudan, Uganda, Tanzania, Angola, Congo and Central African Republic.

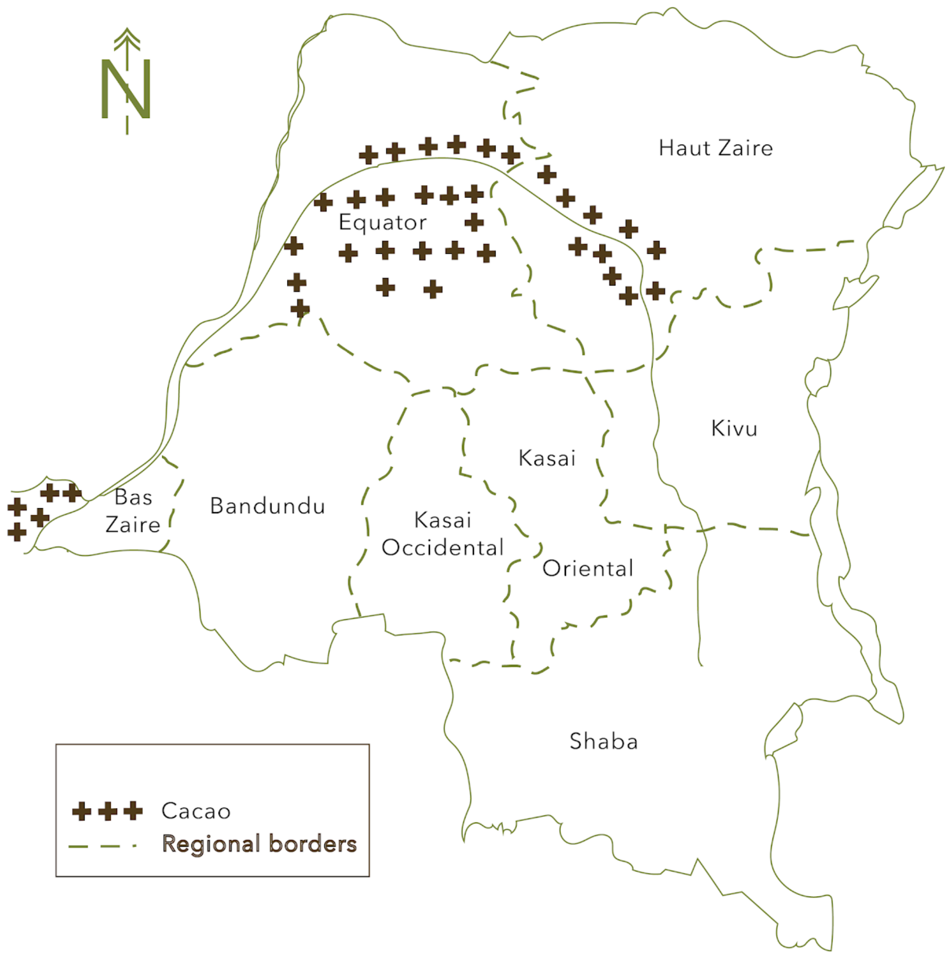


Figure 23
Map of cacao-producing regions in the Democratic Republic of Congo. Adapted from Anon (1987)

Historical Introductions

Nieburg (2017) and Rottiers et al. (2018) summarized this country's cocoa history, stating that the crop was introduced in the late 19th century, when the country was the private colony of Belgium's King Leopold II. During the 1920s and 1930s organized cocoa plantations began with plantings of around 20,000 ha along the Congo River (Nieburg 2017). The planting material was sourced from Sao Tomé (Brazilian Amelonado and other varieties from Ecuador, Trinidad and Venezuela) and first planted at Lukolela, along the Congo River, and Mayumbe, at the mouth of the river (Rottiers et al. 2018). The Congolese government set up research stations and botanical gardens at Ganda-Sundi (Mayumbe), Barumbu, Lukolela, Eala, Gazi and Yangambi, where breeding and selection experiments were carried out (Rottiers et al. 2018). In 1915, Amelonado was crossed with a red-fruited Ecuadorian Nacional and achieved highly productive offspring with large fruits, but in contrast Criollo progeny never performed well in DRC (Rottiers et al. 2018).

Collections

The Institut National pour l'Etude de la Recherche Agronomiques (INERA) still houses some old trees, thought to be related to the first trees introduced into Belgian Congo.

Recent Cultivation

By 1987 cacao was grown in the regions at the equator (Budjala, Bumba, Bikoro, Boerde, Lukolela and Lisale), Bas-Zaire (mainly located between Boma and Tshele) and Haut-Zaire, the forest region (Kisangani region and the Uele) (Fig. 23). Cacao was introduced to Eastern Congo in 1998 by the private company Edmond Schluter et Compagnie in North Kivu (ESCO Kivu), which distributed improved germplasm, leading to North Kivu becoming the main cacao-producing region (Rottiers et al. 2018).

Genetic Studies

Rottiers et al. (2018) examined 62 of the trees at INERA with 14 microsatellites. These authors showed that the INERA trees were distinct from the population references and Trinitario samples and clustered into two groups. One group had ancestries from Amelonado, Trinitario, Marañon and Nanay, whereas the second group had ancestries from Amelonado, Nanay, Contamana and Nacional. One accession, CRY 1323, was associated with the Criollo-Trinitario material. Two accessions, CRY12 and CRY14, were closely related to the Nacional references EET 19 and EET 183.

Flavor Quality

Over the period from 2010 to 2021, a batch of chocolate sample from Congo DRC was selected for the best 50 International Cocoa Awards for 2013 but did not win (CoEx 2013).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

EQUATORIAL GUINEA/BIOKO

Overview

Equatorial Guinea (#9/#7 in Figure 22), a former Spanish colony, is located between Cameroon and Gabon on the west coast of Central Africa. Bioko (previously Fernando Pó or Fernando Poo) is an island off the west coast of Africa close to Sao Tomé and Principe. Bioko is now part of the country of Equatorial Guinea. Equatorial Guinea produced 413 metric tons of cocoa in 2021, ranking 41st out of 59 cocoa producing countries (World Population Review 2022). In 2020, Equatorial Guinea exported US$39.7 million in cocoa beans, making it the 18th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/gin).

Historical Introductions

Bioko was first a Portuguese and then a Spanish colony. Cook (1982) stated that Amelonado cocoa from eastern Venezuela was introduced to Fernando Poo by Spaniards in the 17th century. In 1854 cacao was introduced from Principe (Wood 1991) or Sao Tomé (Swarbrick et al. 1964 cited in Toxopeus 1971; Aikpokpodion 2012). Lockwood and End (1993) indicated that the introduced cacao was Amazonian in nature.

Details about the number of plants moved were not provided by the authors (Olasupo and Aikpokpodion 2019; Wood 1991). In 1866 the "Gobierno de la Metrópoli" brought cacao from Caracas (Venezuela) and Guayaquil (Ecuador) (Rodríguez 1924). In the 1880s seeds were obtained and planted from the germplasm in Sao Tomé that originated from Ecuador, Trinidad and Venezuela (Aikpokpodion 2012). A map of the cocoa farms on the island in the 1950s is provided (Fig. 24).

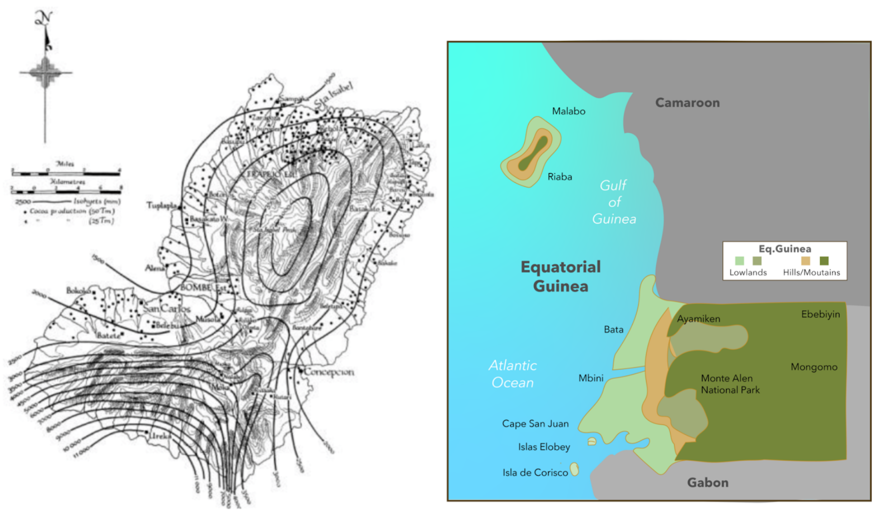


Figure 24 Map of Bioko and Equatorial Guinea
Left - Map of Bioko (previously Fernando Po or Fernando Poo) showing mean annual rainfall and cacao production. Modified from Thorold (1955).
Right - Bioko positioned with respect to Equatorial Guinea.
Map adapted from World Atlas

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

GABON

Overview

Gabon (#11 in Fig. 22), formerly a French colony, is bordered by Equatorial Guinea, Cameroon and Congo on the west coast of Africa. Gabon produced 187 metric tons of cocoa in 2021, ranking 50th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Gabon exported US$94,200 in cocoa beans, making it the 70th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/gab).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Gabon were selected for the best 50 International Cocoa Awards in 2010, 2011 and 2013, but none of the three batches secured a win (CoEx).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

GHANA

Overview

Several European powers (England, Portugal, Spain, France, Holland, Germany, Sweden, Denmark) established a presence in Ghana. A former British colony, Ghana is bordered by Ivory Coast, Burkina Faso and Togo on the west coast of West Africa (#4 in Fig. 22).
Ghana currently has 16 administrative regions (www.ghanamissionun.org/map-regions-in-ghana/; Fig. 25). Ghana produced 883,652 metric tons of cocoa in 2021, ranking 2nd out of 59 cocoa producing countries (World Population Review 2022). Contrariwise it was listed as the third top cocoa producer in the world by the Chocolate Codex. In 2020, Ghana exported US$1.28 billion in cocoa beans, making it the 2nd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/gha). Ghana's industry started on a putatively pure Amelonado base, which is currently being replaced with hybrids of various ancestries.

Historical Introductions

Some researchers stated that in 1757 Forastero type was introduced to Ghana from Venezuela; however, others affirm that cocoa introduction was carried out in 1868 by the missionaries of the Basel Mission of Akropong. In 1857 there was an unsuccessful attempt by the Basel Missionaries to establish seeds from Suriname, which they followed up with a more successful introduction in 1861 of Amelonado cacao from Sao Tomé and Principe (Aikpokpodion 2012). The Basel Mission at Akropong (in Akwapim, Eastern Province) reportedly in 1868 had a few cacao trees (Howes 1946). "Tetteh Quarshie," a native, who was from the Basel Mission, brought cacao from Fernando Poo in 1875 (Bardin 1937), 1878 (Lockwood and Gyamfi 1979; Edwin and Masters 2005; Aikpokpodion 2012) or 1879 (Howes 1946; Cook 1982). Bardin (1937) reported the name as "Tette Kwesi;" the seeds were planted in his garden in Mompong/Mampong in the Akwapim mountains in the east (Bardin 1937; Edwin and Masters 2005) and he distributed seeds of the first fruits to his friends. The Amelonado cacao from the "Tetteh Quarshie/Tette Kwesi" farm reportedly spread throughout Ghana by farmers purchasing fruits from the farm (Opoku et al. 2007). The cultivation of cocoa developed around the village and expanded through Koforichna, and from Tafo to Ashanti region, which today is the main cocoa producing area of Ghana (Effiom n.d.; Fig. 26).

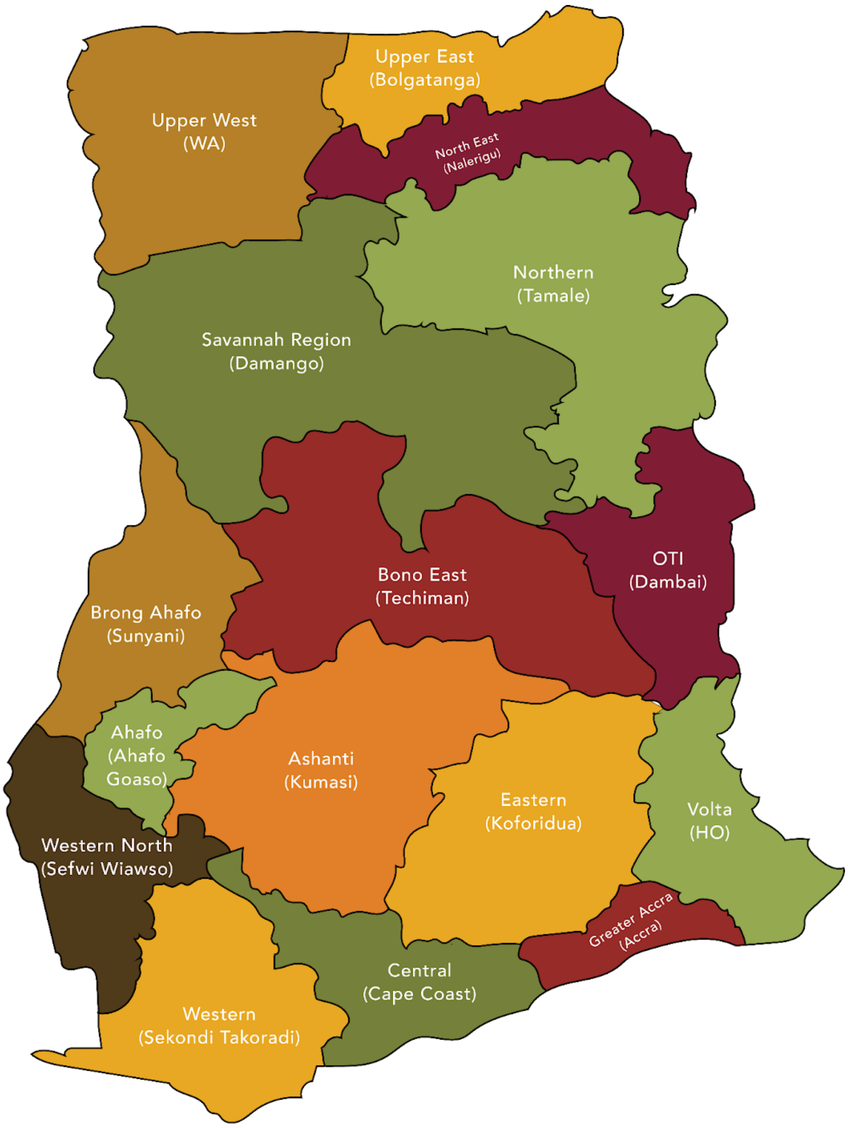


Figure 25
Administrative map of Ghana
Adapted from Ghana Mission UN

Edwin and Masters (2005) indicate that Amelonado cacao was brought in before 1887 from Equatorial Guinea. Cacao farms were first established in the Eastern Province, initially expanded into the Ashanti region and moved westward from the late 1930s into Brong-Ahafo, Central and Western regions (Anti-Slavery International 2004).

Later introductions occurred by the governor in 1887 and by missionaries in the early 1900s as Trinitario and West African Amelonado (Lockwood and Gyamfi 1979). Cacao from Sao Tomé was introduced to Aburi Botanic Gardens in the 1880s (Legg 1972), 1887 (Aikpokpodion 2012) or by 1890 (Posnette and Todd 1951), and a large quantity of seed from these plants was distributed (Posnette and Todd 1951). European cocoa plantations started as early as 1890 and survived into the 1940s (Anti-Slavery International 2004). Edwin and Masters (2005) indicated the introduction of Trinitario cacao during the period of 1900 to 1909 from Jamaica, Trinidad and Venezuela. In 1900 and 1901 Cundeamor and Pentagonum Nicaraguan cacao from Trinidad and Red Forastero, Criollo and White variety of a Caracas type from Jamaica were obtained from the Royal Botanic Garden England (Aikpokpodion 2012). In 1903, further introductions from Trinidad involved Ocumare, Trinidad Criollo, Nicaraguan Criollo, Red Criollo and Yellow Criollo varieties that were established at Aburi Botanic Garden (Aikpokpodion 2012). Similarly, but not exactly, Lockwood and Gyamfi (1979 cited in Abdul-Karimu et al. 2006), indicated that in 1901, 1905, 1906 and 1909 Pentagona, Ocumare, Cundeamor and Criollo respectively were introduced to Aburi Botanic Gardens. These materials were reportedly "largely self-incompatible" and the likely ancestors of the red-fruited trees in Ghana (Aikpokpodion 2012).

Green and Hymer (1966) caution that there were historical inaccuracies in the official versions of cacao introductions and industry growth and that more credit to cacao movements needs to be given to Ghanaian smallholders. Green and Hymer (1966) further suggest that there was too much emphasis on the one Tette Kwesi/Tetteh Quarshie/Teteh Quashi but that instead Ghanian workers employed mainly as artisans and craftsmen in Nigeria, the Cameroons, Sao Tomé, Fernando Po, Principe and the Congo Free State brought knowledge and interest in cacao farming when they returned to Ghana. Nevertheless by the early 1940s nearly 95% of the cacao trees in Ghana were believed to be West African Amelonado (Abdul-Karimu et al. 2006).

"New plantings" made with a variety called Amazon (Pound collection of the University of West Indies-Upper Amazon River area) was the most successful introduction (Wood 1991). Posnette (1943) collected Amelonado and Trinitario from botanic gardens, experimental stations and farmers' fields to establish a germplasm collection. The recognition of cacao swollen shoot disease and its spread led to the eradication of dead, infected and neighboring cacao trees from 1936 and replacement with hybrid trees (Legg 1972). Opeke (1972a) indicates that the first batch of introductions from Trinidad was from 121 ripe fruits from Pound's Amazon collection but does not specify the year of introduction. In 1944 Upper Amazon cacao from Trinidad was introduced to Ghana (Pound 1938; Posnette 1948; Lockwood and End 1993) from 100 fruits (Toxopeus 1985b). The progeny came from seven Upper Amazon Forastero (IMC 60, NA 31, NA 33, NA 34, PA 7, PA 35, SCA 12) parents (Toxopeus 1968). Some of the seeds were planted at Mampong-Akwapim in Ghana (Wood 1991). This Upper Amazon material was used to create various hybrids that were distributed throughout Ghana (Opoku et al. 2007 and references therein). By the late 1950s, some 11 selected Upper Amazon types were used to produce second and third generations of Amazon known as F3 Amazon or Mixed Amazon and were distributed to farmers (Steijn 2018). Edwin and Masters (2005) also indicate the introduction in the 1950s of mixed Amazon material from Peru via Trinidad. Hybrids (originally Series II Hybrids) were developed from 1966 to 1970 among the Peruvian Upper Amazon material and Amelonado or Local Trinitario material (Edwin and Masters 2005). This was followed by the Modified Series II hybrids developed from 1971 to 1985 among the Upper Amazon and Amelonado cultivars; the

Inter-Amazon varieties in the 1980s, and mutant hybrids from irradiation in the 1990s (Edwin and Masters 2005).

Recent Cultivation

Cacao cultivation is carried out in the Ashanti, Brong Ahafo, Central, Eastern, Volta and Western regions (Appiah et al. 1997; Aikpokpodion et al. 2009). Cacao cultivation is concentrated in the Western Region of Ghana, where the soil is generally unsuitable for cacao farming (Appiah et al. 1997) but accounts for 50% of the Ghana's total production (Richard and Ræbild 2016). Hybrid varieties developed by the Cocoa Research Institute of Ghana (CRIG) were adopted by a third of Ghanian farmers (Padi and Owusu 1998 cited in Gockowski et al. 2011), 57% by 2002 (Asante-Poku and Angelucci 2013 cited in Steijn 2018) and 41% adoption by 2007 (Opoku et al. 2007). The majority of farmers select planting material from seeds on their own or neighboring estates (Opoku et al. 2007). In 2017, the Ghana Cocoa Board reportedly freely distributed 60 million seedlings and 400,000 pieces of hybrid seedlings (Godfred 2017). In 2020/2021, the Ghana Cocoa Board was expected to distribute 92 million seedlings that are high-yielding, early bearing and disease-tolerant to rehabilitate farms with aged and diseased cacao trees (Ghana Cocoa Board 2021b). Wiredu et al. (2011) in a study of 366 farmers in the Ashanti region of Ghana found that 39% have replanted old cocoa farms and 43.7% of these farmers use hybrid varieties but on 11% of the cocoa land area. In the Western, Brong-Ahafo and Ashanti regions about 49% of farmed cacao are hybrids (Kolavalli and Vigneri 2017). Bymolt et al. (2018) found that the Amelonado "Tetteh Quarshie" was produced by 15%, Amazonia cultivars by 42% and hybrid varieties by 66% of the 1,560 surveyed households. Organic cacao farming, carried out on about 600 ha in Brong Densuso in the Eastern region, is facilitated by the use of sex pheromones, neem seed extract and a predatory ant, Oecophylla longinoda, to control capsid damage (Ayenor 2006).

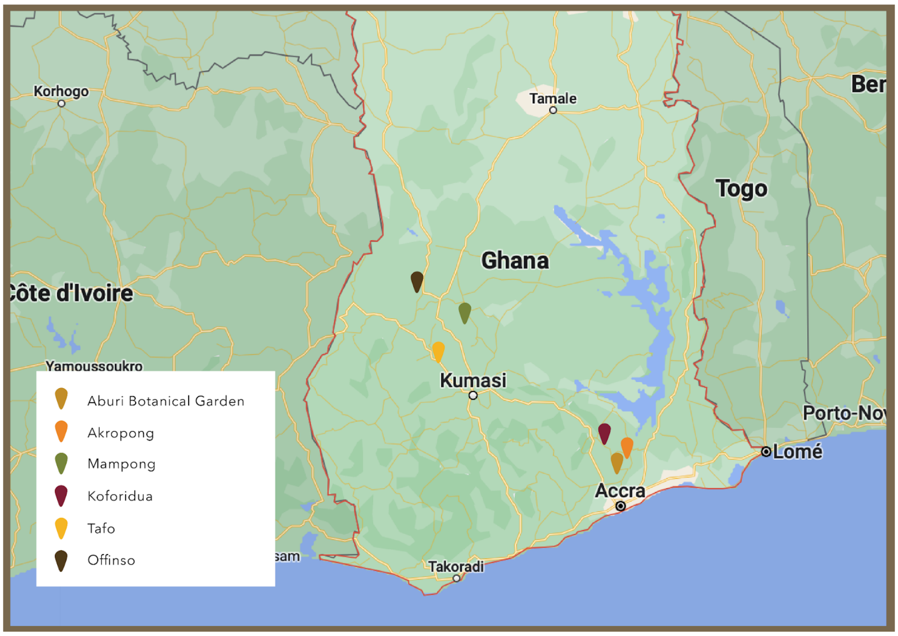


Figure 26
Approximate locations of historical cacao sites in Ghana.
Mampong is the site of Tette Kwesi's farm. Koforidua is used as a place holder for Koforichna (see Effiom nd) as it is one of the oldest cacao growing areas in Ghana (https://www.britannica.com/place/Koforidua)
Map extracted 11 September 2021 from google.com/maps. Map data © 2021 AfriGys (Pty) Ltd GeoBasis - De/BKG (©2009) INEGI.

Genetic Studies

Opoku et al. (2007) sampled 235 trees from farmers' fields throughout the cacao-growing regions, 104 trees from breeders' seed gardens, and 38 parental clones used in breeding at CRIG (Fig. 27).

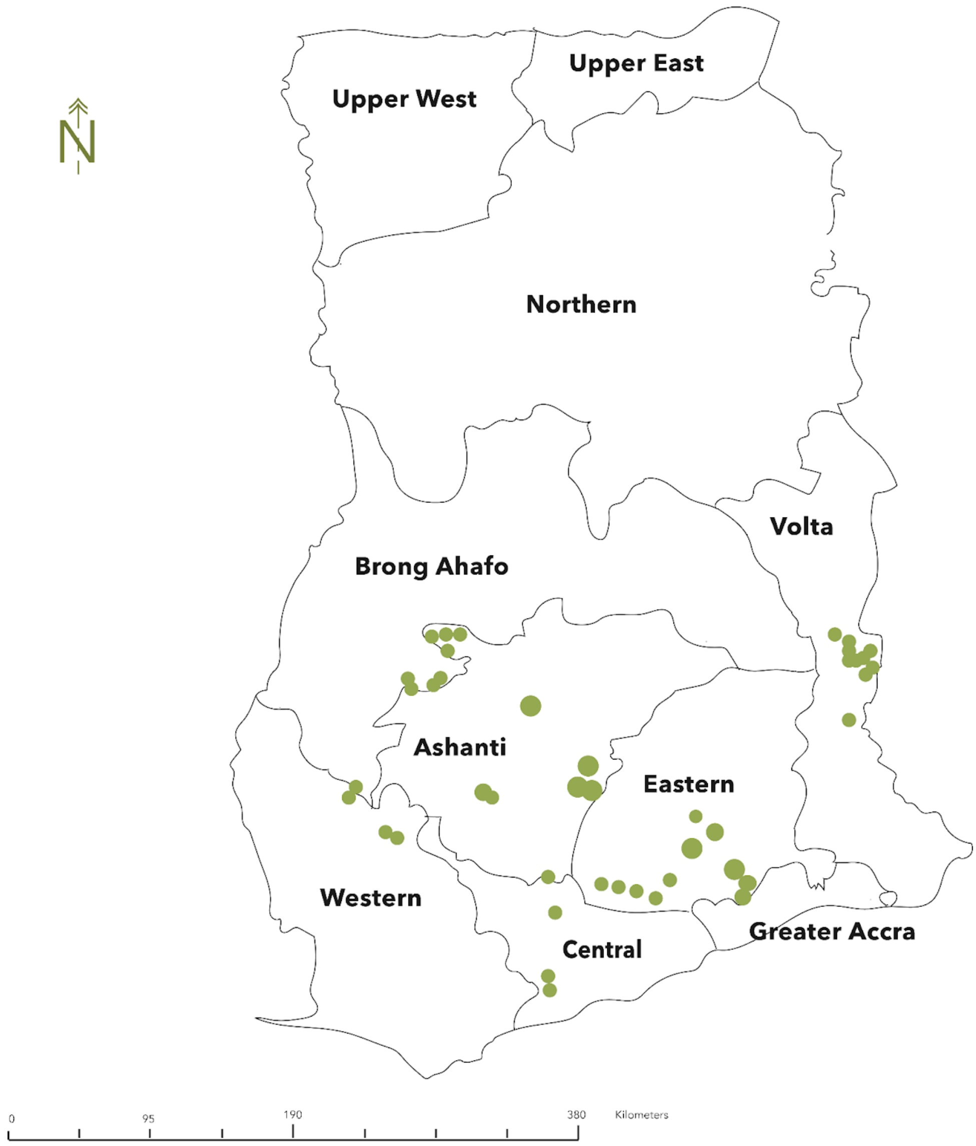


Figure 27
Sampled areas of 377 accessions from cocoa growing regions and genebank of Cocoa Research Institute of Ghana. Samples included trees from Aburi Botanic Garden and Tette Kwesi's farm. Map modified from Opoku et al. (2007)

The samples were analyzed using 17 microsatellite markers and revealed two main clusters. The accessions on Tetteh Quarshie farm and Aburi Botanic Garden clustered together apart from the other samples. These sites had the earliest original introduced cacao trees and the difference is indicative that all other farm materials are now different. The other cluster of farm material, parental and breeders' clones had three main subclusters representative of the use of hybrids obtained either from private farms or from government sources. One subcluster was only composed of farm samples from the Western region, indicative of less impact from early distribution of germplasm from breeders' seed gardens. Opoku et al. (2007) reported that the Western region had the most recently improved material. Another subcluster contained the local Amelonado, Trinitario, hybrids and farm material from Brong Ahafo. Opoku et al. (2007) indicated that most of the planting in this region occurred when hybrids from biclonal seed gardens were being developed and, being popular, were likely to be the source of planting material. The other subcluster contained the Upper Amazon material and farm selections from the Eastern, Central, Ashanti and Volta, with the latter three being a tight grouping. Opoku et al. (2007) indicated that these regions were the earliest cacao-growing regions. This agreed with the closer ties to the early Upper Amazon material brought in 1944.

Aikpokpodion et al. (2009) sampled a total of 578 cacao accessions from gene banks in the four West African cacao-growing regions (Ghana, Nigeria, Cote d'Ivoire and Cameroon) and commercial farm plantations and analyzed them using 12 SSR markers. The accessions were categorized as either parental clones (introduced Upper Amazon clones represented by IMC, Nanay, Parinari and Scavina) or local clones (a mixture of local Amelonado and local Trinitarios as well as ICS Trinitario). Farms representing the eight cacao-growing regions (Tetteh Quarshie Farm, Aburi Gardens, Volta Region, Central Region, Eastern Region, Ashanti Region, Brong Ahafo Region and Western Region) were sampled across three agro-ecological zones (ideal cocoa climate ecology, ideal cocoa soil ecology, and marginal cocoa ecology). The farmer populations sampled from the ideal soil ecology were similar to the local Trinitario and the ICS Trinitario from the parental clone grouping. The samples from the ideal climate ecology were similar to the F3 Amazon progenies (T-clones/Posnette introductions) and the introduced Upper Amazon clones. The marginal cocoa ecology samples were most closely related.

Takrama et al. (2014) used 53 SNP markers to examine 160 trees of 39 accessions, including 10 of the T-clones, from the CRIG germplasm collection. Correct representatives of reference accessions were found and the ancestry of the T-clones matched to their recorded pedigree with Iquitos, Marañon and Nanay. Padi et al. (2015), using 66 SNPs, showed that 220 progeny of 11 full sib families had the expected main contributions of Amelonado, Nanay and Iquitos. However, the female parents as opposed to the male parents had a better match to their expected ancestry from the breeding records. Progeny that arose from crosses with these suspect parents were found to have parental contributions from known or unknown accessions that were in the same or different population groups.

Highlighted Cultivars

Ofori et al. (2020) compared crosses of Ghanaian seed garden parents with eight Guiana clones and evaluated the progeny for yield and resistance to black pod rot. Progenies PA 150 × GU 290/H and PA 150 × GU144/C were common best performers in yield and black pod incidence. Progeny from PA 150 × GU 290/H had also been previously identified by the same authors' earlier work as highly resistant to cacao swollen shoot virus (Ofori et al. 2015).

Flavor Quality

Camu et al. (2018) showed that flavor profiles of chocolates from two farms (New Tafo and Old Tafo, 15 km apart) differed by farm especially for sour note and exhibited a seasonal effect with mid crop being different from main crop within a farm, especially for the farm in Old Tafo for fruity, cocoa and flowery notes. The highest cocoa, fruity and flowery notes were from the Old Tafo farm and the highest acidity from the New Tafo farm (Camu et al. 2018). Gockowski et al. (2011) recommended empirical testing of the flavor of cocoa beans in all districts to select superior beans for the production of premium chocolate. This appeared feasible based on the likely profitability of a high input fine flavor system and the production by Scharffen Berger Hershey Chocolate Ltd. of a premium chocolate bar after sampling 40 different Ghanaian cocoa lots. Ghanaian cocoa has an international reputation for absence of defects, high fat content and consistently good flavor (Ministry of Agriculture 2012). Organic cocoa production started in 2007 and is concentrated in the Eastern region (Onumah et al. 2013). A fine flavor initiative started in 2008 in Offinso in the Ashanti region (Ghana Cocoa Board 2021a). This initiative currently produces about 30 metric tons of a premium variety of cacao and is expected to increase as three other sites with good soils were identified (Ghana Cocoa Board 2021a). Daniels et al. (2012) selected 27 potential fine flavor clones from CRIG gene bank for evaluation and eight of these were chosen for their fine flavor notes. One sample was said to be unanimously rated for having floral notes coupled with unusual fruity notes such as apricot, citrus and apple.

A putative batch of West African Amelonado from Ghana sample was associated with woody and burnt flavors with low winey and acid-fruity/citrus flavors (Sukha et al. 2008). Over the period from 2010 to 2021, chocolate samples from Ghana were selected for the best 50 International Cocoa Awards for 2010 (three batches), 2011 (two batches), 2013 (two batches), 2015 (one batch), 2017 (three batches), 2019 (three batches) and 2021 (three batches) with 1, 0, 1, 1, 1, 1 and 3 wins respectively. There were three top-50 samples in the 2019 Cocoa of Excellence (CoEx 2019). Chocolate was made from a Forastero cacao batch from Nobi, Abuakwa North, Eastern region, with strong cocoa; moderate roast, bitterness, astringency, fresh fruit and brown fruit; and low acidity, sweet, floral, spice, woody and nutty flavors (CoEx 2019). The second chocolate entry was made from a Forastero batch from Tikobo 2, Elubo, Western region, with strong cocoa, moderate roast, bitterness, astringency and brown fruit; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019). The third chocolate was made from a Forastero batch from Toobotoobo, Elubo, Western region, with strong cocoa; moderate roast, bitterness, astringency and brown fruit; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from Tetekasum Amanfrom, Suhum, Eastern region, was given the following flavor profile description: "Dark brown color. Rich, deep cocoa/chocolate notes emerge early and are sustained to the finish with low bitterness and astringency throughout. Mild fruit acidity with dark fresh fruits and browned fruits (raisin) and spice notes provide a textured floor for the chocolate notes. Clean and bright with harmony and balance and a long, rich aftertaste" (CoEx 2021). Another entry from Amanfrom, Suhum, Eastern region, was given this description: "Medium-reddish brown color. Deep chocolate base notes with balanced bitterness and astringency and a fruit/acetic mild acidity with a unique and complex trace fresh fruit, browned fruit, green-vegetal, dark wood, and spice notes. Long, balanced and complex finish" (CoEx 2021). The third winning sample in 2021 was from Offinso South Municipal, Ashanti, and was given the following flavor profile description: "Slightly lighter in colour, trace yellow hues, smooth, easy melt in the mouth. Chocolate note emerges quickly with mild fruit acidity and a complex range of fresh fruits, browned fruits, green-grassy, wood, spice and nut skin notes. Bitterness is balanced with a slightly high astringency. Complex." (CoEx 2021).

Recommended Collection

Old Amelonado and Trinitario cacao should be re-evaluated in farms in and around Tette Kwesi's farm in Mompong, in Koforidua and from Aburi Botanic Garden. The Western and Brong Ahafo regions are the areas with most promise to select older material with less adulteration from Upper Amazon varieties. The recent push for organic or origin chocolate of fine flavor within a bulk cocoa-producing country should be sustained. The empirical results suggest that fine flavor can be obtained in non-traditional fine or flavor cocoa-producing countries. This would be an attractive opportunity to increase farm gate prices and improve livelihoods of smallholders in Africa. The eight fine flavor clones (Daniels et al. 2012) should be safely propagated and maintained in a gene bank. Ancestry studies to confirm parentage or lineages from descendants of ICS 1, ICS 43, ICS 95, SCA 12, SCA 6 and SCA 9 should be undertaken as these offer promise for good flavor. With the exception of ICS 1, these accessions were listed as members of the CRIG collection (Takrama et al. 2014). The white-seeded CATONGO variety was also listed by these authors. Pure stands of CATONGO trees may offer promising marketing approaches as a single-origin accession chocolate bar (white chocolate but not composed mainly of butterfat) among others. The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

GUINEA

Overview

Guinea, formerly a French colony, shares borders with Mali, Senegal, Guinea Bissau, Sierra Leone, Liberia and Ivory Coast on the west coast of West Africa. Guinea produced 10,638 metric tons of cocoa in 2021, ranking 21st out of 59 cocoa producing countries (World Population Review 2022). In 2020, Guinea exported US$39.7 million in cocoa beans, making it the 18th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/gin).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

IVORY COAST

Overview

A former French colony, Ivory Coast (#3 in Fig. 22) shares borders with Guinea, Liberia, Mali, Burkina Faso and Ghana on the west coast of West Africa. Ivory Coast produced 2,034,000 metric tons of cocoa in 2021 (World Population Review 2022) and is the foremost cocoa producer in the world (World Population Review 2022; Chocolate Codex). In 2020, Ivory Coast exported US$3.52 billion in cocoa beans, making it the largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/civ).

Historical Introductions

Cacao was introduced either in 1870 as a garden curiosity (Cook 1982), as mainly Amelonado cacao from Fernando Po in 1879 (N'Goran et al. 1993) or 1880 (Aikpokpodion 2012). Other sources put the introduction in 1880 (Bardin 1937; de Planhol 1947; Burle 1961) from the Gold Coast (Ghana) to the Elima plantation in the East region (Bardin 1937; Burle 1961). In contrast, Chauveau (1993) and Chauveau and Léonard (1996) stated that the first coffee and cocoa plantations occurred in the southwest rather than the southeast. In the 1890s, the Kru people living on the frontiers of Liberia and Ivory Coast in the region of Tabou were said to be growing cocoa and coffee for export (Chauveau and Léonard 1996). Cacao is said to come to Ivory Coast from the forest region of Aivo, Sierra Leone, Togo and Benin (Effiom n.d.). In 1895 a small plantation was created on the lagoon Potou in M'Bato (southeastern Ivory Coast); in 1897 some cocoa trees were planted in Dabou (southern Ivory Coast), and between 1895 and 1898 Anglican missionaries brought the cocoa tree to Grabo (southwestern Ivory Coast) (Bardin 1937). In 1905 William Gaume, a "Fanti" native of Ghana, planted the seeds of a few fruits from Ghana in Tiassalé in southern Ivory Coast, which grew into very vigorous plants (Bardin 1937). In October and November of 1908 some 11,760 fruits were freely distributed and originated from the Elima plantation (2,000 fruits), the M'Bato plantation (3,000 fruits), Liberia and Ghana (4,000 fruits), and Gabon (2,760 fruits) (Bardin 1937). The next year 35,500 cacao fruits from Gabon were received and distributed free of charge, which European settlers exploited to create plantations (Bardin 1937). In 1910 the plantations of M'Bato and Elima and areas of Tiassalé and Prallo provided 5,132 fruits for distribution (Bardin 1937). These fruits from 1870/1880 to 1910 would have all been from open pollinations. Hybrid varieties were introduced in 1950 (Bruno et al. 2015) and in 1954 as progenies from Upper Amazon crosses in Ghana (N'Goran et al. 1993). N'Goran et al. (1993) indicated that the old red-fruited Trinitario material was introduced from Cameroon and Nigeria.

Collections

In 1947 and 1953 cacao germplasm as open-pollinated progenies of selected trees was collected from old farms (N'Goran et al. 1993). This germplasm set was subsequently enhanced with Lower Amazon germplasm from neighboring countries and South America (N'Goran et al. 1993). Recent Trinitarios like ICS, GS and UF as well as a few Criollo cultivars were said to be present in the germplasm collection (N'Goran et al. 1993).

Recent Cultivation

The pioneer front of cacao expansion in forested areas in the 1950s to 1980s from the center to the southwest regions of Ivory Coast was faster and more intense than in other West African countries, leading to Ivory Coast becoming the world's largest cocoa supplier (Chauveau and Léonard 1996). The main cocoa production sectors have progressed from the East (before 1960) to the Center-West (1960 to 1980), and then the southwest and the west of the country (from 1980) (Assiri et al. 2016).

Genetic Studies

In a survey of 90 rehabilitated farms, unselected hybrids (76.7%) and Amelonado (45.6%) were the main types found (Assiri et al. 2016). However, in a survey of 800 farmers distributed across the 10 regions of the three main producing areas (East/South East, Centre-West, Southwest/West), planting material was mainly unselected varieties (52%) and mixed varieties (30%) with minor contributions from selected varieties (10%) and Amelonado (8%) (Assiri et al. 2009). Similarly in the Kokoumbo region a survey of 103 agroforestry farmers in the forest-savannah zone revealed that they planted three main types: Amelonado, Upper Amazon Forastero and their hybrids, and a hybrid mixture of Upper Amazon Forastero, Amelonado and Trinitario (Yao et al. 2016). Bruno et al. (2015) and Ruf (1991) contend that the introduction of hybrid varieties led to the progressive disappearance of the complex agroforestry systems in Côte d'Ivoire. However, these systems persist in the forest-savannah transition area (Bruno et al. 2015).

Highlighted Cultivars

Around 2007 to 2012, a new hybrid, 'cocoa Mercedes,' selected for early bearing (18 months) and productivity (3 tons per ha per year), was freely distributed and expected to become the industry base (Steijn 2018). Bymont et al. (2018) found that the varieties used were Amazonia a.k.a. Ghana variety (45%), Cacao Français a.k.a. Amelonado with Trinitario (19%), hybrids (7%) and second-generation hybrids like the Mercedes (5%) by the 1,485 surveyed households.

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Ivory Coast were selected in the best 50 International Cocoa Awards for 2010 (eight batches), 2011 (four batches), 2013 (four batches), 2015 (two batches), 2017 (three batches), 2019 (three batches) and 2021 (one batch) with 1, 1, 2, 2, 0, 1 and 1 wins respectively.

There were three top-50 samples in the 2019 Cocoa of Excellence (CoEx 2019). One was chocolate made from a Forastero cacao batch (CNRA cultivar) from Azaguié, Abé begnini, Lagunes, Agnéby-Tiassa, with moderate cocoa, roast, bitterness, astringency, brown fruit and floral flavors; and low acidity, sweet, fresh fruit, spice, woody and nutty flavors (CoEx 2019). The second was chocolate made from a Forastero cacao batch from Daako, Niafouta, Hiré, Divo, Lôh-Djiboua, with strong cocoa; moderate roast, bitterness, astringency and brown fruit; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavours (CoEx 2019). The third was chocolate made from a Forastero cacao batch from Divo, Irporia, Gôh, Lôh-Djiboua, with strong cocoa; moderate roast, bitterness, astringency, acidity, fresh fruit and brown fruit; and low sweet, floral, spice, woody and nutty flavours (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Tankessé, Tanda, Gontougo, was given the following flavor profile description: "dark colour with moderate chocolate aroma; smooth, rich chocolate base note with balanced bitterness and astringency; mid-taste presents clear brown fruit with mild earthy / mushroom and dark wood notes. Some trace nut notes along with spice (tobacco) notes" (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

LIBERIA

Overview

Liberia (#2 in Fig. 22) had Portuguese, Dutch and British interests but became colonized by the United States of America. Unlike other African countries, Liberia was not a formal colony and was independent since 1847, when it was founded (Skoog 2016). Liberia is bordered by Sierra Leone, Guinea and Ivory Coast on the west coast of West Africa. Liberia produced 8,552 metric tons of cocoa in 2021, ranking 22nd out of 59 cocoa producing countries (World Population Review 2022). In 2020, Liberia exported US$32.8 million in cocoa beans, making it the 20th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/lbr).

Historical Introductions

In the early 1860s, possibly 1861, Amelonado cacao was imported from Sao Tomé (Aikpokpodion 2012). Since the 1900s, cacao has been cultivated in Liberia (ACDI/VOCA 2021).

Recent Cultivation

English (2018) indicated that in 2008 the Ministry of Agriculture estimated there were 40,000 households producing cocoa, most of them located in the counties of Bong, Lofa and Nimba. A more recent estimate is 30,000 (Karmo 2020) or 25,000 to 30,000 (Ministry of Agriculture 2012). Other counties like Grand Cape Mount have abandoned cocoa farms (English 2018). Existing cocoa trees were reportedly present since the 1970s (Karmo 2020).

Prior to 2003, improved varieties as seed stock were imported from neighboring countries (English 2018). The majority of recent plantings, however, were reportedly from unimproved varieties (Wilcox and Pay-Bayee 2006; Weise and David 2005; both cited in English 2018). In 2019, farmers in Grand Cape Mount County received 8,000 cacao seedlings (Chan 2020). As of April 2021, 600,000 hybrid cacao seedlings will be distributed to over 1,500 smallholder farmers in Grand Gedeh and River Gee counties of southeast Liberia (Koinyeneh 2021). However, neither Chan (2020) nor Koinyeneh (2021) provides any details as to the background of these seedlings. The most impactful change to the cacao industry in Liberia is suggested to come from the use of improved planting material, which is estimated in the tens of millions of seedlings (Ministry of Agriculture 2012) although seedlings from existing farmed trees may be used by farmers (Skoog 2016). Private nurseries and NGOs are reportedly producing improved cacao seeds and seedlings (Skoog 2016), but the varieties involved are not in the available documents. Similarly, new high-yielding varieties are said to have entered Liberia (Skoog 2016). Wilcox et al. (2007) indicated that improved germplasm arrived in the 1970s but was hardly used. The quality of the putatively high-yielding varieties was questioned by interviewed market actors in Skoog's (2016) study. Details on the improved varieties as to the source country, number of types, genetic background or varietal names are absent from the available documentation.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

MADAGASCAR

Overview

Madagascar (#15 in Fig. 22), a former French colony, is an island in the Indian Ocean off the east coast of Africa. Although in the same geographic region as Africa, the path of cocoa introduction is different from that of the African countries and more aligned with the Oceania/Asia region. Madagascar produced 11,010 metric tons of cocoa in 2021, ranking 20th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Madagascar exported US$29.4 million in cocoa beans, making it the 21st largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/mdg).

Historical Introductions

Criollo cacao was first planted in the 1800s on the East Coast until 1878 when Forastero was introduced (Akesson presentation). Van Hall (1914) credits Fauchére's "Culture Pratique" indicating that a red-fruited Criollo cacao was imported from La Réunion, which got its cacao from Sri Lanka. Van Hall (1914) therefore suggests that the Criollo in Madagascar is descended from the "Old Red" Criollo variety of Sri Lanka that likely originated in Caracas, Venezuela. Cacao was also imported to Madagascar from Mauritius (Akesson presentation) which together with La Reunion is an island off the east coast of Madagascar. However, Roussel (1967) states that around the 1900s the only introductions were Criollo from the West Indies but many of these failed due to low temperature and cyclonic winds except in Sambirano. In 1904, Lucien Millot established the first large cacao plantations in Andzavibe with plants imported from Java (Topik 2003). Around 1910, Forastero and Trinitario were introduced on the east coast (Roussel 1967). Cacao was said to be planted in the Sambirano Valley by Louis Millot in 1922 using material from Bohor Gardens in Java and later from the east coast of Madagascar and by Guy de la Motte Saint Pierre in 1924 and 1958 (Akesson presentation). Around the 1920s, Forastero and Trinitario were introduced into Sambirano from the east coast (Roussel 1967).

Collections

In 1966, 42 pure Criollo trees and 31 Trinitario trees (18 of which were Criollo hybrids) were identified in Sambirano (Roussel 1967).

Recent Cultivation

A survey from 1958 to 1963 found that the 700 to 800 ha in Sambirano of mature trees were mainly Trinitario (90%) with a few areas (7–8%) of Criollo and Forastero, although a few dozen hectares of pure Criollo trees (c. 30 years at the time) were present (Roussel 1967). Most of the production (95%) is centered in the Sambirano valley, Diana Region in northwest Madagascar (Duchaufour et al. 2016). Organic cacao is present e.g. the Akesson plantation in Ambanja (Davrieux et al. 2018).

Genetic Studies

Guy de la Motte Saint Pierre's 1924 plantation in Bejofo was taken over by Akesson, and cacao on this plantation was reportedly pure Criollo (Akesson presentation). Li et al. (2021) used 96 SNPs to analyze 40 farmer clones, from four traditional farms in the Sambirano valley. The results showed that the collected germplasm was Amelonado (16), Criollo (9) or Amelonado/Criollo hybrids (15) with the latter having 25% to 57% Criollo contribution.

Flavor Quality

Madagascar is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Davrieux et al. (2018) showed that light- and dark-colored beans from the organic Akeeson plantation in Ambanja under different small-scale fermentations gave similar acceptability and flavor (fruity aroma, a cocoa taste note with a balanced acidity/bitterness ratio) with the exception of one batch (notes of fresh fruit, floral and alcoholic acid).

Over the period from 2010 to 2021, chocolate samples from Madagascar were selected for the best 50 International Cocoa Awards in 2010 (three batches), 2013 (one batch), 2017 (one batch), 2019 (three batches) and 2021 (three batches) with 1, 1, 1, 2 and 3 wins respectively.

There were three top-50 samples in the 2019 Cocoa of Excellence Awards (CoEx 2019). Chocolate made from a Trinitario cacao batch with Forastero and Criollo contributions from Mangabe, Antranokarany, Ambanja, Diana, had moderate cocoa, roast, bitterness, astringency, acidity and fresh fruit flavors; and low sweet, brown fruit, floral, spice, woody, nutty and flavors (CoEx 2019). The second chocolate sample was made from a Trinitario batch from Ambohimena Sud, Ambohimena, Ambanja, Diana, with strong cocoa; moderate roast, bitterness, astringency, acidity, fresh fruit and brown fruit flavors; and low sweet, floral, spice, woody and nutty flavors (CoEx 2019). The third chocolate was made from a Trinitario batch from Antanamandrirana, Marotolana, Ambanja, Diana, with strong cocoa; moderate roast, bitterness, astringency, acidity and brown fruit; and low sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019).

One of the three winning entries in the best 50 of the International Cocoa Awards 2021 from Ambodimanga Ramena, Ambodimanga, Ambanja, Diana, was given the following flavor profile description: "Light brown color with an aroma of chocolate, dried fruits and nuts. Creamy mouthfeel. Smooth, blended chocolate note with fresh fruit acidity (underripe berries, citrus, banana and pineapple). Dried and browned fruits with nuts and caramel / panela lasting into the finish. Smooth, harmonious and balanced yet complex." (CoEx 2021). Another winning entry, from Antsatsaka, Ambanja, Diana, was given the following flavor profile description: "Medium-reddish brown color and a creamy mouthfeel. Mild overripe fruit, then traces of fresh fruit (ripe raspberries, mandarin and pineapple). Mild browned fruit with hints of nuts, nut skins, and wood. Chocolate note is moderate throughout. Finish is a mild bitter and astringent with lingering acidity and citrus fruit." (CoEx 2021). The third winning entry was from Fofifa Ankatafahely, Ambanja, Diana, and was given the following flavor profile description: "Medium-reddish brown color and a creamy mouthfeel. Mild overripe fruit, then traces of fresh fruit (ripe raspberries and pineapple). Mild browned fruit with hints of green vegetative, nuts, wood, and caramel notes. Chocolate note is moderate throughout. Finish is mild bitter and astringent caramel." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

NIGERIA

Overview

Nigeria (#6 in Fig. 22), a former British colony, shares borders with Niger, Chad, Cameroon and Benin in West Africa. Nigeria produced 328,263 metric tons of cocoa in 2021, ranking 4th out of 59 cocoa producing countries (World Population Review 2022). The Chocolate Codex also ranked Nigeria as the 4th top producing cocoa country in the world. In 2020, Nigeria exported US$489 million in cocoa beans, making it the 5th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/nga).

Historical Introductions

In 1857, the first set of cocoa seeds was sown on Africa mainland from a variety known as "West African Amelonado" (Olasupo and Aikpokpodion 2019). However, Howes (1946), Are and Gwynne-Jones (1973 cited in Effiom n.d.), Opeke (1972a) and Aikpokpodion (2012) indicated that Amelonado cacao was introduced in 1874 into what is now Nigeria from Fernando Po by Chief Eguiss Ibaningo at approximately the time that "Teteh Quashi" introduced the crop into Ghana (Effiom n.d.; Olasupo and Aikpokpodion 2019). However, Opeke (1972a) records the name as Chief Squiss Ibaningo. The plantation was reportedly in Bonny in the eastern part of Nigeria (Amos 2007 cited in Anyanso 2014; Opeke 1972a; Aikpokpodion 2012). Cacao trials also occurred between 1860 and 1868 at Akropong (Webster 1963). Ojua (1980, cited in Effiom n.d.) suggested that cacao in the Central River Basin, particularly in Ikom, was brought in by persons returning to Nigeria from Cameroon. Cacao seedlings, raised at Akropong in 1861, were distributed to neighboring areas in 1865, and by 1868 there were 4 acres of cocoa trees at Akropong (Webster 1963). Between 1877 and 1888, cacao from Fernando Po and Trinidad was introduced into Lagos county (Aikpokpodion 2012). By 1880, cacao was planted at Ijan on the lagoon close to Agege by J.P.L. Davies, a ship captain with a route among Freetown, Lagos, and the Niger (Webster 1963). Cacao seedlings from the old botanic gardens of Ebute Metta (Effiom n.d.; Deutsch 1990) in 1887 were sent for trials in Ibadan, leading to the first and earliest cultivation around Ibadan in Oyo State (Effiom n.d.). By the early 1890s, cacao was grown in western Nigeria (Berry 1968) south of Ibadan and around Abeokuta, spreading to Ondo by 1890 (Berry 1968), Ilesha in the late 1890s and Ife in 1910 (Berry 1975 cited in Deutsch 1990). A few fruits from Ilesha were taken to Okeigbo and planted, but most farms were thought to have started from material brought in from Agege (Berry 1968). In the 1890s, J.K. Coker was also said to have started a cacao farm in Ifako with about 30,000 seedlings (Webster 1963) that were likely obtained from Davies due to prior business and family relations (Webster 1963; Toxopeus 1971). In 1899, two shipments of cacao plants from the Royal Botanic Gardens were sent to Nigeria (Aikpokpodion 2012).

Workers returning from Agege are also believed to have brought cacao fruits from Okeigbo. Around 1900, red-fruited Trinitario was imported from the British West Indies to the botanical garden in Agege Lagos (Olasupo and Aikpokpodion 2019), likely from Trinidad (Toxopeus 1971). Also, in 1900 the Pentagonum variety probably from Trinidad was brought to the Old Calabar Station (Aikpokpodion 2012). In 1905, non-Amelonado types probably from Trinidad or Sao Tomé were also brought to the Old Calabar Station. A barrel shipment of 60 Forastero fruits from Trinidad in 1909 also reportedly occurred (Aikpokpodion 2012). By 1903 there was a cacao plantation at Agbowa near Ijebu Ode (Webster 1963). Cacao was introduced in Qndo Province and the Ekiti area after 1918, and by the 1920s cacao farms were established in all the major areas of the cocoa belt (Berry 1975 cited in Deutsch 1990). Many people from church, state, business and as individuals were involved in the original wave of cacao spread in Nigeria (Deutsch 1990; Olasupo and Aikpokpodion 2019). All these introductions created a range of variability on the different plantations (Olasupo and Aikpokpodion 2019).

In the 1930s, cocoa swollen shoot virus disease severely impacted the existing Amelonado germplasm (Aikpokpodion et al. 2009). Trinitario and Criollo selections from Trinidad and Ceylon, respectively, were introduced in 1933 (Jacob et al. 1971 cited in Olasupo et al. 2018). Soon after 1944, cacao was moved from Ghana into Nigeria and the open-pollination progeny gave rise to the F3 Amazon hybrids (Olasupo et al. 2018). Toxopeus (1968) explains that progeny from seven Upper Amazon Forastero parents (IMC 60, NA 31, NA 33, NA 34, PA 7, PA 35, SCA 12) were introduced to Ghana in 1944 and that subsequent seedling selection from open-pollinated fruit from these F1 progeny gave rise to the F2 and subsequently the F3 progeny known as F3 Amazon. Toxopeus (1968) indicated that until the late 1930s the predominant West African Amelonado variety could not be established in deforested areas and that instead cultivars that were well adapted to exposed environmental conditions were needed. Between 1931 and 1956, the first cacao breeding program of Nigeria conducted progeny trials, double hybrid crosses and clonal trials that led to the selection of C clones from West African Amelonado and local Trinitario families (Olasupo et al. 2018).

By the late 1950s (Aikpokpodion et al. 2009), hybrids from the first program included the third-generation progenies from among 11 Upper Amazon parents obtained from Trinidad and the Mixed Series II hybrids (WACRI Series II) from Upper Amazon crossed with local selections (Olasupo and Aikpokpodion 2019; Olatoye and Esan 1993). The first selections from the first program were listed as NCTA 1–43, and 18 of these were derived from open pollinations (Olatoye and Esan 1993). Within this batch a Criollo from Kumba in Cameroon is listed as a self-incompatible white-bean type (Olatoye and Esan 1993). Between 1952 and 1963, about 120 genotypes and open-pollinated pods from Ghana germplasm arising out of the introduced Trinidad material were established (Opeke 1972a). A wider and more ambitious Trinidad-Nigeria introduction occurred during the period from 1962 to 1970 than the 1944 Trinidad-WACRI Introduction Scheme in Ghana. From November 1965 to October 1966, a total of 18,043 seeds from 279 crosses were sent, of which 6,499 seedlings were released for planting (Opeke 1972b). From October to December 1966, a total of 10,001 seeds from 140 crosses were sent, of which 8,709 seedlings were raised, and from January to March 1967, a total of 12,671 seeds from 164 crosses were sent, of which 10,547 seedlings were raised (Opeke 1972b). Other shipments up to 1970 had similar success as the latter two movements (Opeke 1972b). All of the surviving Trinidad-Nigeria introductions were distributed over five ecological different sites viz. Gambari Experimental Station, Ibule, Owena, Alade and Uhonmora (Opeke 1972b).

Collections

Germplasm introductions from various countries led to the creations of gene banks, and planned and unplanned breeding efforts provided various hybrid seeds and clones that were distributed to and among farmers. The cocoa conservation and breeding efforts in Nigeria have been treated (Olatoye and Esan 1993; Aikpokpodion et al. 2009). The germplasm collection at the Cocoa Research Institute of Nigeria (CRIN) is the source of material for distribution to farmers. Since West African farmers usually propagate cocoa from seeds, the research station is involved in breeding programs and seed garden establishments for superior varieties to improve productivity (Olasupo et al. 2018). Seed gardens are regarded as most efficient to introduce improved cacao varieties to the farmers as planting materials (Adewale et al. 2016). Seven germplasm collections of CRIN are the most widely used in cacao breeding in Nigeria (Olasupo et al. 2018). These are IBIC (international clone plot) of CRIN, established in 2003; IBLC (local clone plot) of CRIN, established in 2004; IBN (clonal plot) of CRIN, established in 2004; AGS (polyclonal plot) in Ago Store Ondo State established in 1974; OTU (biclonal plot) of Ondo State established in 1974; ADC (polyclonal plot) of ADC Camp, Ikom, established by Cross River State in 2010; AJAS (biclonal plot) of Ajassor-Íkom, established by Cross River State in 2010.

Recent Cultivation

Toxopeus (1971) indicated that the majority of cacao in Yorubaland (Nigeria, parts of Benin and Togo) was morphologically and physiologically similar to the Amelonado variety on Fernando Poo but that there were also red-fruited trees (0.1% in the large cacao areas), which he attributed to the activities of the Agege Farmers Union. In contrast, red-fruited trees accounted for about 40% of the relic cacao of Agege (Toxopeus 1971). A second breeding program occurred from 1961 to 1970 and yielded 12 "CRIN Establishment Ability Elites" (Olasupo and Aikpokpodion 2019). In 1967, some 313 clones and 701 seedling progenies derived from 350 intra-Nanay, intra-Parinari, intra-Iquitos and inter-P (Pound's selections) were imported from Trinidad and became known as the T clones (Olasupo et al. 2018; Olatoye and Esan 1993). These were variously planted out at five locations (Alade, Ibule, Uhonmora, Ikom and Ibadan) with the latter having the only complete set. A set of 118 T clones were selected (Olatoye and Esan 1993). International clones from Costa Rica, Indonesia, Fernando Poo, Kew Gardens (U.K.), Wageningen (the Netherlands) and Miami (U.S.) were also obtained (Jacob et al. 1971 cited in Olasupo et al. 2018).

The third breeding program, from 1971 to 1980, was incomplete, but the fourth breeding program, 1998 to 2008, yielded eight new varieties (CRIN Tc-1, CRIN Tc-2, CRIN Tc-3, CRIN Tc-4, CRIN Tc-5, CRIN Tc-6, CRIN Tc-7 and CRIN Tc-8) in 2010 (Olasupo and Aikpokpodion 2019). In 1980, 27 clones and eight fruits were obtained from Mayaguez in Puerto Rico with 256 progenies being obtained from the eight fruits (Olatoye and Esan 1993). Between 1998 and 2004, 43 international clones were introduced and established at the Cocoa Research Institute of Nigeria (CRIN) gene bank in Ibadan (Olasupo et al. 2018). There are 14 states (Ogun, Cross River, Abia, Delta, Ondo, Ekiti, Akwa Ibom, Osun, Kogi, Taraba, Ekiti, Adamawa, Edo, Oyo) producing cocoa in Nigeria (Anyanso 2014). Ondo State in southern Nigeria is the largest cocoa-producing state (Anyanso 2014).

In 2012 and 2013, there was a reported distribution of 420,000 and 320,000 hybrid fruits respectively (Anyanso 2014). In 2020 CRIN freely supplied 300,000 improved seedlings to farmers, and in 2021 a set of 500,000 seedlings was being distributed (Yahaya 2021). The director of CRIN, Dr. Adebola, reportedly indicated that the seedlings were from improved varieties developed at CRIN (TC1-8) that start producing fruits between 1.5 and 2 years and will yield 1,500 to 2,000 kg/ha (Yahaya 2021). However, Segun (2016) from a survey of 321 cacao farmers in five major producing states (Edo, Ekiti, Ondo, Osun, Oyo) in Nigeria found that few farmers invested in new planting and replanting programs.

Genetic Studies

Olasupo et al. (2018) examined 1,457 cacao trees from seven germplasm collections (IBIC, IBLC, IBN, AGS, OUT, ADC and AJAS) of the CRIN using 89 SNP markers. These workers found a very high degree of mislabeling but established that the varieties were mostly hybrids of Upper Amazon populations (Scavina, Parinari and Iquitos) with a few hybrids of Amelonado and Trinitario.

Aikpokpodion et al. (2009) used 12 microsatellite markers to examine the genetic relationships of 578 cacao trees distributed over two early West African germplasm collections (181), 33 Upper Amazon parentals, 20 local clones, 12 ICS clones, and farmer germplasm from three ecological areas (ideal climate, 111; ideal soil, 156; and marginal, 65). These workers showed that the highest genetic diversity was found in the WACRI Selections and the farmers field, an early germplasm collection introduced by Posnette in 1944, and Upper Amazon parents in increasing order. The lowest genetic diversity was in the local clones. Furthermore, cacaos in ideal soils were clustered with the local and Trinitario clones, those in ideal climates were clustered with the Upper Amazon and Posnette's introductions, and those in marginal climate were separate from the other collections (Aikpokpodion et al. 2009). Germplasm from WACRI encompassed the diversity of the 1944 introduction from Posnette (Aikpokpodion et al. 2009).

On-farm cacao is composed of Amelonado landraces and Upper Amazon hybrids (Aikpokpodion et al. 2003) mainly as 66% Upper Amazon Forastero, 24% Amelonado and 6% Trinitario (Olasupo and Aikpokpodion 2019). The Cross River State accounts for about 30% of the production in Nigeria (Bloomberg 2016 cited in Dadu et al. 2021). In this area, the cocoa trees had age range of 11 to 40 years (Balogun 2019 cited in Dadu et al. 2021) but showed a trend in decreased production (Tiku et al. 2016). Bhattacharjee et al. (2004) examined 346 trees from Cross River State with 11 microsatellites. These 346 trees were obtained from six populations of parental clones (25 samples), five breeding collections (87 samples) and farmer material (234 samples from eight populations across all cocoa-growing regions (Ajassor, Akamkpa, Boki, Etomi, Etung, Ikom, Obudu and Obubra) in Cross River State. Similar to Aikpokpodion et al. (2009), Bhattacharjee et al. (2004) found that the Upper Amazon and breeders' collections had higher genetic diversity than germplasm in farmers' fields. The latter had a higher incidence of homozygous material and were clustered with the parental clones (Bhattacharjee et al. 2004). Furthermore, these authors found that the collected Amelonado material had high genetic diversity indicative of farmer material being hybrids with Amelonado ancestry instead of pure Amelonado. Fruit, seed, and leaf flush color morphological traits supported the heterogenous nature of on-farm, with a tendency to have more Upper Amazon-derived types than Amelonado or Trinitario (Aikpokpodion 2010).

Fifteen new hybrids released by CRIN in 2011 were assessed for juvenile performance data in the field (Adenuga and Ariyo 2020). The 15 hybrids were all different from each other but could be clustered into four main groups, with one of the clusters having just one of the hybrids as its sole member. The latter was the most vigorous and was considered suitable for use in further cacao improvement.

Highlighted Cultivars

The West African Amelonado [T38 (N38)] that was widely distributed arose out of selection from the local resultant Amelonado plantations (Opeke 1972a). The selection code refers to Tree No. 38 in Plot AIN, Moor Plantation, Ibadan, which was recoded as N38 (Opeke 1972a). Clones C77, T9/15 and T72/20 and the progeny of C77 × C64 have a high level of tolerance to cocoa swollen shoot virus (Opeke 1972a).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

SAO TOMÉ AND PRINCIPE

Overview

These two islands (#8 in Fig. 22) in the Gulf of Guinea, off the west coast of Africa, were colonized by Portugal and started cultivating cocoa in the 19th century. Sao Tomé and Principe produced 2,778 metric tons of cocoa in 2021, ranking 30th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Sao Tomé and Principe exported US$3.85 million in cocoa beans, making it the 38th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/stp).

Historical Introductions

In 1822, cacao was transported from the State of Bahia in Brazil to Príncipe (Wood 1991; Bartley 2005; Aikpokpodion 2012) or Sao Tomé (Howes 1946; Toxopeus 1971) by the Portuguese. Cacao was then moved from Príncipe to Sao Tomé in 1830 (Wood 1991). Bartley (2005) indicated that it was in the 1850s that cacao spread to Sao Tomé. However, Cook (1982) stated that the first introduction in 1822 to Príncipe was likely from Fernando Poo and that the subsequent introduction in 1830 was from Brazil. Van Hall (1914) indicated that while cacao was first planted in 1822, cultivation was started in 1870. Bartley (2005) indicated that the original planting in 1822 in Príncipe consisted of 30 plants and hence surmised that a single fruit was involved. Bartley (2005) suggested that while this fruit came from Brazil it may have originated not from Bahia but from the northern part of the State of Espírito Santo or the State of Rio de Janeiro.

In 1850, cacao cultivation began in Sao Tomé with Amelonado seeds from Príncipe (Aikpokpodion 2012) with the first plantation being established in 1855 in Sao Tomé by João Maria de Sousa e Almeida at Praia Rei (Kiesow 2017). Cocoa cultivation started in earnest in 1870 (Knapp 1920) or 1880 (Clarence-Smith and Ruf 1996 cited in Anti-Slavery International 2004). The Baron of Agwa Ze brought Fine Forastero plants from Brazil (exceptional acid sharpness) (Cook 1982). The variety brought into the island is known as "Sao Tome Creolou." Two cacao trees became the parents of the subsequent cacao trees of the island (Toxopeus 1973 cited in Olasupo and Aikpokpodion 2019). In 1880, germplasm from Ecuador, Trinidad and Venezuela were imported including Venezuela Caracas (red smooth fruits); narrow elongated and well-ridged fruits; Guayaquil variety; green fruits; very large, red, slightly ridged smooth fruits; Laranja variety; and various hybrids (Aikpokpodion 2012).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Sao Tomé were selected for the best 50 International Cocoa Awards (CoEx) in 2010 (one batch), 2011 (one batch) and 2013 (one batch) but without any wins.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

SIERRA LEONE

Overview

Sierra Leone (#1 in Fig. 22), a former British colony, is located on the southwest coast of West Africa and shares borders with Liberia and Guinea. Sierra Leone produced 14,670 metric tons of cocoa in 2021, ranking 17th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Sao Tomé and Principe exported US$47.3 million in cocoa beans, making it the 15th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/sle).

Historical Introductions

Prior to 1900, cacao from Fernando Po, Sao Tomé and Cameroon was introduced (Aikpokpodion 2012). It is believed that a shipment of West Indian cacao seed in 1864 from Kew was destined for Freetown, Sierra Leone (Howes 1946). In 1902 germplasm from Trinidad was obtained, including 60 plants of Ceylon Red, Nicaraguan Criollo, Forastero and Pentagonum (Aikpokpodion 2012). In the same year 1,000 seeds from unknown varieties were also obtained from Fernando Po (Aikpokpodion 2012).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Sierra Leone were selected for the best 50 International Cocoa Awards in 2017 (one batch) and 2019 (one batch), with a win in 2017. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Criollo cacao batch (Amazon cultivar) from Bonbordu, Bonbordu, Kono, Eastern Region, had moderate cocoa, roast, bitterness, astringency and brown fruit flavors; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

TANZANIA

Overview

Tanzania (#14 in Fig. 22), located in East Africa, shares borders with Uganda, Kenya, Mozambique, Malawi, Zambia, Rwanda, Burundi and the Democratic Republic of the Congo. Tanzania was colonized by the Germans and later by the British. Tanzania produced 8,548 metric tons of cocoa in 2021, ranking 23rd out of 59 cocoa producing countries (World Population Review 2022). In 2020, Tanzania exported US$23.9 million in cocoa beans, making it the 26th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/tza).

Historical Introductions

In the early 1890s, cacao cultivation at Derema was reportedly unsuccessful due to the altitude, unlike the 3,600 ha at Muoa that are closer to sea (Anon 1896).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Tanzania were selected for the best 50 International Cocoa Awards in 2017 (two batches), 2019 (one batch) and 2021 (one batch), winning one award each year. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario/Forastero cacao batch from Mbeya, Kyela, Kisyosyo, had moderate cocoa, roast, bitterness, astringency, acidity, fresh fruit and brown fruit flavors; and low sweet, floral, spice, woody and nutty flavors (CoEx 2019). The winning entry in the best 50 of the International Cocoa Awards 2021 from Chiwachiwa Village, Mbingu Ward, Mlimba District, Morogoro Region, was given the following flavor profile description: "Medium brown, reddish hue colour. Smooth chocolate note evolves with a base of dried and browned fruit (dates). Complex flavour with hints of fresh dark and yellow fruits, earthy and herbal notes, and spice notes. Finish is long with chocolate and browned fruit notes. Smooth and balanced." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

TOGO

Overview

Togo (#5 in Fig. 22), on the coast of West Africa, shares borders with Ghana, Benin and Burkina Faso. Togo was colonized by the Germans and later by the British. Togo produced 22,522 metric tons of cocoa in 2021, ranking 15th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Togo exported US$23.9 million in cocoa beans, making it the 25th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/tgo).

Historical Introductions

Cacao was introduced to Togo between 1890 and 1900 by the Germans from Ghana (Gnongbo 2003). The first attempt in 1895 was in the Kpalimé region but failed (Pontié 1992). The beginning of the 20th century saw Amelonado cacao being planted in forested areas (Gnongbo 2003). In the 1930s, cacao cultivation expanded especially in the north and in the Litimé region (Pontié 1992).

Recent Cultivation

Cacao cultivation occurs in the Adélé, Akébou, Akposso and Dayes plateaus and their foothills of the southern mountain ridge of Atakora but principally in the Litimé in the western foothills of the Akposso plateau (Antheaume and Pontie 1990). Old Amelonado trees are mainly present although there are replanting efforts (Antheaume and Pontie 1990). There are three zones of cacao cultivation (Antheaume and Pontie 1990). According to these authors, the first includes the large villages along the road to Badou in Kpété-Béna south of the prefecture with about 400 farmers. The second zone, of about 300 farmers, occurs along this same main road in villages located north of the prefecture from Badou and is the most receptive to innovation in cocoa farming. The third and most extensive zone includes villages scattered throughout the Western Litimé with about 800 farmers. Replanting efforts with hybrid trees and the removal of old trees occurred mainly from 1975 onward as either interplanting or complete felling of all cocoa trees (Antheaume and Pontie 1990).

Highlighted Cultivars

Three best hybrids based on yield were identified from UPA 413 × C 1, C 69 × C 20 and UPA 402 × C 410 (Deuss 1981).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Togo were selected for the best 50 International Cocoa Awards in 2011 (two batches), 2013 (one batch), 2015 (one batch) and 2021 (three batches), winning three awards in 2021 and one award in previous years.

A winning entry in the best 50 of the International Cocoa Awards 2021 from Efoupkani, Wawa, Plateaux Ouest, was given the following flavor profile description: "Dark reddish-brown colour and raisin/chocolate aroma. Quick chocolate note emerges with undertones of dark fresh fruits (cherry) and raisin browned fruit. Bitterness and astringency are blended, smooth, and balanced with a hint of spice. Creamy-buttery mouth feel with a smooth long finish of raisin and chocolate notes." (CoEx 2021). Another winning entry in 2021 from Gadzawukpe, Agou, Gadza, Plateaux Ouest, was given the flavor profile description: "Dark reddish-brown colour. Chocolate note emerges steadily with a mild fruit acidity and a unique presence of fresh and browned fruits then dark wood, spice, and nut meat notes. Bitterness and astringency disappear in this complex yet simple flavour profile finishing with a mélange of all notes in the aftertaste." (CoEx 2021). The third winning entry, from Dedomé-Ferme, Amlamé, Amou, Plateaux, was given the flavor profile description: "Medium brown with reddish hues. Chocolate note emerges gradually with a fruit acidity that shows citrus, berry, and tropical fruit notes with a hint of browned fruit like a sweet jam. Center taste has a hint of herbal and floral flowers that persists into the aftertaste." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

UGANDA

Overview

Uganda (#13 in Fig. 22), a former British colony, is in East Africa and is surrounded by Kenya, South Sudan, Democratic Republic of the Congo, Rwanda and Tanzania. Uganda produced 31,312 metric tons of cocoa in 2021, ranking 12th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Uganda exported US$101 million in cocoa beans, making it the 11th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/uga).

Historical Introductions

In 1901, cacao was first introduced to Uganda and established at the Botanic Gardens in Entebbe in the Central Region (Brown and Hunter 1913). The plants were sourced from the Royal Botanic Gardens in England and were likely descendants of germplasm from Trinidad between 1880 and 1881 (Urquhart 1958; Bartley 2005). Germplasm was later imported in 1903 from the West Indies, and in 1910 from Sri Lanka mainly as Forastero seedlings, and in 1913 as seeds from Zanzibar (Urquhart 1958). Planting material for estates was obtained from the aforementioned plantings, but by 1924 the early plantings were abandoned for several reasons including low yields (Krug and Quartey-Papafio 1964; ADC/IDEA 1998). Later, in 1956, Upper Amazon hybrid seeds were imported from Ghana (Krug and Quartey-Papafio 1964). Amelonado and Upper Amazon material from Ghana were likely used for replanting (Krug and Quartey-Papafio 1964; ADC/IDEA 1998).

Recent Cultivation

Bundibugyo and Mukono in the Western and Central Regions are the major cacao-growing areas (Gopaulchan et al. 2019). In 1986, cocoa nurseries were developed in Damba Island on Lake Victoria for the quarantining of imported materials (ADC/IDEA 1998). In 1987, high-yielding Criollo, Forastero and Trinitario varieties were imported from Ghana and South America (ADC/IDEA 1998). Then in 1988, hybrid seeds from open pollination mainly between Upper Amazon and Trinitario were imported from Costa Rica and Trinidad (Petithuguenin 2000).

Genetic Studies

In 2011, local landraces were surveyed in Central (Buikwe, Kampala, Luweero, Mpigi, Mubende and Mukono districts) and Western (Bundibugyo and Kabarole districts) Uganda and genotyped with 96 SNP markers using a Fluidigm platform by Gopaulchan et al. (2019). None of the material sampled displayed cream or white beans (Gopaulchan et al. 2019).

Most of the Ugandan samples were hybrids of Marañon ancestry with Amelonado and Iquitos contributions. Sixteen of the collected samples displayed genetic similarity with the Refractario 1 group. Four of the samples, all from the Central region (U026 from the Luweero district and U030, U032 and U033 from the Mukono district), could be considered as exclusive members of the Amelonado, Nanay, Iquitos and Contamana groups respectively (Gopaulchan et al. 2019). Highest Criollo ancestry was found in two samples, U019 (Luweero district, Central Region) and U037 (Mukono district, Central Region), at 31% and 24% respectively (Gopaulchan et al. 2019).

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Uganda were selected for the best 50 International Cocoa Awards in 2019 (one batch) and 2021 (one batch), winning an award in 2021. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Forastero cacao batch from Bumate Village, Bundibugyo, Western Region, had strong cocoa flavor; moderate roast, bitterness, astringency and woody flavor; and low acidity, sweet, fresh fruit, brown fruit, floral, spice and nutty flavours (CoEx 2019). A winning entry in the best 50 of the International Cocoa Award 2021 from Bundibugyo, Buganikire, was given the following flavor profile description: "Medium brown colour with creamy mouthfeel. Flavour is bright with moderate chocolate note mixed with fresh fruit acids and a range of fresh fruit notes. Clear browned fruit (raisin) note in the center taste along with some herbal and earthy notes. Medium bitterness and astringency." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

CARIBBEAN

According to Cook (1982), after its domestication process in Mesoamerica, cacao was moved first to Trinidad, Haiti and Jamaica. Gonzalo Fernández de Oviedo in his Historia General y Natural de las Indias (1851–1855) reportedly stated that cacao trees were not of the West Indian islands but of the mainland (Bergmann 1969).

1. Cuba
2. Jamaica
3. Haiti
4. Dominican Rep.
5. Puerto Rico
6. St. Lucia
7. Grenada
8. Trinidad and Tobago
9. Martinique
10. Dominica

Figure 28
Cacao growing regions in the Caribbean region
Modified from Chocolate Codex (http://chocolatecodex.com/portfolio/countries-of-origin/).

CUBA

Overview

Cuba (#1 in Fig. 28) produced 231 metric tons of cocoa in 2021, ranking 47th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Cuba exported US$1.38 million in cocoa beans, making it the 47th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/cub).

Historical Introductions

Cacao was reportedly introduced to the island from Mexico/Central America in 1540 by the Spaniards (Hernandez 1978 and Cuban Agricultural Ministry; Núñez González 2010 cited in Bidot Martínez et al. 2015). The first farm was the "Mi Cuba" farm in Cabaiguán at the center of the island (Hernandez 1978; Núñez González 2010 cited in Bidot Martínez et al. 2015). This is congruent with Liogier (1992) and Nosti (1970). It is also believed that cacao was introduced between 1791 and 1803 at Ti Arriba, Santiago de Cuba, by French cacao growers who emigrated from Haiti during the Haitian Revolution (Núñez González 2010 and Hernández Castillo 1978; cited in Bidot Martínez et al. 2015). Núñez González (2010) stated that literature reported wild cacao growing in Bayamo in the late 18th century. This cacao had a very small and fatty seed.

Van Hall (1914) indicated that cacao seeds were imported at the beginning of the19th century from Venezuela. By 1827 cacao was being grown and harvested in few districts on small areas of land and was estimated to produce 5 pounds per tree with 5,000 trees in one caballeria (33.162 acres/13.420 hectares) (Sagra y Peris 1842). Prior to 1827 cacao was said to be grown more but it then declined until there was no export of cacao in 1840 (Sagra y Peris 1842). In the early 1800s, cacao was grown especially on the Baracoa side in San Juan de los Remedios, Trinidad, and in the surroundings of Matanzas (Sagra y Peris 1845). The flowers were said to be dirty white and the fruit oblong-ovate being acuminate on both sides with 10 ridges and fairly rough (Sagra y Peris 1845). Hybrids were introduced from Costa Rica by the United Fruit Co. in 1955 and seeds from Trinidad Selected Hybrids (TSH) varieties from Trinidad in the 1970s (Bidot Martínez et al. 2015).

Recent Cultivation

Agroforestry is the main farming system (De Smet 2018). Cacao plantations are mainly distributed in the mountains of the eastern provinces as organic agroforestry systems particularly in the Baracoa region of Guantánamo, where more than 70% of the national cacao production takes place (Bidot Martínez et al. 2015 and references therein). According to Bidot Martínez et al. (2015) there are four types of cocoa in Cuba based on origin:

1. Clonal varieties produced by grafting in national research institutes from hybrids introduced from Costa Rica in 1955 by the United Fruit Co. They represent 53% of Cuban cacao and are found in the major producing areas of Baracoa, Imías and Maisí in the province of Guantánamo.
2. Hybrids of selected Trinitario and Forastero clones introduced in 1991 and produced by hand pollinations at research centers. They represent 37% of Cuban cacao and are propagated by seed for distribution in eastern and central Cuba.
3. Progeny of TSH clones from Trinidad, introduced as seeds in the 1970s and grown in the eastern cacao-producing provinces of Granma, Santiago de Cuba, Holguín and Guantánamo. This TSH-progeny group constitutes 4% of Cuban cacao.
4. Finally, traditional or ancient cacao of unknown origin constituting 6% of Cuban cocoa. These plants are either isolate or on plantations and are managed by farmers including propagation by seed.

Genetic Studies

Bidot Martínez et al. (2015) assessed the old Cuban cacao most representative of the original introductions with 15 microsatellites on 537 trees throughout the country (Fig. 29). Plants from the eastern region tended to cluster away from plants in the central region. The two clusters are consistent with two introductions separated spatially and temporally. The putatively older introduction in the center had lineages from seven groups (Criollo 35.6%, Amelonado 25.4%, Marañon 13.6%, Iquitos 10.2%, Contamana 6.8%, Nanay 5.9% and Nacional 3.4%) whereas the later eastern introduction had a genetic background from only three groups (Amelonado 71.8%, Criollo 25.1% and Marañon 3.1%). Overall, the relic Cuban cacao was found to be hybrids of Amelonado, Criollo and Marañon.

The same relic Cuban cacao samples were also assessed at 33 morphological traits and were found to group with Trinitario (Bidot Martínez et al. 2017b). These authors also found moderate to high frequency of white seeds (68 plants), light purple seeds (106 plants), Amelonado fruits (158 plants), Angoleta fruits (269 plants) and Criollo fruit (49 plants) among the traditional accessions. A core collection of 187 samples was recommended based on the microsatellite and morphological diversity (Bidot Martínez et al. 2017a).

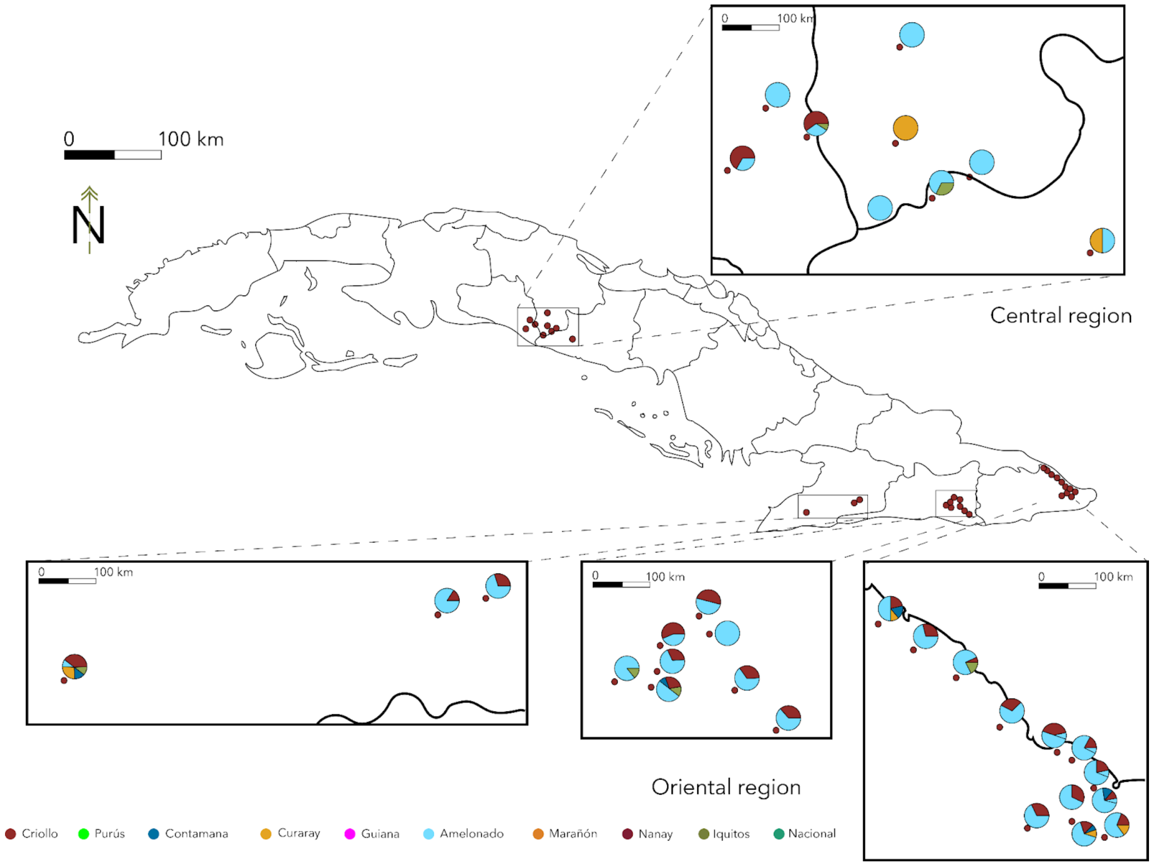


Figure 29
Cuban cacao ancestry
Adapted from Bidot Martínez et al. (2015)

Flavor Quality

Over the period from 2010 to 2021, a batch of chocolate sample from Cuba was selected for the best 50 International Cocoa Awards for 2011 but did not win.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

DOMINICA

Overview

Dominica (#10 in Fig. 28; Fig 30) produced 312 metric tons of cocoa in 2021, ranking 44th out of 59 cocoa producing countries (World Population Review, 2022). In 2020, Dominica exported US$5330 in cocoa beans, making it the 97th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/dma). Dominica consists of seven geographical regions, all of which can grow cacao (Fig. 30).

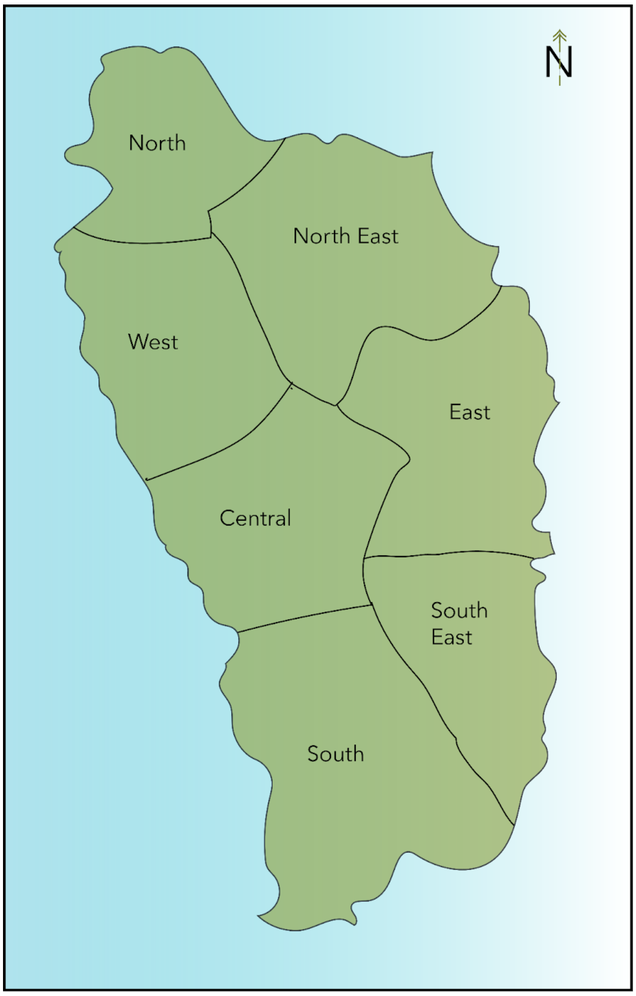


Figure 30
Map of Dominica showing administrative regions.
Cacao was collected in all regions by Gopaulchan et al. (2020).
Map adapted from Gopaulchan et al. (2020)

Historical Introductions

According to Cook (1982), Dominica cacao came from Martinique. Cacao was reportedly first introduced in the late 1600s or early 1700s into Dominica (Borome 1967; Baker 1994; Hess 1991 cited in Bekele et al. 2000; Bartley 2005). Other introductions were made in the late 1800s and early 1900s, from the islands of Trinidad and Montserrat (Bartley 2005) and the Ocumare region of Venezuela (Imperial Department of Agriculture for the West Indies 1903). However, increased competition from the British West African colonies and heavy losses sustained in the hurricanes of 1915 and 1916 (Imperial Department of Agriculture for the West Indies 1920; Harrison 1935) caused a severe decline in the industry. Bekele et al. (1999, 2000) indicated that 17 Trinitario varieties (11 Imperial College Selection (ICS) from Trinidad and six Grenada Selections (GS) from St. Vincent) were introduced into Dominica in 1948 followed by other high-yielding Trinitario varieties from Trinidad in the 1950s to help revive the industry.

Collections

Bekele et al. (1999) identified 32 trees from the Northeast (four farms), North (five farms), South (three farms), Southeast (one farm), Central (three farms), West (three farms) and East (five farms) and found that despite the lack of management many trees showed prolific bearing. Gopaulchan et al. (2020) undertook a wider survey, identifying 156 cocoa trees across 72 distinct sites of the seven geographical regions (Fig. 30).

Recent Cultivation

Germplasm from Trinidad as 11,440 seeds derived from eight known crosses and 15 open-pollinated varieties was further introduced from 1969 to 1972 for field trials (Bartley and Chalmers 1970; Hartley and Chalmers 1970; Chalmers 1972, 1973). Rehabilitation of old orchards and new plantings started in the late 1980s (IICA 1997; Hess 1991 cited in Bekele et al. 2000; Division of Agriculture 2019). In this effort, hybrid seedlings from nine commercial TSH varieties and from two TSH crosses with ICS varieties were used (Bekele et al. 1999) but by 1996 there were still many abandoned or semi-neglected farms (IICA 1997). Cacao is cultivated mainly in the northern leeward slopes and valleys and in the sheltered valleys and slopes of the windward side (Harrison 1935). The seven regions (Fig. 30) all have cacao farms in various stages of maintenance. Some cacao trees are isolated or in abandoned estates or exist as remnant vegetation along roadways and on homesteads.

Genetic Studies

Bekele et al. (1999) using 25 phenotypic traits showed that the 32 trees from farms in the Northeast (four), North (five), South (three), Southeast (one), Central (three), West (three) and East (five) were all different from each other. Fruit morphology indicated similarities to ICS, GS and IMC varieties. Ten trees had pale-colored seeds, eight had high seed mass and seed number, and five trees were common to both classes (Bekele et al. 1999). Gopaulchan et al. (2020) undertook a wider survey, sampling 156 cocoa trees across 72 distinct sites of the seven geographical regions. Trees were selected based on farmer preference compared against 1,181 reference accessions from the International Cocoa Genebank Trinidad (ICGT) using 192 SNP markers. The trees were found to be mostly mixed from Amelonado, Criollo, Iquitos, Contamana and Marañon ancestries but predominantly as Amelonado-Criollo hybrids. At least 30% Criollo ancestry was found in 28 trees. Identical or near-identical matches were found to ICS 60, ICS 40, GS 29, MAR 9, DOM 33 and DOM 34. Only one population, Amelonado, had samples with at least 75% ancestry, and 23 trees were exclusively Amelonado.

Highlighted Cultivars

A local variety known as Creole is present with a pale green smooth Amelonado-type fruit and was confirmed from ancestry analysis as belonging exclusively to the Amelonado population (Motilal, pers. comm.)

Flavor Quality

Dominica is an exclusive (100%) fine or flavor cocoa producer (Sukha and Ali 2018; ICCO 2016–2020b). Gopaulchan et al. (2020) demonstrated that the regions were not different from each other based on genetic composition of farmed cacao. These authors indicated that this could be used to support central fermentaries for best fermentation practices and the development of a single country brand or regional branding without compromising the flavor profile. Over the period from 2010 to 2021, Dominica was selected for the best 50, and secured a win in the International Cocoa Awards for 2017.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

Dominican Republic

Overview

Dominican Republic (#4 in Fig. 28) produced 86,599 metric tons of cocoa in 2021, ranking 9th out of 59 cocoa producing countries (World Population Review 2022). The Chocolate Codex also ranked the Dominican Republic as the 9th top producing cocoa country in the world. In 2020, Dominican Republic exported US$193 million in cocoa beans, making it the 8th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/dom).

Historical Introductions

Cacao was reportedly first introduced in 1665 or 1666 by Hernán Cortés but was said to be unsuccessful. A second attempt by the French in 1665 (Batista 2009) resulted in the introduction of Criollo varieties from Mexico to Santo Domingo (Cook 1982). Batista (2009) indicated that the Criollo germplasm was introduced from Mexico and Venezuela. Later, between 1895 and 1900, an Amelonado variety originally from Venezuela was introduced from Trinidad (Cook 1982).

Collections

The Criollo germplasm is being collected to prevent its loss from within the country (Batista 2009).

Recent Cultivation

Cacao is mainly grown in 28 municipalities in five regions — North, Northeast, East, Northcentral and Central (Fig. 31; Batista 2009). The cacao varieties are based on old Criollo and Trinitario from Venezuela as well as Amelonado and Calabacillo types from Trinidad with the Trinidadian types occupying about 85% of the plantations (Ortiz et al. 1981; Batista 1985 and references therein). Ciferri (1930; cited in Batista 1985) indicated that the Nacional of Ecuador is also a major contributor. Hybrid materials started being introduced in 1962, leading to their adoption in 17% of the growing area (Ortiz et al. 1981).

In October 1962, seeds (F1 hybrids) from Trinidad were imported and planted in Barranca, La Vega (Batista 2009). Over the period from 1962 to 1966, hybrid seeds from Trinidad and the Tropical Agricultural Research and Higher Education Center (CATIE) in Costa Rica were introduced (Sofreco and Ecocaribe 2001 cited in Boza et al. 2013). Starting from 1970, clonal germplasm from germplasm stations in Costa Rica (CATIE), Miami (Subtropical Horticultural Research Station; SHRS) and Puerto Rico (Tropical Agriculture Research Station; TARS) and from the countries of Brazil, Cameroon, Central America, Ecuador, Mexico, Peru and Venezuela were introduced (Boza et al. 2013 and references therein). A clonal field was started in 1973 containing 61 varieties from TARS from which crosses were made and evaluated (Batista 1985).

By the 1980s about 60% of the cacao farms were monoclonal and 40% interplanted (Ortiz et al. 1981). It is estimated that about 30% of the trees are traditional varieties and 70% are biclonal hybrids derived mainly from imported cultivars that were selected for yield, pest and disease resistance, and quality (Batista 2009). In general, the old cacao is being replaced with hybrids with higher-yielding inter-harvest periods (Celestino and Garrido 2013). The Dominican Republic is the world leading organic cocoa producer (Celestino and Garrido 2013; IICA 2020) with 60% of the world export volume. In 2007, about 79,401 ha were under organic cocoa cultivation (Garibay and Ugas 2010). In 2011, organic cocoa accounted for 32% of the country's cacao export (Celestino and Garrido 2013).

Genetic Studies

Boza et al. (2013) assessed 152 on-farm trees with 14 microsatellites and identified 115 unique trees. These trees were found to have contributions from Amelonado (72%), Contamana (6%), Criollo (9.5%), Iquitos (7.8%) and Marañon (2.6%) with minor contributions (0.87%) each from Nacional and Nanay populations. Trinitario-type hybrids accounted for 42 of the farm selections.

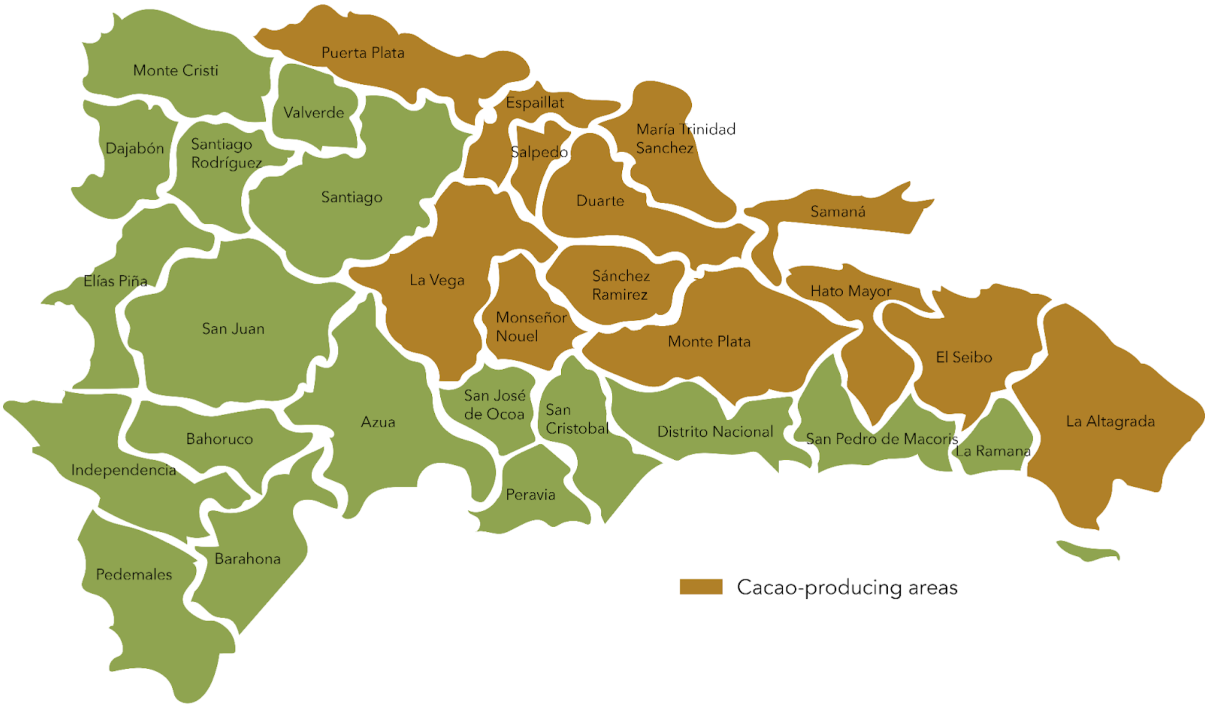


Figure 31
Map of Dominican Republic showing the cacao producing areas
Adapted from Batista (2009)

Highlighted Cultivars

Batista (1985) reported the pre-selection of 88 local cacao trees for productivity in their original locations leading to the selection of 23 trees (Genoveva 5; ML 16, 22, 46, 59, 64, 66, 67, 70, 71, 73, 75, 80, 81, 101, 102, 103, 104, 105, 106, 107; Medio Peso; Pepino) by June 1982.

Flavor Quality

The Dominican Republic is recognized as having 40% fine cocoa with potential of reaching 70% and is one of 15 gourmet cocoa countries (IICA 2020). Currently, ICCO (2016–2020) lists Dominican Republic as exporting 60% fine or flavor in the December 2020 ruling.

Over the period from 2010 to 2021, chocolate samples from Dominican Republic were selected for the best 50 International Cocoa Awards (CoEx) for 2010 (one batches), 2011 (three batches), 2013 (two batches), 2019 (one batch) and 2021 (two batches), with 0, 1, 1, 1 and 2 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Criollo cacao batch (Hispaniola cultivar) from Seccion El Rejon, El Mamey, Los Hidalgos, Puerto Plata, Norte region, had strong cocoa flavor; moderate roast, bitterness, astringency and floral flavors; and low acidity, sweet, fresh fruit, brown fruit, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from 43000 Prov. Sánchez Ramírez, Batero, La Cueva, was given the following flavor profile description: "Medium brown colour. Fast mouth melt with chocolate and browned fruit (dark raisin, prune) notes and mild fruit acidity, clear browned fruit persisting along with some yellow fresh fruits. Spice and slight tobacco notes in center. Balanced bitterness and astringency. Chocolate and raisin finish." (CoEx 2021). Another winning entry in 2021, from San Francisco de Macoris, Provincia Duarte, Cibao, was given the following flavor profile description: "Dark colour, reddish hues. Melts easily, smoothly. Flavour is a blend of chocolate notes and browned fruits (dates, raisins, dried plums), gentle fruit acidity and fresh fruits (plum dark fruit, yellow fruit, trace tropical) with a balanced and low bitterness and astringency. Long finish." (CoEx 2021)

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

GRENADA

Overview

Grenada (#7 in Fig. 28) produced 800 metric tons of cocoa in 2021, ranking 34th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Grenada exported US$1.65 million in cocoa beans, making it the 45th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/grd).

Historical Introductions

Cook (1982) stated that in 1714 the French brought cocoa materials from Martinique, but cacao in this island also resembles Trinidad cocoa with less Criollo in its ancestry. Cruickshank (1970) indicated without referencing that this was cultivation so that introductions had to have started earlier, providing as evidence a census count in 1700 of 150,000 cacao trees.

Collections

Between 1940 and 1943, 79 local clones were selected, becoming the Grenada selected (GS) clones and being distributed from 1946 (Cruickshank 1970).

Flavor Quality

Grenada is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Over the period from 2010 to 2021, a batch of chocolate sample from Grenada was selected for the best 50 International Cocoa Awards in 2019 but did not secure a win. The chocolate was made from a Trinitario cacao batch (Caracas, GS, ICS cultivars) from Belmont Estate and had moderate cocoa, roast, astringency, bitterness, acidity, fresh fruit and brown fruit flavors; and low sweet, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

GUADELOUPE

Guadeloupe was not listed as a cocoa-producing region among 59 cocoa producing countries (World Population Review 2022). According to Cook (1982), Guadeloupe cacao came from Martinique. Van Hall (1914) indicated that this Amelonado variety from Martinique became the oldest variety in Guadeloupe. At the end of the 1790s, cacao was present in the Grande-Rivière valley, located in the town of Vieux-Habitants (Benoît 2012).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

HAITI

Overview

Haiti (#3 in Fig. 28) produced 14,173 metric tons of cocoa in 2021, ranking 18th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Haiti exported US$6.46 million in cocoa beans, making it the 33rd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/hti).

Historical Introductions

Introduction of cacao plants (1665–1666) was first led by Hernán Cortés; however, the establishment of profitable cocoa production was unsuccessful. According to Nieburg (2015), the first attempt to produce cacao in Haiti was done by Hernán Cortés, although unsuccessfully. This affirmation coincides with Cook (1982), who reported that Criollo variety was introduced to Haiti from Mexico in the late 1500s and, as in Trinidad, Forastero seeds were brought from eastern Venezuela.

Recent Cultivation

Criollo and Trinitario varieties are reportedly the dominant varieties and cacao is produced in an agroforestry system usually as organic cacao in northern Haiti (Chery 2015).

Genetic Studies

Boccara et al. (2018) surveyed the Department of Grand Anse in the southwestern peninsula and assessed 361 trees with 177 SNP markers. These workers found that 42.5% of the samples had at least 80% Amelonado ancestry, 94% with some Amelonado ancestry and 34% as pure Amelonado. Pure Amelonado was more prominent in the areas of Dame Marie and Los Iros while Chambellan had the most Amelonado hybrids. There were 55 hybrids with at least 10% Iquitos origin and 25 hybrids with at least 10% Nanay origin, all collected in the town of Anse d'Hainault. There were also 17 varieties with at least 10% Marañon origin, all from the commune of Dame Marie, and 22 varieties with at least 10% Contamana origin. There were 97 trees with at least 10% Criollo ancestry but only 14 of these had between 30% and 50% ancestry.

Highlighted Cultivars

The trees CRS 3_201, CRS 5_392 and CRS 2_144 from Fondin, Mandrou and Zaïre respectively have 37% to 49% Criollo ancestry (Boccara et al. 2018).

Flavor Quality

Haiti is a 4% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. All the regions with cocoa farms should be visited.

JAMAICA

Overview

Jamaica (#2 in Fig. 28) produced 305 metric tons of cocoa in 2021, ranking 45th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Jamaica exported US$1.31 million in cocoa beans, making it the 48th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/jam).

Historical Introductions

Cook (1982) indicated that Spaniards introduced the crop, specifically Criollo from Mexico or Trinidad from 1635 to 1640, and that later, in 1757, Amelonado type and Forastero were introduced from Eastern Venezuela. This information corresponds with Diaz-Valderrama et al. (2020), who stated that Criollo genetic background seeds were introduced to Jamaica by the Spanish between 1638 and 1640 from Guatemala and surely Caracas.

Fagan (1984) and Topper (1993) reported that cacao was first introduced to Jamaica about 1638 and was probably first exported in 1646 (Fagan 1984). Van Hall (1914) indicated that in 1655 when the British took possession of Jamaica from the Spanish cacao was already extensively grown. In 1673 a cacao tree in Jamaica was described as a slender (usually 4-inch diameter) single-trunk tree with fruits having 20 to 30 seeds (Anon 1673). In the same note, cacao trees in Jamaica were said to be “exceedingly different among themselves” and to have suffered from a “blast disease” as did Cuba and Hispaniola (now Haiti and Dominican Republic). The “blast” in 1727 destroyed plantations on the island (Fagan 1984 and references therein; Topper 1993). Soon after 1870, cacao experiments on cultivation and manuring were being conducted in not more than 30 sites representing typical soils throughout the island (Edwards 1961).

Fagan and Topper (1988) document the introduction of germplasm from Trinidad, St. Vincent, Costa Rica and Mexico. They indicated with referencing the following:
Five ICS types were established from budwood from Trinidad in 1942; two ICS types were imported from St. Vincent in 1950; two GS and six ICS types from St. Vincent in 1956; five varieties from Costa Rica in 1957; and 11 varieties from Mexico in 1957. Rooted cuttings of two IMC clones, seven PA clones, three SCA clones, one TSA clone and one TSH clone, all from Trinidad, were imported in 1959 (Dow 1960 cited in Fagan and Topper 1988). Seeds of 12 TSH crosses were imported between 1982 and 1985 from Cocoa Research Unit (now Cocoa Research Centre) in Trinidad (Topper 1993).

Recent Cultivation

A large number of local seedlings were reportedly produced by 1956, and by 1960 hybrid seeds from manual and open pollinations were being obtained from selected parents, particularly ICS 1, ICS 6, ICS 8, ICS 60, IMC 67, PA 150, PA 169 and SCA 12 (Fagan and Topper 1988). Topper (1993) indicated that from 1952 to 1964 six ICS clones (ICS 1, 6, 8, 60, 95, 98) were distributed and from 1965 to 1968 ICS 1 and ICS 60 were distributed. From 1958 to 1963 progeny of five PA clones (PA 39, 46, 121, 150, 169), two POUND clones (POUND 7, POUND 18), two IMC clones (IMC 57, IMC 67) and two SCA clones (SCA 6, SCA 12) were obtained from Trinidad and distributed (Topper 1993). From 1962 to 1964, progeny from the local crosses of IMC 58 × ICS 60 and SCA 12 with ICS 1, ICS 6 and ICS 8 were disseminated, followed in 1964–1988 with progeny from local crosses of PA 150 with ICS 1 and ICS 60 and ICS 60 × PA 150 (Topper 1993). It was reported that 200,000 open-pollinated seedlings were being obtained in the late 1980s (Fagan and Topper 1988). Fagan and Topper (1988) and Lindo (2018) credit Fagan (1984) with recording the introduction of TSH germplasm from Trinidad and establishing same in the Montpelier Agricultural Research Station in the St. James Parish. However, Fagan (1984) only indicates that high-yielding, black pod-resistant hybrid seedlings from Trinidad were introduced without indicating the establishment site(s). The cultivars were likely to be TSH but could have included any of the material leading up to the development of the TSH cultivars at the time. Seedlings were reportedly available to farmers in 2012 from the Orange River Research Station and the Montpelier Agricultural Research Station (MICAF 2012 cited in Lindo et al. 2018). Over 350,000 seedlings have been distributed to farmers between 2013 and 2015 under an EU-funded project (Hunter 2015). In 2007 about 30 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Genetic Studies

Lindo et al. (2018) used 94 SNPs to assess the genetic diversity in Orange River Agricultural Research Station (70 trees), in Montpelier Agricultural Research Station (49 trees) and at one farm, Bachelor's Hall Estate in St. Thomas parish (41 trees) (Fig. 32). Cacao trees from the Orange River and Montpelier research stations and Bachelor's Hall Estate sites generally clustered with the Iquitos, Marañon and Nanay groups and with a Trinitario assemblage (Lindo et al. 2018). However, the ancestry of the trees in the research stations was from predominantly five genetic groups as opposed to three genetic groups for the farm material (Lindo et al. 2018). Trees on Orange River research station were predominantly of Amelonado (31%), Iquitos (20%), Criollo (18%), Marañon (14%) and Contamana (12%) with minor contributions from Nanay (4%) and Nacional (1%). Trees on Montpelier research station were predominantly of Marañon (37%), Amelonado (22%), Iquitos (14%), Criollo (12%) and Contamana (11%) with minor contributions from Nanay (3%) and Nacional (1%). On-farm cacao at Bachelor's Hall Estate was predominantly Marañon (43%), Amelonado (24%) and Criollo (21%) with minor contributions from Iquitos (4), Nanay (4%) Contamana (3%) and Nacional (1%). The Marañon, Amelonado and Criollo genetic groups made the greatest contributions to the ancestry of the Jamaican samples. Examination of the ancestry plots provided in Lindo et al. (2018) revealed the presence of only three pure ancestry samples (>95% ancestry) as one Iquitos in Orange River and Marañon (one each) in Montpelier and Bachelor's Hall Estate but many admixed individuals with two to six ancestral groups. Furthermore, hybrids containing in part Amelonado-Criollo (47%), Amelonado-Iquitos (35.8%), Amelonado-Marañon (34%) and Amelonado-Contamana (32%) hybrids were predominantly present in Orange River. At Montpelier, hybrids containing in part Amelonado-Marañon (61.7%), Amelonado-Criollo (48.9%), Amelonado-Contamana (42.6%) and Amelonado-Iquitos (40.4%) hybrids were predominant. At Bachelor's Hall Estate, the farm trees presented mainly as trihybrids of Amelonado-Criollo-Marañon (80%).

Figure 32
Sampling sites by Lindo et al. (2018) for cacao genetic diversity in Jamaica.
Adapted from Lindo et al. (2018).

Flavor Quality

Jamaica is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Over the period from 2010 to 2021, chocolate samples from Jamaica were selected for the best 50 International Cocoa Awards (CoEx) in 2010 (one batch), 2011 (two batches) and 2017 (one batch), with a win only in 2010.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

MARTINIQUE

Overview

Martinique (#9 in Fig. 28) was not included in World Population Review's list of 59 cocoa producing countries.

Historical Introductions

Cacao in Martinique may be either natural or introduced. Van Hall (1914) credited a source (Histoire nature-lie du cacao et du sucre) with indicating that in 1655 the colonials were shown cacao trees growing wild in the forests of northeastern Martinique. Banbuck (1935) provided archival record (Lettre de Robert du 30 juillet 1699, Arc. Nat. Col. C8A-11) opining that cacao is "not foreign to Martinique, being natural in the island and found in the woods unless it has been brought in from outside." Historicus (Richard Cadbury) stated that cacao is indigenous to these islands. In contrast Cook (1982) credited Van Hall with saying that cacao as the Criollo variety was introduced in 1660–61 by the French. Yet Adenet et al. (2020) citing Ouellet (2014) report the writings of a priest in 1660 mentioning cacao being grown and previously maintained by the Amerindians in the Capesterre forests in the east and that the cacao was the best species for making chocolate. Adenet et al. (2020) also cited several sources indicating that cacao trees were present around 1660 and their discovery was attributed to the Amerindians. As reported by Adenet et al. (2020), cacao, called Créole at that time, was presumably, but not verifiably, introduced in Martinique in 1660, between Morne-Rouge and Saint-Pierre by Sieur Benjamin d'Acosta, a Portuguese trader expelled from Brazil. The Créole cacao coming from Brazil is likely to be of Amelonado ancestry. Banbuck (1935) informs that Benjamin was the first, around 1660, to set up a cocoa house in the vicinity of Saint-Pierre but that the plantation did not develop rapidly and by 1699 was still not very important. Van Hall (1914) also writes that Benjamin Dacosta was said to introduce cacao in 1664, likely Criollo seeds, from Venezuela. From 1692 to 1719, cacao was a secondary crop to sugarcane (Petitjean Roget and Bruneau-Latouche 1983). Sainton (2004 cited in Adenet et al. 2020) indicated that the number of cacao trees in 1715 and 1726 was 1,900 and 13,500,000 respectively with an approximate 692-fold increase in acreage with the main production area being around Gros-Morne. The cultivated variety in 1727 was described as coming from the Lower Amazon basin and being recognizable by its elongated fruits with red or green ridges, a very accentuated apex and fresh white cotyledons (Hatzenberger 2001 cited in Adenet et al. 2020). This description is a reasonable fit for Criollo cacao. By the 1760s cacao was established as commercial plantations (Louis 2011), and in the 1800s cacao was cultivated in all the municipalities (Adenet et al. 2020). In 1767 an Amazonian Forastero from the Orinoco Basin in Venezuela was being used (Adenet et al. 2020). By 1895–1900 eastern Venezuelan hybrids and Ecuadorian Forasteros were introduced (Cook 1982).

Genetic Studies

In 2012 and 2013, Adenet et al. (2020) sampled 161 cacao trees on the island (Fig. 33) and using genotyping by sequencing identified 4,113 SNPs from a retained set of 147 trees. Fig. 34 shows an example of the diverse morphology, but specific genotypes were not associated with the indicated morphology. These workers found that six of the 10 ancestral groups (Amelonado, Contamana, Criollo, Iquitos, Marañon and Nanay) were present with Amelonado, Marañon and Criollo being predominant. Adenet et al. (2020) found that 80 genotypes in the survey, or 54% of samples, had some Amelonado ancestry, and 57 genotypes showed 100% Amelonado parentage. In addition, at a minimum threshold of 20%, individuals also present with Contamana (8), Criollo (15), Iquitos (2), Marañon (35) and Nanay (2) ancestries. Amelonado ancestry was present throughout the island. However, Criollo and Marañon ancestry were found to be higher in north Martinique. Criollo ancestry was highest in the areas of Saint Joseph, Case Pilote and Fond Saint Denis whereas Marañon ancestry was highest in Saint Joseph, Fond Saint Denis, Le Carbet and Basse Pointe areas.

Figure 33
Cacao sampling in Martinique (North Atlantic, North Caribbean, Centre. South). In 2014 and 2015, 94 trees and 67 trees were sampled respectively. Image adapted from Adenet et al. (2020)

Cacao Morphology on Martinique

Basse-Pointe	Gros-Morne	Fonds-Saint-Denis	Saint-Joseph	Carbet	Rivière-Pilote
NA	NA	NC	C	NC	S

Figure 34
Diversity of cacao pod morphology on Martinique.
Adapted from Adenet et al. (2020)

Flavor Quality

Over the period from 2010 to 2021, a chocolate sample batch from Martinique was selected for the best 50 International Cocoa Awards in 2017 and secured a win. Adenet et al. (2020) assessed the sensory profile of 70% dark chocolate made from cocoa in different producing areas of Martinique and characterized five types. Chocolate made by a local manufacturer from mixed lots originating from different production areas was characterized by the presence of animal, grassy, spicy, earthy, cocoa and dried fruit notes and was reportedly of an inferior quality. Chocolate from Lorrain (North Atlantic) had less pronounced dried fruit aromas, spicy aromas, and an alcoholic note linked to fresh fruit aromas. Chocolates from Riviere-Salee (South), Carbet (North Caribbean) and Riviere-Pilote (South) had chocolatey and exotic fruit aromas similar to Colombia. Chocolates from regions in the South (Vauclin, Francois), Central (Lamentin) and North Caribbean (Carbet, Precheur) were chocolatey with soft, spicy and dried fruit aromas. Chocolate from Saint-Joseph (Centre) had spice, woody, dried fruit, floral, citrus, red fruit and alcoholic notes, presenting as an aromatic and complex chocolate.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

PUERTO RICO

Overview

Puerto Rico (#5 in Fig. 28; Fig. 35) is not included on World Population Review (2022) list of 59 cocoa producing countries.

Historical Introductions

In colonial times Puerto Rico was used as a bridge between South/Central America and Spain, leading to cocoa being introduced and established in the island by 1625 by the Spaniards (Bartley 2005). Barrett (1925) indicated that cacao from Central America was introduced after the arrival of the Spanish colonists but did not provide a time period. Yet later on in the same document it is reported that cacao was introduced in 1636 from continental tropical America. Barrett (1925) also indicated that cacao was cultivated sparingly in the Maricao and Las Marias districts, occurring principally as Forastero (red and yellow) while "Criollo is extremely rare and the Calabacillo is seldom seen." Carroll (1898 cited in Cosme et al. 2016) indicated that the chocolate made in the factory at Mayaguez was considered one of the best in the world.

After the destruction of the cocoa plantations that occurred during the 1700s the importance of the crop declined and the remaining production sites were abandoned (Cosme et al. 2016). Núñez González (2010) reported an exportation of cacao seeds from Grenada to Puerto Rico during the late 19th century. In 1903, cacao fruits from Trinidad (14 different fruit forms as well as Nicaragua cacao) were introduced to the U.S. Experiment Station in Mayaguez (Barrett 1925).

Genetic Studies

Cosme et al. (2016) sampled 180 old trees across 32 municipalities throughout Puerto Rico (Fig. 35), with most collection sites along the western side of the island and from abandoned farms. The final dataset involved 87 SNPs and 145 trees.

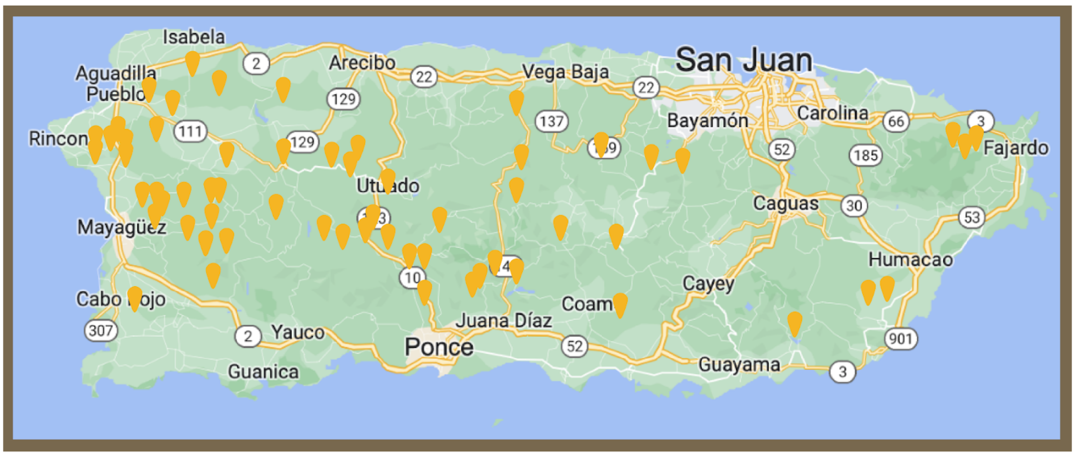


Figure 35 Sampling of old cacao trees in Puerto Rico.
Adapted from Cosme et al. (2016).

Cosme et al. (2016) found that the cacao trees were arrayed in four distinct groups with the majority as Criollo (49%), followed by Upper Amazon Forastero hybrids (27.6%), Trinitario (17.2%) and lastly Amelonado (6.2%). The Criollo trees were found throughout the island and had fruits that were red, yellow or pink when mature, showed high levels of homozygosity and could represent "Ancient" Criollo germplasm. Puerto Rico has not cultivated cacao commercially since the 1890s, so the trees have not hybridized to the extent that they would have if farming had continued (Cosme et al. 2016).

Highlighted Cultivars

Goenaga et al. (2009) identified nine high-yielding clones (TARS 1, 9, 14, 15, 23, 27, 30, 31, and 34) from full-sib families of EET 62, EET 400, SCA 6, SCA 12, POUND 7 and UF 668.

Flavor Quality

Chocolates (65%) from selected TARS clones (1, 9, 14, 15, 23, 27, 30, 31 and 34) had a wide flavor profile (Goenaga et al. 2009). TARS 1 had a very complex nut character like chestnuts roasting with a blend of hazelnut skins. TARS 9 had a "gorgeous color and a really good chocolate" with a very smooth flavor profile, very mild chocolate notes up front with low overall bitterness and a distinct persistent nut character. TARS 14 gave a good base chocolate with slight earthy, woodsy, and mushroom notes, very complex and very dark. TARS 15 chocolate had a very dark color, early mild astringency with an interesting wood resin/floral note, with a late aldehyde, fruit character and a notable aftertaste with complex floral/mild fruit note. TARS 23 gave a rich, smooth chocolate with lots of deeper, mild dark wood notes and a really good overall flavor profile and a really good chocolate aftertaste. TARS 27 gave an attractive light brown chocolate with a smoother flavor profile from the beginning with some very mild floral notes, mild cocoa, mild spice notes along with slight flowers. TARS 30 gave a chocolate with a woody late floral taste with an astringent aftertaste. TARS 31 gave a chocolate with interesting fruit tartness, astringency and a complex mildly floral profile with tropical fruit notes. TARS 34 gave a mild chocolate note with some mild fleshy yellow fruit flavor.

Over the period from 2010 to 2021, chocolate samples from Puerto Rico were selected for the best 50 International Cocoa Awards in 2017 (one batch), 2019 (two batches) and 2021 (two batches), with both batches winning in 2021.

In the best 50 of the International Cocoa Award 2019, chocolate made from a Trinitario cacao batch from San Sebastian, Barrio Mirabales, Sector Orta, San Sebastián, had strong cocoa flavors; moderate roast, bitterness, astringency, brown fruit, floral and woody flavors; and low acidity, sweet, fresh fruit, spice and nutty flavors (CoEx 2019). Another selection of best 50 was chocolate made from a Trinitario cacao batch (COLORADO, ICS 45, RIM 53, SPA 10, TARS 9, TARS 14, TARS 23, TARS 27, TARS 30, TARS 34 cultivars) from Ciales, Pozas, Sec Hoyo, Utuado, had strong cocoa flavor; moderate roast, bitterness, astringency and fresh fruit flavors; and low acidity, sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Award 2021 from Pr-119, Km 64.7, Bo. Montoso, Maricao, was given the following flavor profile description: "Rich, dark brown colour. Soft, smooth melt. Complex mélange of chocolate, browned fruit (date), floral herbal and earthy, dark, slightly resinous wood, spice notes (pepper, cardamom), with a balanced bitterness and astringency. Long finish of the chocolate blend. Balanced." (CoEx 2021). The other winning entry in 2021, from Carr 984 Km 3.4, Fajardo, Bo. Naranjo, Pr 00738, was given this description: "Dark brown colour. Chocolate with browned fruit, floral herbal, earthy, trace flowers, woody, nut and nut skins notes, and a late caramel / panela is expressed. Balanced bitterness and astringency. Complex, unique, and harmonious with a long aftertaste of chocolate, panela, and dark raisin notes." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

SAINT LUCIA

Saint Lucia (#6 in Fig. 28) produced 51 metric tons of cocoa in 2021, ranking 54th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Saint Lucia exported US$140,000 in cocoa beans, making it the 66th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/lca). St. Lucia is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b).

ST. VINCENT AND THE GRENADINES

Overview

St. Vincent and the Grenadines produced 222 metric tons of cocoa in 2021, ranking 48th out of 59 cocoa producing countries (World Population Review 2022). In 2020, the country exported US$133,000 in cocoa beans, making it the 67th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/vct).

Flavor Quality

Over the period from 2010 to 2021, a chocolate batch from St. Vincent was selected for the best 50 International Cocoa Awards in 2017 and won an award. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch from Lowmans Windward, Georgetown, Charlotte, had strong cocoa flavor; moderate roast, bitterness, astringency, acidity and fresh fruit flavor; and low sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

TRINIDAD AND TOBAGO

Overview

Trinidad and Tobago (#8 in Fig. 28) produced 320 metric tons of cocoa in 2021, ranking 43rd out of 59 cocoa producing countries (World Population Review 2022). In 2020, the country exported US$671,000 in cocoa beans, making it the 57th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/tto).

Historical Introductions

The island of Trinidad has a different colonial history than that of Tobago, and the two islands remained independent until 1889 (Carmichael 1961). In 1525, the Spaniards reportedly planted the first Criollo cacao trees in Trinidad (Van Hall 1914), importing these from Central America (Purseglove 1968). However, these authors did not provide their sources for this information. There are also reports of the Spanish encountering cacao in Trinidad around 1616 or 1617 (De Merva 1618; Ottley 1955; Newson 1976). Quesnel (1967) instead indicated that the demand for the novelty luxury drink led to its plantation by 1618 in Trinidad. Aspinall (1928) noted that cacao was introduced to Trinidad by Governor Don Tiburcio de Aspe y Zuñiga from Caracas, Venezuela, in 1678 or by the Dutch from the island of Curaçao or Guiana. The early Spanish settlers also introduced Criollo from Mexico and Forastero from Brazil. Ciferri and Ciferri (1957) suggested that the early Criollo cacao of Trinidad came via the Spanish from the Paria Peninsula of Venezuela or the delta of the Orinoco River. Cacao became a main crop in Trinidad at the beginning of the 18th century (Coke [1810] 1971).

In 1725, most of the cacao plants were destroyed by an unknown event that was attributed to a combination of poor agronomic practices, low temperatures due to the Little Ice Age and susceptibility of the Criollo-like trees (Motilal and Sreenivasan 2012). Díaz-Valderrama et al. (2020) argue that Ceratocystis wilt was more likely given that the lowest temperatures for the Little Ice Age were between 1400 and 1700, that no other tropical crops reportedly suffered and sugarcane itself seemed to increase throughout the 18th century. Subsequently, remnant trees probably of Forastero origin and lucky escapes of Criollo trees hybridized with later introductions to create the Trinitario variety (Motilal and Sreenivasan 2012). About 1755, Forastero cacao from Venezuela was reintroduced into Trinidad and widely cultivated (Van Hall 1914). In 1756, Forastero cacao was also brought into Trinidad from Brazil (Joseph [1838] 1970; Aspinall 1928) by the Aragonese Capuchin Fathers (Shephard 1932). In 1757, Calabacillo cacao was introduced from the Amazon basin (Bartley 2005) as well as a Calabacillo-type Trinitario from Venezuela (Preuss 1901; Van Hall 1914; Cheesman 1932) into Trinidad. In 1893, the Nicaraguan Criollo was imported into Trinidad (Van Hall 1914). Multiple introductions of Forastero and Criollo cacao were imported into Trinidad from Rio Amazon, Hispaniola, Venezuela (Ocumare type) and other unknown sources pre- and post-1880 (Bartley 2005). In 1890, seedlings of the Nicaraguan Creole variety were imported into Trinidad (Cheesman 1932; Bartley 2005). From 1932 to 1935 the search for promising varieties (primarily for yield) identified 100 ICS trees from about 50 million trees in Trinidad (Pound 1933, 1935, 1936; Cheesman 1934). Duthie (1938) stated that there were few true Criollo trees in Trinidad but that an area in Arden Estate in Tobago was planted with budded Criollo trees.

Recent Cultivation

Abdul-Karimu et al. (2003) found that farmers in Trinidad generally preferred seedlings, with farms in the Central region having more mature and old trees, in contrast to the Southern region, which had similar incidences of young and mature or mature and old mixtures. The Eastern region had a greater incidence of young trees and a mixture of young and old trees. The TSH clones are the recommended cultivars for farm material. These were produced from a variety of crossings involving mainly ICS 1, IMC 67, SCA 6, and POUND 18 although ICS 95, POUND 7 and some PA clones were also used (Maharaj et al. 2011). Selection of trees derived from open pollination on superior mother trees also occurred (undocumented source from L. Motilal). Early selections from the breeding program were distributed to farmers but 20 commercial TSH types are known to have been distributed (Maharaj et al. 2011). However, Abdul-Karimu et al. (2003) noted that in the 1980s there were reports of unauthorized distribution of non-commercial TSH varieties.

Genetic Studies

Johnson et al. (2009) assessed the diversity of the Trinitario accessions (88 ICS and 32 TRD) from Trinidad housed in the ICGT using 35 microsatellite markers. The ICS and TRD clones, considered as the old Trinitario, formed a homogenous population and were classified together as a landrace. These clones clustered primarily with Criollo (84%) and to a lesser extent with Upper Amazon clones (10%) and Ecuadorian clones (6%). In a World Bank Project from 2009 to 2011 (Fig. 36), 106 putatively relic trees were collected, of which 94 accessions from farmer fields were phenotypically assessed for fruit, flower and leaf traits (Maharaj et al. 2019). In Trinidad, trees were collected from the North (29), Northeast (14), Central (13), Southeast (21) and Southwest (12) regions. In Tobago, 12 samples were collected from the areas of Betsy Hope, King's Bay, Lanse Fourmi, Roxborough and Runnemede (Maharaj et al. 2019).

Farm material was more phenotypically diverse than the reference Trinitario material (ICS, TRD, GS) used from the ICGT (Maharaj et al. 2019). In addition, samples with the palest cotyledons indicative of more Criollo ancestry were found in both Trinidad (Brasso Seco) and Tobago (Moriah and Lanse Fourmi). A molecular study in this project examined 95 Trinitario trees (64 trees from 34 farms in Trinidad; eight trees from six farms in Tobago; 23 reference Trinitarios from the ICGT with SNPs in the chloroplast genome) (Yang et al. 2013). Three founder lineages (Criollo, Upper Amazon Forastero and Lower Amazon Forastero) exist as Lower Amazon, Upper Amazon and Criollo in descending order (Yang et al. 2013).

Bekele et al. (2020) assessed 1,900 accessions from the ICGT inclusive of 260 Trinitarios (of which 132 (73 ICS and 59 TRD) were from Trinidad, 23 were from Dominica, 32 from Grenada, 11 from Martinique, 19 from Mexico and 18 from Costa Rica) at 25 morphological descriptors. These authors found that the Trinitario group had the second best pod index,
23% of the 254 accessions with the best pod index were Trinitarios and several Trinitarios combined large seed number and large seed mass.

Highlighted Cultivars

Cacao farmers in Trinidad and Tobago are recommended to use TSH cultivars and 20 of these are commercially available, 10 of which are from the TSH 1300 series (Maharaj et al. 2011).

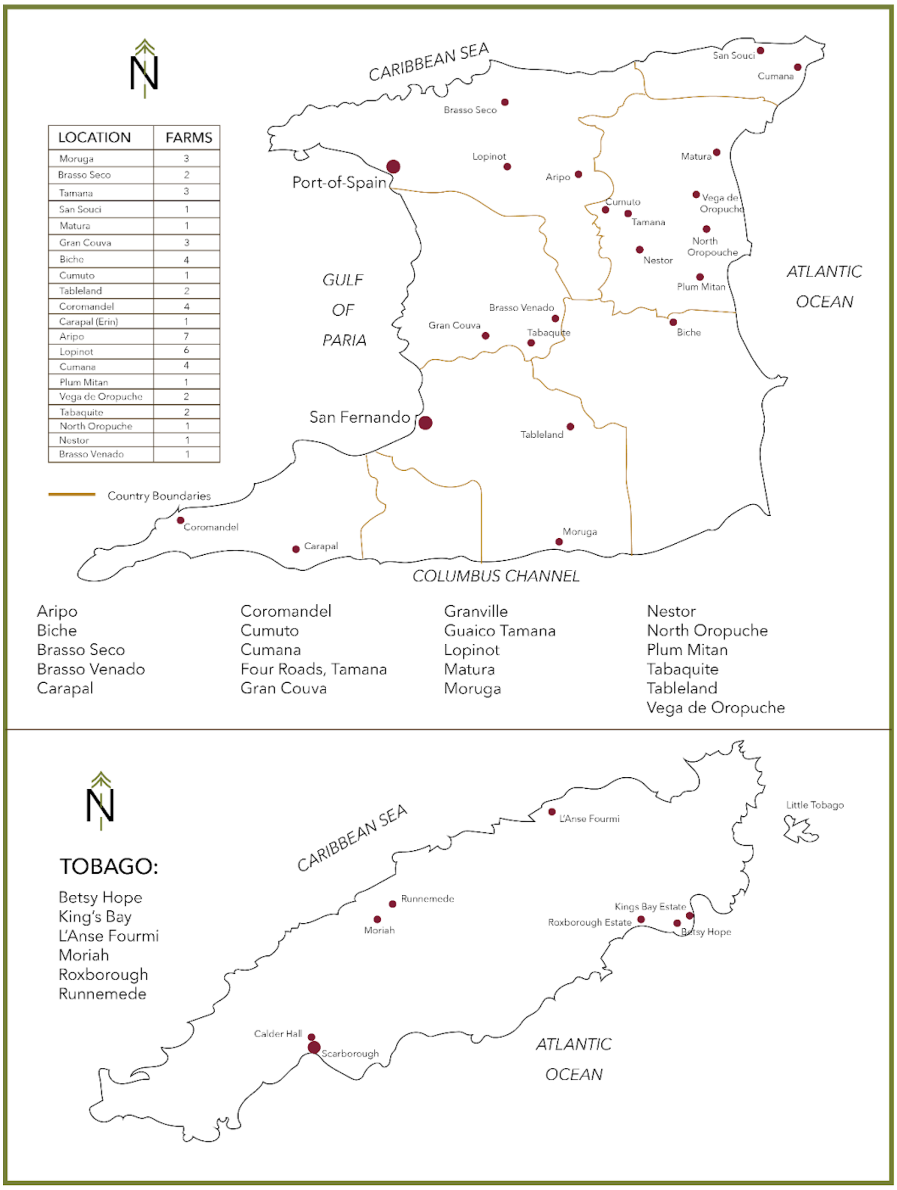


Figure 36
Sampling of farms in Trinidad and Tobago in World Bank Development Market Place Project 2009-2011, Identification and promotion of ancient cacao diversity through modern genomics method to benefit small-scale farmers'- World Bank Project TF 093747 (DM2008). Figure adapted from Maharaj et al. (2019)

Flavor Quality

Trinidad and Tobago is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Trinitario flavor profile is reportedly fruity with floral attributes and pleasant ancillary flavors such as molasses, licorice, caramel and raisin (Sukha and Butler 2005). Over the period from 2010 to 2021, chocolate samples from Trinidad and Tobago were selected for the best 50 International Cocoa Awards in 2010 (three batches), 2011 (three batches), 2013 (four batches), 2015 (two batches), 2017 (two batches), 2019 (three batches) and 2021 (three batches), winning 2, 1, 1, 2, 0, 2 and 3 awards respectively.

There were three top-50 chocolate samples in the 2019 Cocoa of Excellence made from Trinitario cacao batch from Paria Main Road, Grande Riviere; Four Roads, Tamana; and El Carmen Estate Road, Talparo, all from the St. George East District of Trinidad (CoEx 2019). They all had strong cocoa flavor; moderate roast, bitterness, astringency, acidity, fresh fruit and brown fruit flavors; and low sweet, spice, woody and nutty flavors (CoEx 2019). However, floral flavor was moderate in the sample from Talparo but low in the other two samples (CoEx 2019). A winning entry in the best 50 of the International Cocoa Award 2021 from John Trace, Heights of Aripo, Arima, Aripo, St. George East, was given the following flavor profile description: "Rich, dark brown color. Smooth, soft mouth melt. Chocolate note blended with browned fruits (tamarind, dates), floral green herbal, earthy and mushroom, woods, mild spice notes (tobacco, pepper). Astringency is velvety. Unique, complex, balanced and harmonious." (CoEx 2021). Another winning entry in 2021, from Watts Trace, Tableland, Princes Town, Tableland, Victoria, was given the following flavor profile description: "Rich, dark brown color. Smooth, mouth melt. Chocolate note blended with browned fruit (raisin and rum), trace fruit acid with a mild mélange of fresh fruits. Center of floral dried herbs, earthy / mushroom, and trace floral flowers. Wood is present along with mild nutty. Velvety astringency." (CoEx 2021). The third winning entry in 2021, from Four Roads, Tamana, Sangre Grande, Tamana, St. George East, was given the following flavor profile description: "Medium-dark brown color. Soft, smooth mouth melt. Chocolate note combines with browned fruit (dates, figs, slight raisin) with a mild fruit acidity and trace fresh fruits. Center emerges with herbal and earthy notes. Trace mild nuts / nut skins. On the mild side overall. Harmonious and balanced." (CoEx 2021).

Locally, 20 finalists were recognized in 2019 for their cocoa quality with the following descriptions (National Organization Committee, Trinidad and Tobago, 2019):

1. La Deseada Estate, Santa Cruz – "The beans … exhibited browned fruit and dried fruit notes at varying intensities, particularly raisin fruit notes … as well as fresh fruit notes. Balanced acidity and aromatic floral notes present as well. Moderate bitterness, astringency, as well as a mild to moderate basal cocoa flavor."
2. La Carlota Estate, Guaico Tamana – "The beans … had dried fruit notes and fresh yellow fruit notes reminiscent of ripe banana present. Bright fruit, acidity, balanced astringency and bitterness with a robust basal cocoa flavor and a clean finish."
3. Matsay Estate, Guaico Tamana – "Matsay Estate sample had dried and cooked brown fruit notes, with a molasses-like quality. Mild to moderate acidity, bitterness and astringency with moderate basal flavor. The cocoa liquor from these beans had a clean finish."
4. Cradley Estate in Moriah, Tobago – "The … sample revealed yellow flesh fruit note coming across at the front, along with dried fruit and browned fruit notes. Mild pleasant floral mossy note. Some mild nut and nut skins character to the bitterness and astringency in this sample. Moderate basal cocoa flavor and a clean finish."
5. Rio Claro – "Aromatic cooked browned fruit notes with some fresh fruit notes including some berry notes were prominent in the bean sample submitted. Moderate acidity, astringency and bitterness also characterized these beans. Clean finish with good basal cocoa flavor."
6. Rio Claro – "A floral green vegetal note characterized this sample. Browned and fresh fruit notes as well as dark and orange flesh fruits are also present. Mild overall with a clean finish and a moderate basal cocoa flavor. Mild acidity, with mild to moderate astringency and bitterness."

7. Rio Claro Demonstration Station – "The beans ... had flavors balanced between fresh and browned fruit notes, with floral notes as well. Moderate acidity, bitterness and astringency, with a robust basal cocoa flavor."
8. Ecclesville, Rio Claro – "[The] bean sample possessed bright fruit acidity, followed by cooked browned fruit notes and tropical and yellow flesh fresh fruit notes. Moderate basal cocoa flavor and a clean finish were also present. Slightly higher astringency due to the acidity of this sample."
9. Tabaquite – "[The] sample tasted of browned fruit notes balanced with yellow flesh and ripe tropical fresh fruit notes. Floral notes were present as well as mild woody notes. Mild fruit acidity and a mild to moderate basal cocoa flavor. Clean finish."
10. Coryal, Tamana – "The flavor notes ... were balanced between browned fruit and fresh yellow flesh fruit notes, with mild floral notes. There was moderate bitterness, astringency and acidity. Robust basal cocoa flavor with a clean finish."
11. Lopinot – "[The] beans exhibit bright acidity with fresh and browned fruit notes, as well as floral notes, more specifically orange blossom notes. Mild tobacco dried leaf notes with moderate bitterness and astringency and a moderate basal cocoa flavor."
12. Grande Riviere – "The sample of beans ... tasted of browned and raisin dried fruit notes, as well as dark and yellow fruit notes. Mild fruit acidity and robust basal cocoa flavor. There were strong floral perfumery notes that persisted throughout. Flavors were well-balanced, aromatic and had a mild spice note at the end."
13. Mundo Nuevo, Talparo – "The samples ... tasted of browned and raisin dried fruit and fresh fruit notes. Balanced fruit acidity and robust basal cocoa flavor."
14. Bethany Estate, Talparo, Tamana – "Raisin brown fruit notes like prunes which persist throughout and sweet yellow fruit notes like banana with mild acidity, bitterness, astringency and a moderate basal cocoa flavor. Towards the end there were herbal and dark wood notes."
15. Cedros – "[The] sample yielded fresh fruit notes, namely tropical and dark fruit notes, with some mild berry notes, followed by browned fruit notes. Mild overripe fruit note indicating a higher degree of fermentation, and a mild lactic acid note to the acidity. Woody and spice notes are also present toward the end. There is a robust basal cocoa flavor, moderate bitterness and an astringency that builds throughout the taste experience."
16. Monserrat Hills, Gran Couva – "This ... sample exhibited browned fruit notes as well as fresh fruit, specifically ripe tropical fruit, and floral notes. Mild woody notes and mild basal cocoa flavor. Balanced acidity, bitterness and astringency."
17. Ortinola Estates Limited, Maracas Valley, St. Joseph – "The flavor notes for the Ortinola beans were tropical, berry and yellow flesh fruit notes present in this sample as well as some dried and browned fruit notes. Pleasant overall acidity and balance of fruit notes. Moderate to robust basal cocoa flavor."
18. Carmichael Village, Coryal – "The bean sample ... exhibited a floral aroma, dominant floral flowers and orange blossom flavor notes. Berry, fresh fruit and browned fruit notes also present, as well as nutty and sweet notes. Balanced acidity, bitterness and astringency with a moderate basal cocoa flavor and a clean finish."

19. Brasso Seco, Paria – "The combination sampled presented balanced browned and fresh dark fruit notes with mild fruit acidity. Moderate basal cocoa flavor. Not especially bright but clean finish. Very mild sample overall."
20. Ramnath Estate, Tableland – "[The] beans have a clear, distinct raisin dried fruit character that lingers throughout the taste experience. Browned fruit, yellow flesh fruit and dark fruit notes are also present. Mild bitterness and astringency with a robust cocoa flavor and a clean finish."

The on-farm varieties would include pre-ICS, ICS, early TSH, middle TSH and latest TSH hybrids across farms in Trinidad and Tobago with varying mixes and combinations. Differential flavor profiles within Trinidad are recognized, with descriptions of winey, floral, acid (fruity/citrus), acid, woody, burnt, coconut and nutty flavors (Sukha et al. 2008). Processing location, growing environment and cacao genotype in Trinidad were shown to affect flavor profile (Sukha et al. 2018). Ali et al. (2018) corroborated a genetic effect showing that Trinitario and Refractario cacao had different flavor profiles and these were also affected by length of fermentation time.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

NORTH AMERICA

North America
1. Hawaii
2. Mexico

Central America
3. Belize
4. Honduras
5. Nicaragua
6. Costa Rica
7. Panama

Figure 37 Cocoa countries in North and Central America.
Adapted from http://chocolatecodex.com/portfolio, countries-of-origin/

HAWAII

Overview

Hawaii (#1 in Fig. 37; Fig. 38) is a tropical archipelago state of 137 volcanic islands belonging to the United States of America and located off its western seaboard in the Pacific Ocean. There are eight main islands (Hawai'i, Maui, O'ahu, Kaua'i, Moloka'i, Lāna'i, Ni'ihau and Kaho'olawe), with Hawaii being the biggest island (Fig. 38). Hawaii was not listed as a cocoa producing region out of 59 ranked cocoa producing countries (World Population Review 2022).

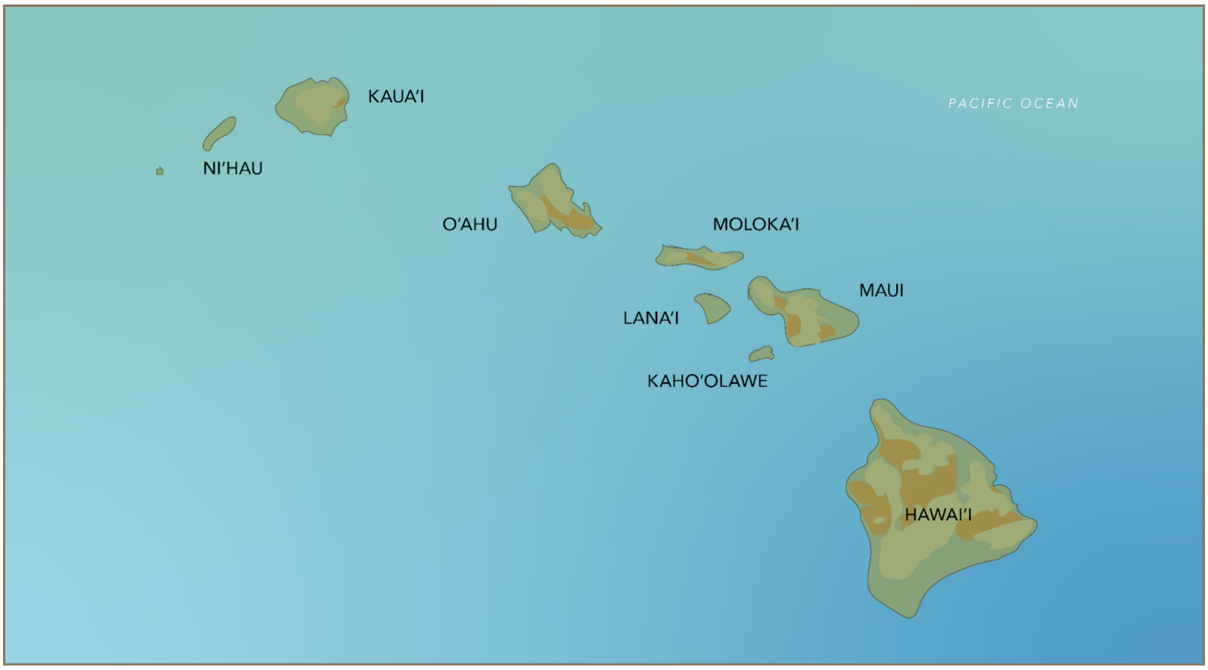


Figure 38
Map of the eight main islands of the state of Hawaii, USA.
Modified from Google Maps 7 November 2021

Historical Introductions

Billock (2018) and Hill (2019) credit the Hawaii Chocolate and Cacao Association with reporting that the first documented cacao plant was imported from Guatemala and grew in the 1830s in King David Kalakaua's gardens. In 1850, an unknown type of cacao (Nagai et al. 2009) was introduced by William Hillebrand in the current Foster Botanical Garden, Honolulu (CTAHR 2011; Billock 2018). Dame Cacao (2021b) cited Dan O'Doherty as detailing the importation of two Criollo varieties, one from Mexico and one from the Philippines, by a botanist some time during the American Civil War (1861–1865). It should be noted that Hillebrand, although a medical doctor by profession, was also acknowledged as a botanist and his estate with many introduced plants became the Foster Botanical Garden (Tsutsumi 2008). In 1890, cacao planting was started in Hilo, Hawaii (CTAHR 2011). Criollo (both red- and yellow-fruited) was reportedly imported in 1900 and planted at the experimental station at Poamoho, Oahu (Skip Bittenbender in Nagai et al. 2009). In the 1950s, Criollo was moved from Poamoho to Kealia Ranch, Kona, Hawaii (Elizabeth Stack in Nagai et al. 2009).

Recent Cultivation

Cacao seeds from the Hershey Hummingbird Farm in Belize that originated from a selected hybrid population in CATIE, Costa Rica, were planted in the early 1980s at Malamaki, Hawaii (Nagai et al. 2009; Schnell et al. 2005). A set of 100 of these seedlings was also planted in 1985 at the Hawaii Agriculture Research Center (HARC), Kunia, Oahu (Nagai et al. 2009). Schnell et al. (2005) contend that open-pollinated seed was taken from Malami Ki and planted in Kunia. Also in the 1980s, Upper Amazon Forastero seeds from the Tagnanan estate in Mindanao, Philippines, were imported and planted at Keaau, Hawai'i (Nagai et al. 2009). Schnell et al. (2005) reported the same movement but as hybrid seeds of Upper Amazon Forastero and Trinitario. Seeds from these trees were subsequently planted in 1988 at the Waimanalo Station of the University of Hawaii in Oahu (Nagai et al. 2009 and reference therein). In 1986, Jim Walsh planted 18,000 cacao trees originating from Belize and the Philippines in Hawaii (Billock 2018). In 1993, Criollo was planted in Kikuchi Garden, Kalaheo, in the island of Kauai, but from unknown sources (Nagai et al. 2009). Commercial planting started in 1998 with Dole Fresh Fruit Co. with 20,000 seedlings on former Waialua Sugar Co. land in Oahu (Nagai et al. 2009). These seedlings were from an undisclosed number of various varieties (Shimabukuro 2005). Criollo was also planted in 2000 at Ferris Farm, Kilauea, Kauai, as red- and yellow-fruited from two different sources in Hawaii (Nagai et al. 2009). Bittenbender (2005; cited in Nagai et al. 2009) indicated that cacao is being grown by small farmers on all of the principal islands. CTAHR (2011) concurred, giving the 2000s as a time stamp of occurrence. However, the trees are usually derived from seeds imported from various sources with unknown bean quality and size (Nagai et al. 2009). Criollo progeny from Kealia Ranch was planted at Choobua Farm, Kona, Hawaii, in 2003 (Nagai et al. 2009).

Genetic Studies

An analysis of 218 trees collected from Hawaii (nine farms in Kona and Hilo), Kauai (two farms and the National Tropical Botanical Garden) and Oahu (seven farms and the Lyon Arboretum) with 11 to 19 microsatellites was reported by Nagai et al. (2009). These authors found that there were 77 genetically unique individuals and they could be partitioned as Criollo, Trinitario, Upper Amazon Forastero, Trinitario-Lower Amazon Forastero and Trinitario-Upper Amazon Forastero hybrids. The Trinitario and Trinitario-Upper Amazon Forastero groups were predominant, accounting for 47 and 33 samples respectively (Nagai et al. 2009). Criollo trees (19) were found in the four expected sites from the historical literature, two (Choobua Farm and Kealia Ranch) in Kona, Hawaii, and the others in Kalaheo (Kikuchi Garden) and Kilauea (Ferris farm) from the island of Kauai (Nagai et al. 2009). Nagai (2019) reported 12 Criollo trees (two from Hawaii, 10 from Kauai) and a prevalence of Trinitario and Upper Amazon Forastero-Trinitario hybrids in Hawaii and Oahu. Schnell et al., (2005) using 19–65 microsatellites, grouped cacao in the state of Hawaii as Trinitario (HARC research station, Kunia, Oahu; UH research station, Malama Ki, Hawaii) or as Upper Amazon Forastero-Trinitario hybrids sampled from the UH research station (Waimanalo, Oahu), Waialua Sugar Plantation (Oahu) and Hawaii Gold (Ophihicao, Hawaii). These authors also found that anecdotal evidence detailing Kuna as the source of seedling material for Waialua was not supported by the molecular data but that itwas instead derived from the UH research station at Waimanalo, Oahu.

Highlighted Cultivars

A sampling of some of the fruit types in the state of Hawaii is provided in Fig. 39.

Flavor Quality

Over the period from 2010 to 2021, chocolate samples from Hawaii were selected for the best 50 International Cocoa Awards in 2015 (one batch), 2017 (three batches), 2019 (one batch) and 2021 (two batches) with 1, 2, 1 and 2 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Forastero/Trinitario cacao batch from Likao Kula Farm, Kona, Hawaii, had strong cocoa flavor; moderate roast, bitterness, astringency, fresh fruit and floral flavor; and low acidity, sweet, brown fruit, spice, woody and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Award 2021 from Lahainaluna Rd., Lahaina, Ahupuaa Kuia, West Maui, was given the following flavor profile description: "Dark, reddish-brown colour. Mild fruit acidity and low/balanced bitterness and astringency smoothly support the chocolate note. Clear raisin notes blend with wood and mild spice notes along with dried herbs and trace floral flowers. Complex, balanced, unique with a long finish of the blended characteristics." (CoEx 2021). Another winning entry, from 5730 Olohena, Kapa'a, was given the flavor profile description: "Rich dark brown colour with soft, smooth mouth melt. Blended chocolate note and fruit acidity with fresh dark fruit, berries, yellow and tropical fruits. Very complex with a dark raisin center taste that supports the flavours and lasts into the long aftertaste." (CoEx 2021).

Figure 39
A sampling of some of the fruit types present in the state of Hawaii
Taken from Nagai (2019) HARC Fine Cacao Field Day September 21, 2019

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

MEXICO

Overview

Mexico (#2 I Fig. 37; Fig. 40) is located between Texas, U.S.A., and Central America, with its southern end bordering the Central American countries of Guatemala and Belize. In pre-Columbian time and even now, the south-southeastern region of Mexico with Chiapas, Tabasco and Yucatan could be considered as a natural part of Central America rather than as part of North America. Mexico produced 27,827 metric tons of cocoa in 2021, ranking 13th out of 59 cocoa producing countries (World Population Review 2022). Contrariwise, the Chocolate Codex ranks Mexico the 8th top producing cocoa country in the world. In 2020, Mexico exported US$1.12 million in cocoa beans, making it the 50th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/mex). Roughly 30% of the cacao that Mexico produces comes out of the state of Chiapas (SIAP 2013 cited in Vázquez-Ovando et al. 2014) and most of the rest comes from Tabasco (Blare et al. 2020; Ruiz Abreu 2016). Tabasco produced 17,000 metric tons in 2016. Together, Tabasco and Chiapas account for 99% of Mexico's cacao supply (Blare et al. 2020 and references therein). Mexico consumes most of the cacao it produces (ICCO, 2016); only 4% was exported in 2019 (Blare et al. 2020).

Figure 40
Mexico and its positioning with Central American countries. Current country demarcations of Guatemala and Belize would have been non-existent giving a wide common-forested area with cacao confluent with Chiapas, Tabasco and Yucatan
Map adapted from extraction on 28 November 2021 from google.com/maps.
Map data © 2021 AfriGys (Pty) Ltd GeoBasis-De/BKG (©2009) INEGI.

Historical Introductions

Bergmann (1969) indicated that in pre-Columbian time cacao was widely cultivated along the Pacific and Gulf coasts of Mexico. According to the Cacao Mexico Organization (2021) when the Spaniards first came into this country, cocoa cultivation was present throughout the warm temperate zone of the country, from the province of Tabasco, to Michoacan, Colima, Chiapas and Campeche. The regions of Soconusco and Tabasco had large-scale cacao cultivation in pre-Columbian history (Bergmann 1969). Although it is unknown when cacao was first established in Mexico, cacao use in the Chiapas region dates back to 1500–1900 BC (Powis et al. 2007, 2008). On the Pacific side, northernmost planting was probably in the valley of Rio Ameca along the Jalisco-Nayarit border (Paso y Troncoso 1939–1942 cited in Bergmann 1969). On the Atlantic side, northernmost plantings were located near Tuxpan and Papantla (Paso y Troncoso 1905 cited in Bergmann 1969) in the state of Veracruz. The native provinces of Quauhtochco, Cuetlaxtlán and Tochtepec reportedly cultivated cacao (Clark 1938 cited in Bergmann 1969). In pre-Columbian times, Soconusco was the most distant region to send cacao tribute to the Valley of Mexico and it was collected mainly from Cihuatlán, Tochtepec, Xoconochco and Quauhtochco (Clark 1938 cited in Bergmann 1969). Similarly, in Tabasco, the small region of Chontalpa had high cacao production (Bergmann 1969). The Petén Basin shared by the Campeche state of southeastern Mexico and Petén Department in northern Guatemala was also a principal cacao area (Bergmann 1969).

In 1544, cacao was being made into potable concoctions as well as being ground, roasted and made into flour (Paso y Troncoso 1505–1518 cited in Ruiz Abreu 2016). By 1566, cultivation of cacao "groves" in Yucatan was present (de Landa 1941 cited in de la Cruz et al. 1995). Large cacao plantations on the banks of the rivers Usumacinta and Grijalva next to the Indian villages were observed in 1665 (Cabrera Bernat 1987 cited in Ruiz Abreu 2016). Ruiz Abreu (2016) listed Cunduacán, Iztlahuaca, Jalpa, Jonuta, Tacotalpa and Teapa as locations in Tabasco that produced cacao from 1731 to 1783. In 1795 Jalapa, Teapa and Tacotalpa were the main producing areas in Tabasco (Ruiz Abreu 2016).

Recent Cultivation

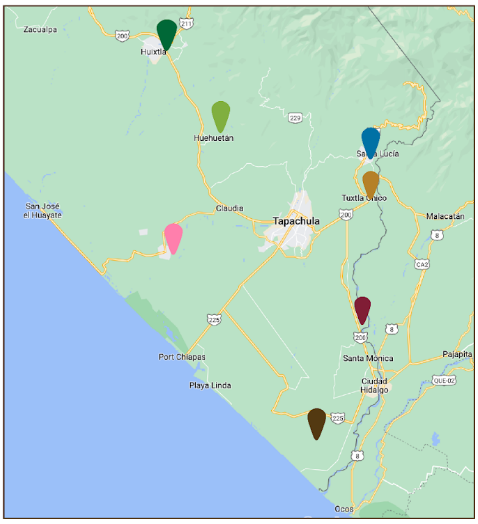
In the 1950s, Mexico worked to revitalize its cacao population. It established its RIM clones (Hunter 1990) and replanted failing Criollo orchards with stronger Forastero and Trinitario varieties (Vázquez-Ovando et al. 2014; Ogata 2003 cited in Vázquez-Ovando et al. 2014). Despite this, Criollo populations still exist in Mexico (Whitkus et al. 1998). In the 20th century, high-performing Forastero and Trinitario genetic material was introduced to Chiapas (Vázquez-Ovando et al. 2015b). Whitkus et al. (1998) indicated that the Criollo material collected in Chiapas and Yucatan was of the red-fruited Criollo type, with elongated ridged fruits and containing white-pale pink seeds. In 2007 about 16,366 ha were under organic cocoa cultivation (Garibay and Ugas 2010). On Nov. 25, 2016, cacao (white berry-shaped seeds 3 cm long and 1 cm in diameter) from the Grijalva Region of Tabasco was given a Designation of Origin (Servicio de Información Agroalimentaria y Pesquera 2019)

Genetic Studies

De la Cruz et al. (1995) studied Mexican and Upper Amazon cacao populations thought to be wild against known genetic material of Criollo, Forastero and Trinitario origin using 105 randomly amplified polymorphic DNA (RAPD) loci. It was found that the "wild" Amazonian material was more similar to Criollo than were the "wild" Mexican accessions, with two wild Mexican accessions being related to each other but distinct from all others including Criollo references. De la Cruz et al. (1995) suggest that the cenote groves in the Yucatan are probably the nearest living examples of an ancient Mayan cultivar. Later work by Motamayor et al. (2002) would demonstrate that these trees in the Lacandona rainforest, once thought to be wild by de la Cruz et al. (1995), are more likely abandoned than wild and are genetically identical to many of the cenote populations. Whitkus et al. (1998) sampled cacao from the extremes of its growth range in Mexico in the states of Yucatan (five samples from a cenote near the village of Yaxcabá) and Chiapas (two populations; six samples near the Maya ruins at Bonampak and 26 samples along the Lacantun River in eastern Chiapas; Fig. 41). These samples were collected from natural populations; the authors avoid the word "wild" due to suspicions that some of these trees may be from previously domesticated "semi-wild" populations. Samples were assessed for genetic diversity with 57 RAPD markers and were found to be less polymorphic and have lower diversity than cultivars or South American varieties. Further, the diversity between the Yucatan and Chiapas regions was greater than than within these regions, in contrast to the cultivars and South American varieties, which had greater diversity within rather than between groups. The Yucatan and Chiapas samples were distinctly grouped as a cluster away from the cultivars and South American material including reference Criollo samples similar to the two Mexican wild samples of de la Cruz et al. (1995). In addition, the Yucatan and Chiapas samples each formed their own subcluster, indicating their uniqueness as geographical collections.

Restriction fragment length polymorphism (RFLP) and microsatellite analysis were carried out on 283 samples including 99 Ancient Criollo-type trees and 68 trees thought to be Criollo introgressed with Forastero genes, referred to as Modern Criollo (Motamayor et al. 2002). The Ancient Criollo material was collected from the Lacandona rainforest, where wild trees had previously been found (de la Cruz et al. 1995; Whitkus et al. 1998). Other samples came from trees previously documented in the Yucatan cenotes near the towns of Yaxcabá, Tixcacaltuyub and Chechmil (de la Cruz et al. 1995; Whitkus et al. 1998) and along the coast of the Pacific. Many samples were also taken from abandoned farms and private gardens in zones where there was a low risk of contamination from Forastero or Trinitario germplasm. The Modern Criollo group also involved farms that had allowed the introduction of Forastero or Trinitario germplasm. The study confirmed that the morphotype "Modern" Criollo is of hybrid character. The seven Yucatan samples shared an identical genotype with nine of the 13 samples from the Lacandona rainforest, with some trees found along Mexico's Pacific coast and with previously sampled material from Mayan ruins in Belize (Mooleedhar et al. 1995). Furthermore, the Lacandona samples, even those collected at a great geographic distance, generally showed very low genetic diversity. Motamayor et al. (2002) suggest that the Lacandona population is not a wild population and probably did not originate in this area but was imported and cultivated. Finally, it was found that some Forastero from Colombia and Ecuador (EBC 5, EBC 6, EBC 10, LCT EEN 37 and LCT EEN 355) is more closely related to the Ancient Criollo group than to other Forastero samples from French Guiana, the Orinoco, the Lower Amazon or Peru (Motamayor et al. 2002).

Figure 41
Cacao sampling sites in Chiapas region, Mexico (top) with expansion of Soconusco area in Chiapas (right).
Map extracted 28 November 2021 from google.com/maps.
Map data © 2021 AfriGys (Pty) Ltd GeoBasis-De/BKG (©2009) INEGI.



Vázquez-Ovando et al. (2014) studied wild Criollo-type germplasm in the Soconusco region of Mexico against reference samples. In order to be selected, the germplasm had to meet the requirements of having elongated, grooved pods with an apex form, a warty external surface, and white or lightly pigmented seeds, and sweet aromatic pulp. The Soconusco samples were not clustered by geographic location but two areas (Villa Comaltitlán, Tuzantán; Fig. 41) offered genetic material with high Criollo ancestry. Samples from Cacahoatán, Suchiate and Mazatán shared few alleles with Criollo references, while Tapachula, Huehuetán, offered likely hybrid material (Vázquez-Ovando et al. 2014; Fig. 41). The Tapachula subpopulation had the highest incidence of private alleles at a particular microsatellite locus indicative of more diverse germplasm.

Gutiérrez-López et al. (2016) examined 28 trees from plantations around the Soconusco region of Chiapas in southern Mexico (all with fruits with Criollo morphology — elongated pods with deep grooves, pointed apexes and lumpy, warty surface, with white or lightly pigmented seeds in sweet pulp), plus seven sequence accessions downloaded from GeneBank, with the chloroplast DNA (cpDNA) intergenic spacer trnH-psbA. There were also 10 reference accessions: CATONGO and EET 399 (Forasteros); RIM 24 (Trinitario) and seven Criollos. Of the latter, one (SL 01) was collected from the Lacandon rainforest and the others were all germplasm sourced from INIFAP (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, México; Yaxcabá, Xocén, Lacandón 06, Lacandón 28, Lagarto and Carmelo). Ten different haplotypes were identified that were partitioned across seven geographic populations, each region containing one or more haplotypes (Gutiérrez-López et al. 2016). Haplotype 1, the most common, was shared by 19 of the 45 trees identified. The Selva Lacandona (population 7) group did not show any haplotype diversity, as expected for being the common ancestor of all other populations in the study (Gutiérrez-López et al. 2016). An unexpected large number of haplotypes were found, especially within the Criollo morphological group, and it is suggested that samples MAJH 02 and Carmelo (morphologically divergent samples that fell into haplotypes 4 and 6, respectively) could have been misclassified (Gutiérrez-López et al. 2016). Although all of the Soconusco trees clustered together without subclustering, similar to Vázquez-Ovando et al. (2014), samples from the Mazatán group (population 4) could be separated and had the highest level of genetic diversity (50% of the identified haplotypes), indicative of a location with a high chance of obtaining diverse germplasm (Gutiérrez-López et al. 2016).

Most recently, Avendaño-Arrazate et al. (2018) studied 99 accessions from the Cocoa Germplasm Bank in the Rosario Izapa Experimental Station, INIFAP, Mexico, to determine the genetic diversity of INIFAP and identify a potential core collection. Using 60 loci from 14 microsatellite (SSR) markers, 22 of the 99 accessions formed a core collection. Genetic diversity was comparatively low among the samples studied. However, although the authors noted that the accession CRIM 88 (T19) was genetically distinct, this accession was not a member of the recommended core. Ogata (2002) surveyed 23 populations along the Gulf and Pacific coast of Mexico using one primer pair to obtain sequence information. Seven haplotypes were obtained, with the most frequent haplotype being found in wild cacaos from the Lacandon and from Calakmul forests, old abandoned populations from Northern and South Veracruz, Oaxaca and Tabasco, and one individual from Venezuela. The most distant haplotype group included individuals from the Lacandon forest, and old abandoned populations from Yucatan peninsula, northern and south Veracruz, Oaxaca and Tabasco. The highest number of haplotypes occurred in Oaxaca and Southern Veracruz, suggesting a greater diversity for collection. The oldest haplotype was found in the Lacandon and Calakmul tropical rainforests, suggesting that this area is the origin for cacao cultivated in Mesoamerica before the arrival of Spanish colonists.

Highlighted Cultivars

Vázquez-Ovando et al. (2015b) assessed 45 farmer selections from the Soconusco region of Chiapas. All the varieties were close to the average bean mass of 1.25 g, except for CAAM 01 (0.63 g) and MAMG 08 (1.85 g). MAMG 08 was also remarkable in that it displayed the greatest bean length, at 3.16 cm as opposed to an average of 2.60 cm. Fat content for all samples was within previously reported ranges, but three samples (TASG 23, CAAM 06 and TCHR 05) showed a fat content above 56%, making them of superior commercial value. All the accessions sampled showed a high proportion of saturated fatty acids relative to other South American cacao samples that have been previously tested (59–72%, with TASG 08 showing the highest proportion at just over 72%). Protein content was more variable, but overall, the protein content of the samples was lower than protein values reported for Forasteros. Polyphenol content, reported as equivalent grams of gallic acid (EAG), ranged from 0.67g EAG/100g (MAMG 03) to 6.85g EAG/100g (FHSA 03) and correlated poorly with antioxidant capacity. Eight varieties (Chak, Supremo, Tabscoop, Olmeca, Caehui, Chibolón, K´in and Canek) have been developed to meet the needs of the international market for attributes of chocolate, cocoa, spices, sweet malt caramel, fresh and dried fruits sensory traits (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias 2019). In these eight cultivars, the highest dry bean mass of 1.9 g was found in Chak and Canek, followed by 1.6 g in Olmeca and Chibolón; highest productive potential in Olmeca (3.2 tons per ha) and Tabscoob (3.0 tons per ha); and highest resistance to moniliasis of 86%, 90% and 92% in Olmeca, Caehui and Tabscoob respectively (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias 2019).

Flavor Quality

The ICCO classifies 100% of Mexican export cacao as fine-flavored cacao.

Cacao beans from Chiapas are reported to be of higher organoleptic quality than Mexican cacao produced from other regions and is mostly used for export. A chemometric survey of farmer selections was carried out by Vázquez-Ovando et al. (2015a,b), who collected 45 cacao varieties and one sample of T. bicolor from the Soconusco region of Chiapas. Collection points included seven municipalities: Suchiate (SUED), Frontera Hidalgo (FHSA), Cacahoatán (CAAM), Tapachula (TASG), Mazatán (MAMG), Huehuetán (HUJF, HUTG), Tuzantán (TUCA, TURA) and Tuxtla Chico (TCHR). All accessions fit the morphological description of a classic Criollo according to the authors (white seeds, pronounced grooves in elongated yellowing pods, sweet pulp) and were described by the farmers as having desirable organoleptic properties (Vázquez-Ovando et al. 2015a,b). Although multivariate analysis of morphological traits found no obvious groupings, the chemical composition of seeds grouped the 45 varieties into seven groups but not as the seven sampling municipalities (Vázquez-Ovando et al. 2015b). The Soconusco samples had sensory characteristics unique to and different from cocoa cultivated in other world regions and were not described as floral or fruity. Instead, the highest sensory quality cocoas were associated with descriptors of sweet taste, less bitterness and chocolate and hazelnut odors presented in MAMG03, HUTG04, FHSA05, SUED05, MAMG0, MAMG04, HUJF05 and HUJF06 (Vázquez-Ovando et al. 2015a). Soconusco cacao is reportedly characterized with predominant chocolate, spicy, hazelnut, acidity and roasting odors with the spicy-odor descriptor being reported for the first time in cacao (Vázquez-Ovando et al. 2015a).

Ayala et al. (2016) found eight Criollo types in Southern Mexico (Soconusco, North Chiapas-South Tabasco and Chontalpa) based on fruit characteristics and with a common feature of light pink or white cotyledons. Three types (two from Chiapas and one from Chontalpa) were evaluated for flavor quality. A low theobromine:caffeine ratio (2.1–4), high preference, and a variety of aromas including pecan nut, citric, banana, peach, white flowers, wood, grapes and mango were present. A potential of 83–100% was ascribed to the samples for producing high-end fine flavor chocolate.

Over the period from 2010 to 2021, chocolate samples from Mexico were selected for the best 50 International Cocoa Awards in 2010 (one batch), 2011 (two batches), 2019 (one batch) and 2021 (one batch), with wins secured in only 2011 and 2021. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Criollo cacao batch (Porcelana Blanca La Rioja) from Ctra Cacahoatán, Carrillo Pto, Cacahoatán, Cacahoatán, Soconusco, Chiapas, had moderate cocoa, roast, bitterness, astringency and nutty flavors; and low acidity, sweet, fresh fruit, brown fruit, floral, spice and woody flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Carretera Cacahoatán-Carrillo Puerto, Km 1.5, Barrio Benito Juarez-La Rioja, Cacahoatán, Soconusco, was described as "Very light in colour — like a dark milk chocolate. Soft, creamy mouthfeel. Mild, unique, complex flavour with low chocolate note, balanced low bitterness and velvety astringency, blended nut and caramel notes, fruit acidity with complex mix of fresh fruits and date, white raisin dried fruits, smooth rich aftertaste." (CoEx 2021).

Recommend Collection

Areas with the potential for old but diverse Mexican cacao are in Mazatán, Oaxaca, Tapachula, Huehuetán and Southern Veracruz. The Lacandon and Calakmul tropical rainforests are likely sites for the oldest material, with Villa Comaltitlán and Tuzantán having high Criollo germplasm. High Criollo germplasm is also likely to be found in cenotes. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

Central America

The first cocoa exodus out of South America was to Central America and probably the first established plantations were in Central America as well. These plantations were based on the Criollo cultivar, and this type and its hybrids were among the first types to be introduced to other countries by the colonial powers. Bergmann (1969) indicated that native cacao cultivation extended from Mexico to Costa Rica. By 1502 cacao cultivation was well established in Central America, with extensive cacao orchards on the lowlands bordering the Gulf of Mexico, Pacific Ocean and Caribbean Sea (Fig. 42; Bergmann 1969).

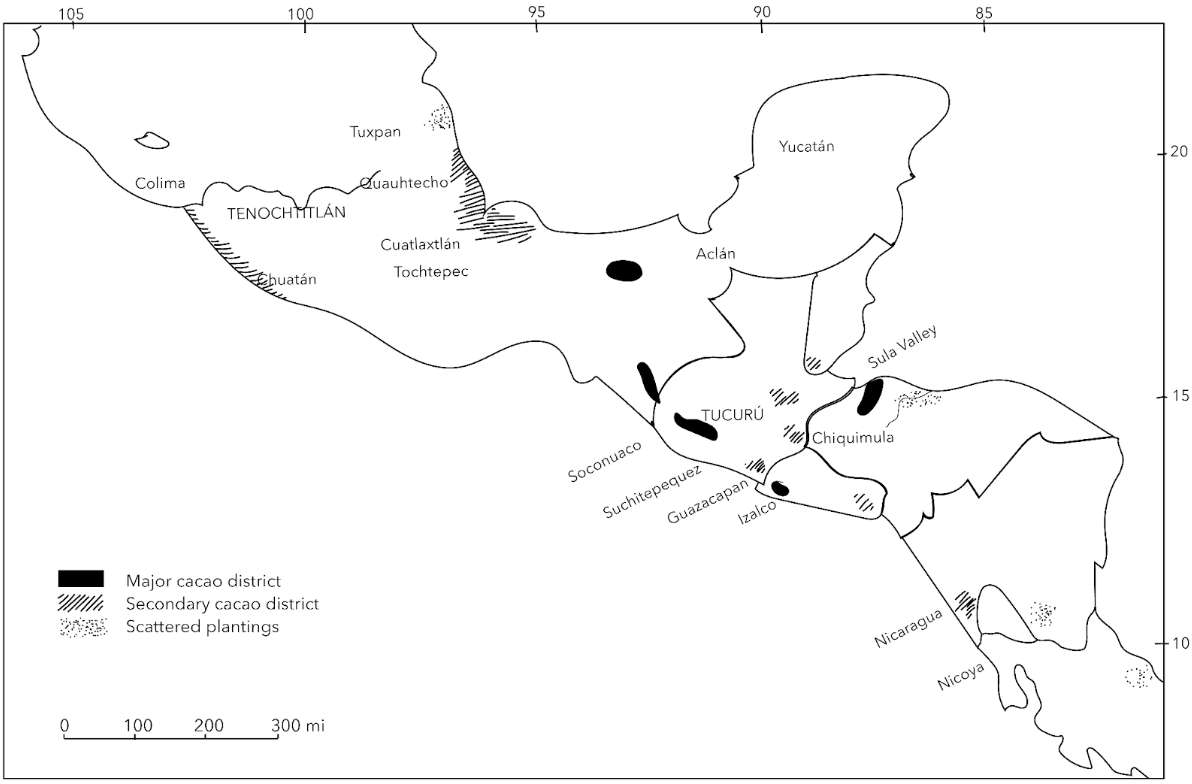


Figure 42
Cacao cultivation in pre-Columbian America.
Adapted from Bergmann (1969).

BELIZE

Overview

Belize (previously Bristish Honduras; #3 in Fig. 37) is located in northeast Central America, bordered on the north by Mexico, on the south/southwestern side by Guatemala and on the east by the Caribbean Sea. Belize produced 244 metric tons of cocoa in 2021, ranking 46th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Belize exported US$782,000 in cocoa beans, making it the 55th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/blz). Relic cacao can be found among Mayan ruins and is expected to be of substantial Criollo ancestry as this population type was used and moved by the indigenous peoples.

Historical Introductions

The Mopan Maya migrated from Peten, Guatemala, to Belize in the late 19th century, settling first in Pueblo Viejo, then moving east and founding San Antonio in 1889 (Wilk and Chapin 1991 cited in Steinberg 2002; Steinberg 2002). Cacao has been grown for a long time in the hill lands of the Mopan Maya (Fig. 43), with remnants of cacao groves in the forests oftimes on unexcavated Mayan ruins (Steinberg 2002). Some groves have been calculated to be as old as the time of arrival of the Mopan Maya in Belize (Steinberg 2002). Wild cacao is reportedly present in the Columbia Forest Reserve north-northeast of the Mopan villages (Steinberg 2002; Fig. 43). Cacao was also said to be grown around the Sarstoon River in southern Belize (Bergmann 1969) in the Toledo District bordering Guatemala. According to Muhs et al. (1985) there were soils and archaeological evidence that demonstrated the presence of cacao orchards in the Mayan settlement of Tipu in western Belize (near to the Guatemalan border), specifically on the floodplain. This site was considered by the authors as an important cacao-growing center during the Spanish colonial period. Muhs et al. (1985) using ethnohistoric evidence in the literature concluded that there were also cacao orchards at the colonial period Maya settlements of Chantome, Zaczuuc and Lucu on the midsection of the Belize River.

Collections

In March 1994, Mooleedhar et al. (1995) prospected the Cayo district in northwestern Belize and the Toledo district in southwestern Belize. Samples (budwood and seeds) from the Cayo District were collected from Arenal, Barton Creek, Caves Branch, Che Chem Ha Falls, Rio Frio and San Antonio. Samples (budwood and seeds) from the Toledo district were collected from Agua Carte, Big Falls, Laguna, Santa Cruz and Santa Elena.

Recent Cultivation

In the late 1970s cacao was imported from Costa Rica, but the Mayan farmers believe the local varieties to be more pest- and disease-resistant (Steinberg 2002). In southern Belize, the Mopan Mayans had cultivated cacao from 1982 to 1987 as orchard gardens with a small grove of trees for home consumption and inter-village trade (Steinberg 2002). In 1988, about 76,000 cacao seedlings were distributed (Donovan et al. 2008). Currently the Mopan Mayan cultivate cacao organically primarily because chemical inputs are unaffordable (Steinberg 2002). Conventional cacao production also exists primarily as a 400-acre plantation in Cayo district by Hummingbird Citrus Ltd. and without plan for extension at the time (Donovan et al. 2008). In contrast the organic cacao in Toledo has expanded with 1 million trees planted in 2005–2007 and with expansion into Cayo and Stann Creek districts (Donovan et al. 2008). The organic cacao cultivars are believed to be Trinitario varieties imported between 1980 and 1995 from Costa Rica and Dominican Republic (Donovan et al. 2008). Criollo white cacao was reportedly absent from the region (Donovan et al. 2008) but whether the authors meant southern Belize or any combination of Toledo, Cayo and Stann Creek was uncertain. Somarriba and Beer (2011) advocated for an agroforestry system with timber or legume service shade trees in Central America.

Genetic Studies

Mooleedhar et al. (1997) surveyed wild Criollo material in Mayan Mountain Range in Belize. This survey took samples from the Colombia River Forest Reserve in Northwestern Belize, the headwaters of the Río Grande. The survey also collected material from the Bladen River Nature Reserve in Southwestern Belize; this area is the watershed of the Bladen branch of the Monkey River. Motilal et al. (2009) assessed 77 grafted Belizean Criollo plants from the Mooleedhar et al. (1997) collection with microsatellites. A low genetic diversity and heterozygosity was present and they were tightly grouped as Criollo material and could be represented as 11 distinct accessions drawn from the AC, AGUACARTE, BANANA CREEK, CRIOLLO, C, CC, HF, HONDURAS, ST and 61B accession groups.

Flavor Quality

Over the period from 2010 to 2021, chocolate from Belize was in the best 50 International Cocoa Awards in 2013 (one batch) and 2019 (one batch) but only won in the latter. The chocolate was made from a Forastero cacao batch from San Jose Village Zone 2, Toledo, and had moderate cocoa, roast, bitterness, fresh fruit and brown fruit flavors; and low acidity, sweet, floral, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved. Areas with high Criollo samples should be revisited for more extensive collection. Two such areas are the headwaters of the Rio Grande and the eastern Columbia Forest Reserve with focus on Prasco Ha, Che Chem Ha Falls, Laguna and Big Falls (Mooleedhar et al. 1995; Mooleedhar 1999). The eastern slopes of the Maya Mountains are recommended to collect relic Criollo germplasm (Mooleedhar et al. 1995).

COSTA RICA

Overview

Costa Rica (#6 in Fig. 37) is in Central America and is bordered on the north by Nicaragua, on the east by the Caribbean Sea, on the south by Panama and on the west by the Pacific Ocean. Costa Rica produced 545 metric tons of cocoa in 2021, ranking 37th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Costa Rica exported US$1.47 million in cocoa beans, making it the 46th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/cri).

Historical Introductions

In pre-Columbian times, cacao was reportedly cultivated in Quepo, the Llanuras de Guatusos south of Lake Nicaragua, Nicoya Province and the Sixaola River Valley (Bergmann 1969 and references therein). Núñez González (2010) reported an exportation of cacao seeds from Grenada to Puerto Rico and Costa Rica during the late 19th century. Cook (1982) pointed out that in Costa Rica and Panama, since 1913–1914 and for a long period of time (cacao golden years), cocoa trade was handled by the United Fruit Co. Due to this, the cacao diversity in these countries was restricted to the varieties that the company had interest in: Amelonado and Forastero (Quesada Camacho 1977). From colonial times to the end of the 20th century, Costa Rican cacao plantations were located mainly in the low-lying district of the Caribbean coastal plain (Limon province), specifically in valley lands or nearby hillsides west from Limón. From there, cacao plantations went along the Northern Railway to the Reventazón river and also what was called the

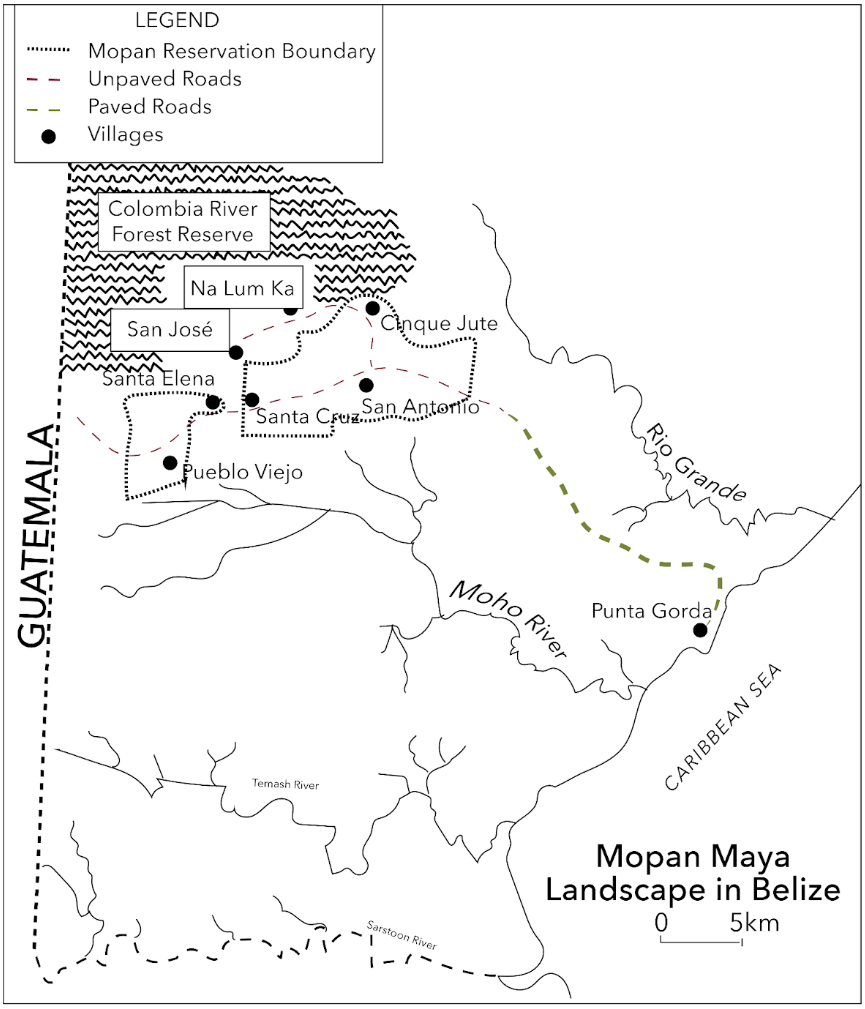


Figure 43
Mopan Mayan villages in Southern Belize. Adapted from Steinberg (2002)

"Old Line" that branched off from the main railway at La Junta. There were some isolated cacao farms in Turrialba (Rosés Alvarado 1982). A small amount was produced in the Pacific slopes of Puntarenas. There were also other small cacao spots southeast from Limon, two or three miles inland from the coast, extending to the Panama border, particularly along the Banano and Estrella rivers (Keithan 1940). During the colony, cacao farms grew in quantity and quality from the Reventazón valley to the lowlands in the Atlantic, called "The plains of Matina," rounded by the Reventazón, Pacuare and Matina rivers, where the cacao production was concentrated. As in Nicaragua, the cacao planted especially in Matina was the same materials planted by the Nicaraos and Chorotegas, and according to Rosés Alvarado (1982) there is written evidence from Spanish friars (1610 and 1660) reporting the high-quality traits of this cocoa, describing this cocoa as superior to Caracas and Guayaquil cocoa.

Genetic Studies

The Centro Agronomico Tropical de Investigación y Enseñanza (CATIE) in Costa Rica is a research institute that manages several germplasm collections. The International Cacao Collection at CATIE (IC3), like the ICGT, is an international cacao collection. Trinitario hybrids from four accession groups (ARF, PMCT, CC and UF) were highly similar with small intergroup DNA variation (Zhang et al. 2009a). The UF clones are known for their resistance to frosty pod and black pod rot (Mata-Quirós et al. 2018). Lachenaud and Motamayor (2017) note, regarding CATIE's germplasm collection, that although many of the trees are labeled "Criollo," only Criollos 12, 13 and 65 are true Criollos — the others are hybrids with some morphological characteristics in common with Criollo. This assertion is based on earlier work by Motamayor (2001), in which the author used 16 microsatellite markers to distinguish ancient Criollos from so-called Modern Criollos. Ancient or "true" Criollos were those collected from locations where contamination with other varieties was impossible or very unlikely and showing low diversity and near complete homozygosity. On the other hand, Modern Criollos were collected from regions with likely sources of genetic contamination and with a higher degree of diversity and heterozygosity.

Rondon Carvajal (1993) describes a variety known as Matina Amelonado, found on Costa Rica's Atlantic Coast. It is a white Calabacillo said to be unique to Costa Rica. Mata-Quirós et al. (2018) used 44 SNP markers to genotype 273 germplasm accessions from CATIE with particular emphasis on CATIE's 44 UF clones. The UF clones were shown to be composed mainly of hybrids involving Trinitario and Nacional genetic groups (Mata-Quirós et al. 2018). Twelve of the 44 UF clones that were identified as classic Trinitario (UF 613, 650, 652, 654, 666, 667, 668, 672, 676, 677, 678 and 679) originated from the germplasm of Trinidad and Tobago. They were selected in 1936 by the United Fruit Co. from Limon, Costa Rica (Mata-Quirós et al. 2018). Further results revealed that some of the UF clones were Nacional hybrids. These UF clones probably represented the selections of 1944–1950 that arose when indigenous germplasm in Ecuador was hybridized with Amelonado cacao in Costa Rica (Mata-Quirós et al. 2018). A more recent study used 90 SNP markers to classify 60 samples from CATIE into four genetic types: Iquitos, Nanay, Marañon and Guiana (Fister et al. 2020).

Highlighted Cultivars

CATIE R6 and CATIE R4 cultivars were identified as a most resistant and most susceptible cultivar to moniliasis respectively (Fister et al. 2020). In 2007, about 390 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Flavor Quality

Costa Rica is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). During 1988 and 1989, fermentation practices were found to be best in the Central Pacific zone and worst in the South zone (Cubero et al. 1992). Recently six high-yielding and moniliasis-resistant clones (CATIE-R1, CATIE-R4, CATIE-R6, PMCT-58, ICS-95 (T1) and CC-137) needed to have the fermentation procedure and duration adjusted to the clonal material and environmental conditions, to obtain best fermentation (Hegmann et al. 2018). Several volatile aroma compounds indicative of fine flavor were detected in fresh fruit pulps of CATIE-R1, CATIE-R4, CATIE-R6, ICS-95 (T1) and PMCT-58 (Hegmann et al. 2018).

Over the period from 2010 to 2021, chocolate samples from Costa Rica were selected in the best 50 International Cocoa Awards for 2010 (one batch), 2011 (one batch), 2013 (one batch), 2017 (one batch) and 2019 (one batch), with winners in 2011 and 2013. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch (B 1, ICS 95, ICS 39, PMCT 58 and TSH 565 cultivars) from San Carlos, San Luis, Betania, Pocosol-Cutris, Alajuela, had moderate cocoa, roast, bitterness, astringency and fresh fruit flavors; and low acidity, sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

EL SALVADOR

Overview

El Salvador is in Central America and is bordered on the north side by Guatemala, on the northeast by Honduras, on the southeast by Nicaragua and on the west by the Pacific Ocean. El Salvador produced 357 metric tons of cocoa in 2021, ranking 42nd out of 59 cocoa producing countries (World Population Review 2022).

Historical Introductions

Izalco in the west El Salvador (Sonsonate department) and Zacatecoluca in the south (La Paz department) were reportedly major cacao cultivation areas in pre-Columbian time (Bergmann 1969). According to ES-CACAO (2014), the first report of cocoa in this country was around 1524, when the Spanish conquerors entered what is now the west of El Salvador. There the settlers found large areas planted with cocoa, in the area called the Izalcos, what is now the river Paz in Ahuachapán, the mountains of Apaneca, reaching Armenia in Sonsonate. The center of cocoa production was located in what are the towns of Izalco and Caluco in Sonsonate. Cacao tribute areas, which may not necessarily be cacao growing areas, in pre-Columbian time for the confluent areas of El Salvador, Guatemala and Honduras were diagrammed by Bergmann (1969); see Fig 44.

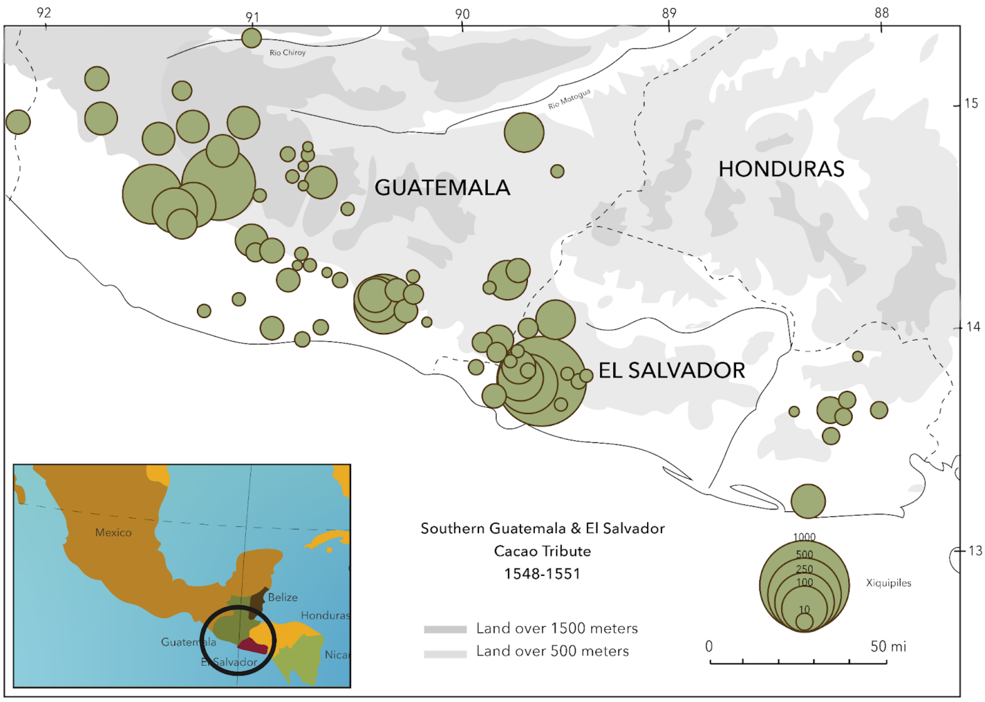


Figure 44

Cacao tributes from the Central American countries of El Slavador, Guatemala and Honduras.
Adapted from Bergmann (1969).

Xiquipiles–a special sack or bag for cacao beans or incense; or, the number 8,000, which may have been the number of cacao beans in the sack, or it meant a very large number; also, the number 1,000, such as we see in the Anales de Juan Bautista for Feb. 18, 1564; we also see xiquipilli to mean 1,000 in some Techialoyan manuscripts (Online Nahuatl Dictionary, Stephanie Wood, ed. [Eugene, Ore.: Wired Humanities Projects, College of Education, University of Oregon, ©2000-present])

In 1576, cacao production by the Spaniards was said to be recently started in Zacatecoluca (García de Palacio 1881 cited in Bergmann 1969). Two villages north of San Miguel in eastern El Salvador, Chalpetique and Xerebaltique, were said to have cultivated cacao under irrigation (Bergmann 1969).

Flavor Quality

Over the period from 2010 to 2021, one batch of chocolate sample from El Salvador was selected for the best 50 International Cocoa Awards in 2017 and one batch in 2021, and each secured a win. The entry in 2021 from Caserio Barra Ciega, Canton Tonala, Sonsonate, Occidental, was given the following flavor profile description: "Medium-light brown colour. Chocolate note blended with fruit acidity, browned fruit-dark raisin notes, and fresh fruits (berry, citrus-lemon, currant, tropical). Center note is spicy with pepper and cinnamon. Bright, balanced, complex. Finish is spicy. Slight acidic chocolate." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

GUATEMALA

Overview

Guatemala is in Central America and is bordered on the north/northwest by Mexico, on the northeast by Belize, on the east/southeast by Honduras and El Salvador and on the west/southwest by the Pacific Ocean. Guatemala produced 11,803 metric tons of cocoa in 2021, ranking 19th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Guatemala exported US$967,000 in cocoa beans, making it the 53rd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/gtm).

Historical Introductions

In pre-Columbian times cacao was reportedly continuously cultivated along the foot of the Pacific highland of Guatemala, including west of Patulul, in the Peten Basin and Quiché lowlands in the north, the Sinca area east of the Río Michatoya, the Izabal lowlands bordering the Río Polochic in the east, in the tributary valley of the Cahábon River, the coastal areas of Iztapa and Amayuca, and in the Taxisco and Guazacápan areas in the Santa Rosa Department in the south (Bergmann 1969 and references therein). The earliest recorded sighting of cacao in Guatemala was from Hernán Cortéz in 1524 as having to force his way through dense growth of forest and cacao orchards to enter the native town of Zapotitlán in Suchitepéquez province (Pedro de Alvardo 1952 cited in Bergmann 1969). The highest cacao production was reportedly from Suchitepéquez and Guazacapán. Hall et al. (1990) from theobromine and caffeine signatures showed that cacao was present in Río Azul, northeastern Guatemala.

Recent Cultivation

Guatemala established its RA clones in the 1950s (Hunter, 1990). The Departments of Alta Verapaz and San Marcos have the highest number of farms and production (Avalos et al. 2012).

Genetic Studies

The Avalos et al. (2012) expedition took place in the southern regions of Huehuetenango, Quiché, Quetzaltenango, Escuintla and Retalhuleu, leading to the collection of 180 cacao trees of different origins. Several of those with Criollo morphology have been grafted and are currently held in a clonal garden in Universidad de Valle de Guatemala Sur (Avalos et al. 2012). The results showed that the varieties with Criollo-type morphological characteristics are 15 R, 22 P, 8 P, SGU 5, 24 R and SGU 32. Quetzaltenango is particularly noteworthy for having some fruits that were round and rough and had white seeds (Avalos et al. 2012). Criollo clones collected from the various localities as well as high-production Criollo varieties from the Los Brillantes Farm, Retalhuleu, were assessed with 10 microsatellite markers. These trees comprised eight "seleccíon guatemalteca" (SGU); five types originating from Rioja, Mexico (R); three "criollos guatemaltecos" (P); and three UF clones from Costa Rica. The SGU and P clones were primarily clustered with the R clones and with one UF clone (UF 650) (Avalos et al. 2012). The R clones, better known as the RIM accessions, have about 50% Criollo ancestry (Motilal, pers. comm.).

Highlighted Cultivars

Some varieties may produce high-quality cacao (SGU 50, 105 R, UFCCO 667, SGU 88, UCO 650, 10 P, 105 R and SGU 67) and were distributed to the farmers in the "Brilliant" area (Avalos et al. 2012)

Flavor Quality

Guatemala is a 75% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Over the period from 2010 to 2021, chocolate samples from Guatemala were selected for the best 50 International Cocoa Awards in 2017 (two batches), 2019 (one batch) and 2021 (one batch), with 2, 0 and 1 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch from Cahabon, Alta Verapaz, Norte Region, had strong cocoa flavors; moderate roast, bitterness, acidity, astringency, fresh fruit, brown fruit and woody flavors; and low sweet, floral, spice and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Km 167 Carretera Ca2, Cuyotenango, Suchitepequez, Sur Occidente, was given the following flavor profile description: "Medium-light brown, reddish hue colour. Flavour starts with mild chocolate note, trace fruit acid, floral earthy/mushroom, green dried herbs, slight tobacco, nut/nut skins, and trace caramel. Balanced bitterness and astringency with chocolate complex in aftertaste. Complex, unique, harmonious, balanced." (CoEx 2021).

Recommend Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved. The farm Los Brillantes may host varieties that could be useful in Guatemala. The region between Belize and Guatemala on the southwestern region of the Maya Mountains is a good site for relic Criollo germplasm (Mooleedhar et al. 1995).

HONDURAS

Overview

Honduras (#4 in Fig. 37) is in Central America and is bordered on the northwest by Guatemala, on the north/northeast by the Caribbean Sea, on the south/southeast by Nicaragua and on the west by El Salvador. Honduras produced 751 metric tons of cocoa in 2021, ranking 35th out of 59 cocoa producing countries (World Population Review 2022). Fine or flavor cacao in agroforestry system is the main farming model in keeping with a model aligned with native peoples (Durán and Dubón 2016).

Historical Introductions

In pre-Columbian times, Sula Valley in the northwest and some coastal valleys as far as Aguán in the north had cacao (Bergmann 1969). Extensive cacao orchards were reported on both banks of Río Ulúa (Oviedo 1851–1855, cited in Bergmann 1969), which flows from northwest Honduras northeasterly into the Caribbean Sea. Woda et al. (2016) also indicated that native inhabitants other than the Mayas would have likely cultivated cacao. Woda et al. (2016) provided as an example the Pech (Payas) people who were living at the time in the Bay Islands and in northeast Honduras. It is uncertain when the Spanish colonists imported cacao to Honduras, but it is thought that it was around 1700 that Forastero cacao was introduced, and it predominated in cultivated areas until the 1970s (Woda et al. 2016). This type had fruits similar to the Matina variety and is known as Cuyamel Indio Amelonado Amarillo (Woda et al. 2016). It is believed that this latter type interbred with the remaining Criollo, giving cacao varieties with characteristics found in the Indio Amelonado Rojo (Eger 2015 cited in Woda et al. 2016).

Recent Cultivation

Criollo cacao is usually found as isolated groups of fewer than 20 trees in the wild, in the yards of farmers, or among coffee plantations in the west of the country (Durán and Dubón 2016). The principal producing areas have established plantations usually from seed with about 66% Trinitario cacao and 34% Forastero cacao (Durán and Dubón 2016). Over the entire country, it is estimated that 85% of the cultivated cacao is Trinitario (Durán and Dubón 2016) with about 1% Criollo (Woda et al. 2016). The Forastero type, Indio Amelonado Amarillo, predominated in the adult plantations in the Cortés department, while Trinitario-type cacao occupied most of the cultivated area on farms in the departments of Atlántida, Copán, Yoro, Gracias a Dios and Santa Bárbara (Durán and Dubon 2016). In the years 1970 to 1990, Trinitario cacao was favored for propagation and distribution (Woda et al. 2016). In 1986, an international collection of cocoa germplasm was established at CEDEC-JAS in La Masica, Atlantida, by Fundación Hondureña de Investigación Agrícola (FHIA), and 40 clones were selected for reproduction and distribution within Honduras and to the neighboring countries of Guatemala, El Salvador, Belize and Nicaragua (Woda et al. 2016). Trinitario cultivars from CATIE have also been distributed as budwood and as hybrid seeds from open or controlled crosses (Woda et al. 2016).

A set of 136 Criollo-like trees were identified across 21 sites from the survey of 527 farms across eight Departments (Durán and Dubón 2016). Both red- and yellow-fruited Criollo-type trees were found (Fig. 45) as well as Forastero types locally called Indio Amelonado Amarillo and Trinitario types (Durán and Dubón 2016). Criollo-type and productive trees were identified (Fig. 46 top) and 21 farms were identified with Criollo trees (Fig. 46 bottom).

Figure 45
Typical fruits from Criollo-like cultivars in Honduras.
Fruits from the Departments of Olancho (left) and Santa Bárbara (right) in Honduras.
Taken from Durán and Dubon (2016)

Figure 46
Selected cacao trees in a country-wide survey of Honduras (Durán and Dubon 2016).
Top Criollo and promising trees characterised by high production,
low incidence of diseases and pests, good structure and good vigour.
Farms numbered with the best candidate Criollo trees.

Genetic Studies

Ji et al. (2013) used 70 SNP markers to investigate genetic diversity in 32 fine-flavor farmer selections (14 Criollo, 13 Honduras Trinitario, two Indio Amarillo, two Indio Alargado Amarillo and one Indio Rojo) from Honduras. There are no details about where any of these accessions were collected. Most of the perceived Criollo types were pure Criollo, and the Indio types were Amelonado. However, the Honduras Trinitario types were clustered with Nacional hybrids and reference Upper Amazon Forastero varieties in agreement with breeding activity from introduced Nacional-Upper Amazon Forastero hybrid germplasm from CATIE (Ji et al. 2013).

Durán and Dubón (2016) reported that 68% of 50 selected Criollo-like trees were pure or almost pure Criollo with the other 32% having Forastero background to as much as 20% as well as Nacional or Iquitos ancestry. López et al. (2021) carried out a follow-up study on 89 farmer selections with Criollo-like phenotypic traits from four Departments of Honduras: Copán, Santa Bárbara, Intibucá and Olancho (Fig. 47).

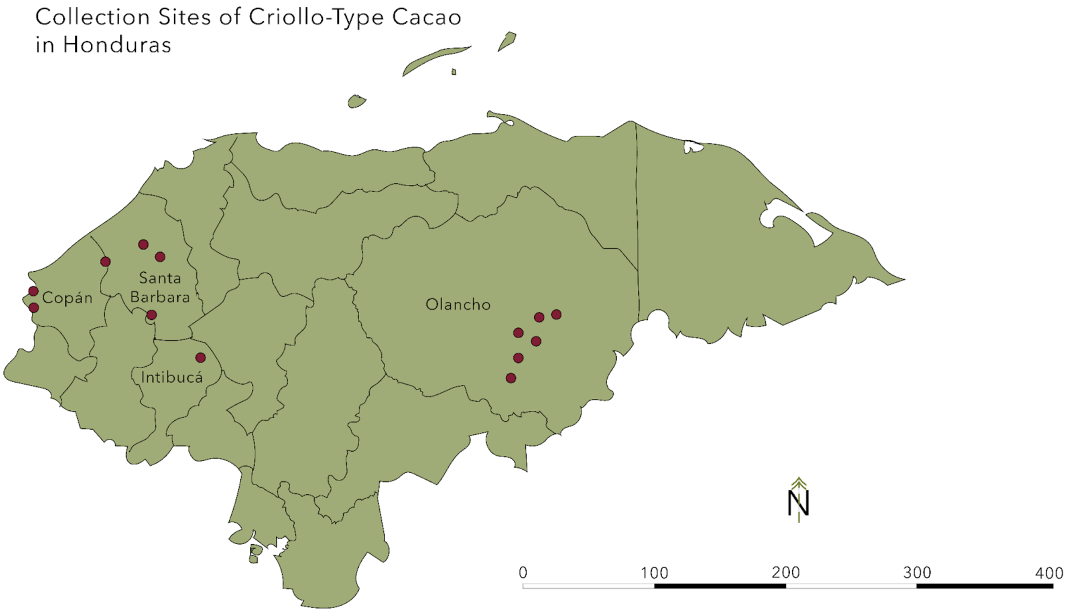


Figure 47
Sites of farmer selection of Criollo-type phenotypes, adapted from Lopez et al. (2021)

The study amplified 88 alleles from 16 SSRs in the Honduras data set and identified 57 unique trees across the four departments, with each department retaining a cultivar if present in more than one department (López et al. 2021). Thirteen of these 57 samples had little Criollo background and the majority were Criollo hybrids. The non-Criollo background was not precisely identified by the authors, but the cluster diagram indicated likely contributions from the Amelonado, Guiana, Iquitos, Marañon and Nanay groups.
Samples with more than 50% Criollo ancestry were found in Copán (COP 22, 23, 24, 28, 29), Santa Bárbara (SAN 3, 4, 7, 19, 20, 21, 90, 93, 94, 100, 104, 106, 107, 109), Intibucá (INT 52, 54, 55) and Olancho (OLA 10, 11, 14, 15, 57, 60, 62, 63, 69, 79, 85, 86). There were eight pure Criollo samples, five from Copán (COP 22, 23, 24, 28, 29) and three from Santa Bárbara (SAN 106, 107, 109). Examples of the collected fruits are provided in Fig. 48 for comparison, but the original photo appears to be distorted in comparison to that of Durán and Dubón (2016).

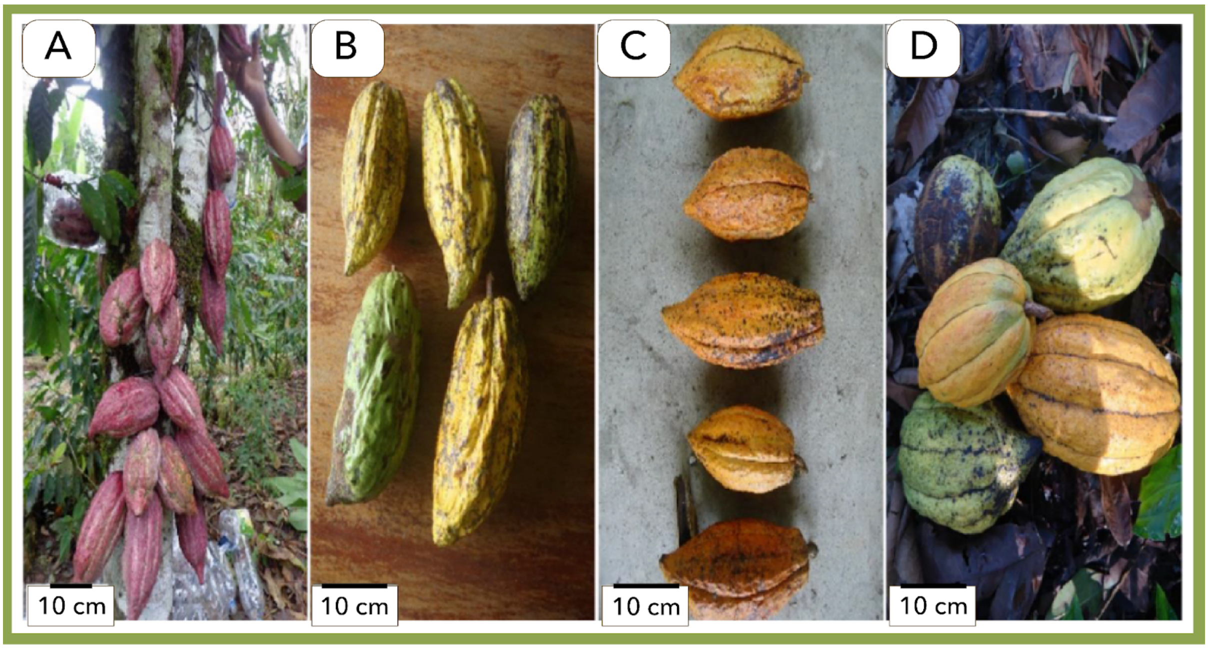


Figure 48
Cacao fruits from Honduras collected from four regions
Collected from the region of (A) Copán, (B) Intibucá, (C) Olancho and (D) Santa Bárbara. Taken from López et al. (2021).

Flavor Quality

In 2016, Honduras was positioned as a 50% exporter of fine and flavor cacao (ICCO 2016–2020c). Durán and Dubón (2016) reported that five samples of Criollo cacao had mild cacao flavor, very low astringency, and herbal, floral, fruity and nutty aromas. Two samples from Copán Ruinas, Copán, had a fruity citrus flavor with notes of pineapple combined with ripe orange in one sample and ripe mango in the other. A sample from El Níspero, Santa Bárbara, had walnut and almond notes while the sample from Pinabete, Santa Bárbara, was said to have aromatic qualities characteristic of herbs and flowers with a predominant flavor of nuts and almonds (Durán and Dubón 2016). Over the period from 2010 to 2021, chocolate samples from Honduras were selected for the best 50 International Cocoa Awards in 2010 (one batch), 2011 (one batch), 2013 (two batches), 2015 (one batch) and 2017 (one batch), with one win each in 2013 and 2015 (CoEx 2010, 2011, 2013, 2015, 2017; Woda et al. 2016).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

NICARAGUA

Overview

Nicaragua (#5 in Fig. 37) is in Central America and is bordered on the north/northwest by Honduras and El Salvador, on the east by the Caribbean Sea, on the south by Costa Rica and on the west by the Pacific Ocean. Nicaragua produced 6,600 metric tons of cocoa in 2021, ranking 25th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Nicaragua exported US$9.98 million in cocoa beans, making it the 31st largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/nic).

Historical Introductions

In pre-Columbian times, cultivated cacao was restricted to the Pacific region with minor cultivation in Léon and Granada and possibly at Nueva Jaén at the head of the San Juan River (Bergmann 1969). Oviedo (1851–1855 cited in Bergmann 1969) reported that it was the Nicarao immigrant natives that introduced cacao to Nicaragua. The Nicarao immigrants were said to have split around 1200 AD from the Pipil people in El Salvador, who in turn were said to have migrated from central and southern Mexico (Fowler 1985). Hart (1900) reported that the main variety distributed in this country was Criollo that, as the norm, was later combined with Forastero. Spaniards recorded the presence of big cacao plantations in the Nicarao kingdom. The Nicarao were an indigenous group originally from Cholula (Mexico) who emigrated south shortly after the Chorotega, escaping the Olmec expansion. In 1745, Bishop Morel de Santa Cruz reported 310 cacao farms with 1,350,545 trees in Valle de Rivas (Morel de Santa Cruz 1752). For 1751 the Spanish cacao farms covered 10–15% of the current area of Rivas (Nicaraocalli 2014).

In 1893, there was a shipment of 25,000 plants from Trinidad to Nicaragua (Hart 1900).
Van Hall (1914) stated that the Nicaraguan Criollo was similar to the red-fruited Venezuelan Criollo but with a rougher surface, deeper furrows, long tapering point and larger seeds. This type was reportedly grown in Soconusco and Tabasco (Van Hall 1914).

Recent Cultivation

The largest cacao-producing regions are Waslala and Rancho Grande in the central northern part of Nicaragua (Trognitz et al. 2011). Commercial planting in these regions started around 1961 (Rios 2007 cited in Trognitz et al. 2011). Trognitz et al. (2011) reported that farmers found few pre-existing cacao trees when they first arrived at their farms in the 1970s and 1980s but did not provide any documentation or citation. The National Institute of Agriculture and Technology (INTA) houses cacao germplasm and introduced about 180 clones in the 1970s and 1980s from Colombia, Costa Rica and Mexico (Aragon Obando 2009). In 1978, INTA introduced 189 clones from Africa, Costa Rica, Indonesia, Jamaica and South America (Aragon Obando 2009). After evaluating these clones for 25 years, superior clones for resistance to disease (black pod and frosty pod) were selected as parental types yielding 14 hybrids that were widely distributed throughout Nicaragua (Aragon Obando 2009). In the 1980s, seeds from CATIE were imported, some of which were planted at Waslala (Trognitz et al. 2011). Forty clones were also imported from Honduras (Woda et al. 2016) some time after 1986. However, introduced cacao to Waslala is primarily as seedlings, which are preferred by farmers as propagation material, although the farmers have reportedly brought in both seed and budwood from other regions (Trognitz et al. 2011). In 2003, INTA started collecting Criollo material from Nicaragua including the Caribbean and Pacific Coast (Aragon Obando 2009). Although CATIE clones were present since 1981, Criollo was said to exist in the area but morphologically Criollo-type material was hardly encountered (Trognitz et al. 2013). In 2007, about 1,546 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Genetic Studies

Motamayor et al. (1998) reported on the presence of Criollo material during a search along the Pacific Coast of the country. Cacao material that was similar to the Mexican Criollo cocoa found in four areas (Lacandon Forest, Yucatan state, Tabasco state and Michoacan state) was found by a house with four trees in La Libertad de Chontalpa, a mining town with no evidence of cocoa cultivation (Motamayor et al. 1998).

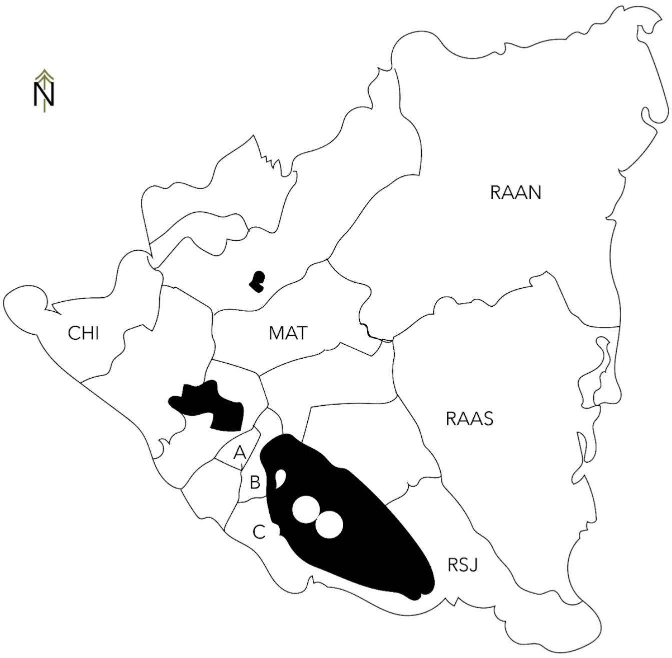


Figure 49
Map of Nicaragua illustrating the collecting regions of and modified from Aragon Obando (2009). RAAS (Región Autonoma del Atlántico Sur), RAAN (Region Autonoma del Atlántico Norte), RSJ (Rio San Juan), MAT (Matagalpa), Chi (Chinandega) and Pacifico Sur (A - Masaya, B - Granada and C - Rivas).

Aragon Obando (2009) collected 60 farmer accessions across six geographical regions (Fig. 49) from 2003 to 2008 based on Criollo characteristics: a trunk with a single plagiotropic branch, pale green flush leaves and white staminodes on flowers, elongated fruits with a pointed apex and a rough ridged surface, and large white cotyledons.

The on-farm cacao trees were assessed with 155 markers from nine microsatellites and provided evidence for the genetic similarity of Matagalpa region with all others but Region Autonoma del Atlántico Norte (Aragon Obando 2009). The results of Aragon Obando (2009) also support the similarity of Region Autonoma del Atlántico Norte, Rio San Juan and Pacifico Sur to each other whereas Región Autonoma del Atlántico Sur and Chinandega was different from all others except Matagalpa. Individuals from the eight regions were dispersed amongst each other in a phylogenetic tree without forming geographical sets. The cultivars RAAS (045, 041) and RAAN 0404 were the most distinctive, being individual items rather than belonging to any of the phylogenetic clusters (Aragon Obando 2009). Farmer cultivars from Rio San Juan and Chinandega were more related to the reference breeding accessions, whereas Región Autonoma del Atlántico Sur and Pacifico Sur were more related to the Criollo reference (Aragon Obando 2009). The cladogram of Aragon Obando (2009) also indicated that the cultivars H 6, CHI 0409 and RAAS 0413 were closely related to the Yucatan reference from Mexico followed by RSJ0406 and CHL 0414. The closest cultivar to the Criollo reference was MAT 0404, which formed its own cluster, with the closest sister cluster comprising six selections (RAAS 0412, MENIER 0108, RSJ 0501, RSJ 0405, RSJ

0403 and MAT 0401) and then associated clusters containing RAAS 0411, RSJ 0402, RSJ 0508, MAS 0401, H 3 and H 5 cultivars.

Ruiz et al. (2011) studied 70 trees collected from five areas in southeast Nicaragua (El Castillo, El Rama, Los Guatusos, Muelle de los Bueyes and Nueva Guinea) with 95 markers from 10 microsatellites. This study found that El Castillo and Los Guatusos were more closely related to each other but different from the other three regions, which were similar to each other. Phylogenetically, samples from the Los Guatusos region were the most distinct from all others, whereas Nueva Guinea and El Rama was the closest pair.

Trognitz et al. (2011) studied 317 trees from 45 sites in Waslala inclusive of two orphan trees (latitude -85.4451, longitude 13.1486) from recently cleared forest with 116 markers from 15 microsatellites. Three main backgrounds were found (Fig. 50), with presumed Criollo ancestry over 95% being found only in the two orphan trees. All the other trees were variously mixed with various combinations of the three ancestral lines, and only one tree from one farm (F204, county Zinica) had over 50% presumed Criollo ancestry, with estimated background of 14% lineage 1, 23% lineage 2 and 63% presumed Criollo ancestry. The Amelonado Común type was confined to trees with lineage 1, Acriollado-type fruits (white seeds and fruit resembling Criollo) were overrepresented in trees with lineage 1 ancestry, and Hibrido type fruits (variable intermediate shape, acuminate apex, crosses of Forastero and Criollo) were overrepresented in lineage 2 (Trognitz et al. 2011). Trognitz et al. (2013) provided an ancestry plot for 100 trees from Waslala that demonstrated high admixture from various combinations of Lower Amazon Forastero, Upper Amazon Forastero, Upper Amazon Forastero from coastal Ecuador and Criollo.

Ji et al. (2013) surveyed 52 farmer selections in Nicaragua (31 Nicaragua Trinitario, 16 Criollo, two Indio Rojo, one Forastero, one Indio Amarillo, one Trinitario) with 70 SNP markers. Most of the non-Criollo selections were dispersed amongst reference Trinitario accessions, whereas the perceived Criollos were true Criollo samples. Matagalpa 13, Matagalpa 20, Oscar, Francisco, Mercedes and Tiburcio (1, 2, 3, 4, 5) were true pure Criollo accessions. Although Lachenaud and Motamayor (2017) using 15 microsatellites found that the Nicaraguan clone Matagalpa 16 was a true Criollo, this cultivar was positioned within Trinitario samples by Ji et al. (2013).

Highlighted Cultivars

Trognitz et al. (2013) assessed farms in Waslala for yield potential during two harvest seasons: 93 trees in the first season and 90 of the same trees in the second. The results showed that the average yield from the superior Trinitario trees was around 6.4 to 6.7 kg/tree. Twenty of the best trees (genetic backgrounds, quality attributes and yield potential) were selected for propagation and distribution but were not disclosed.

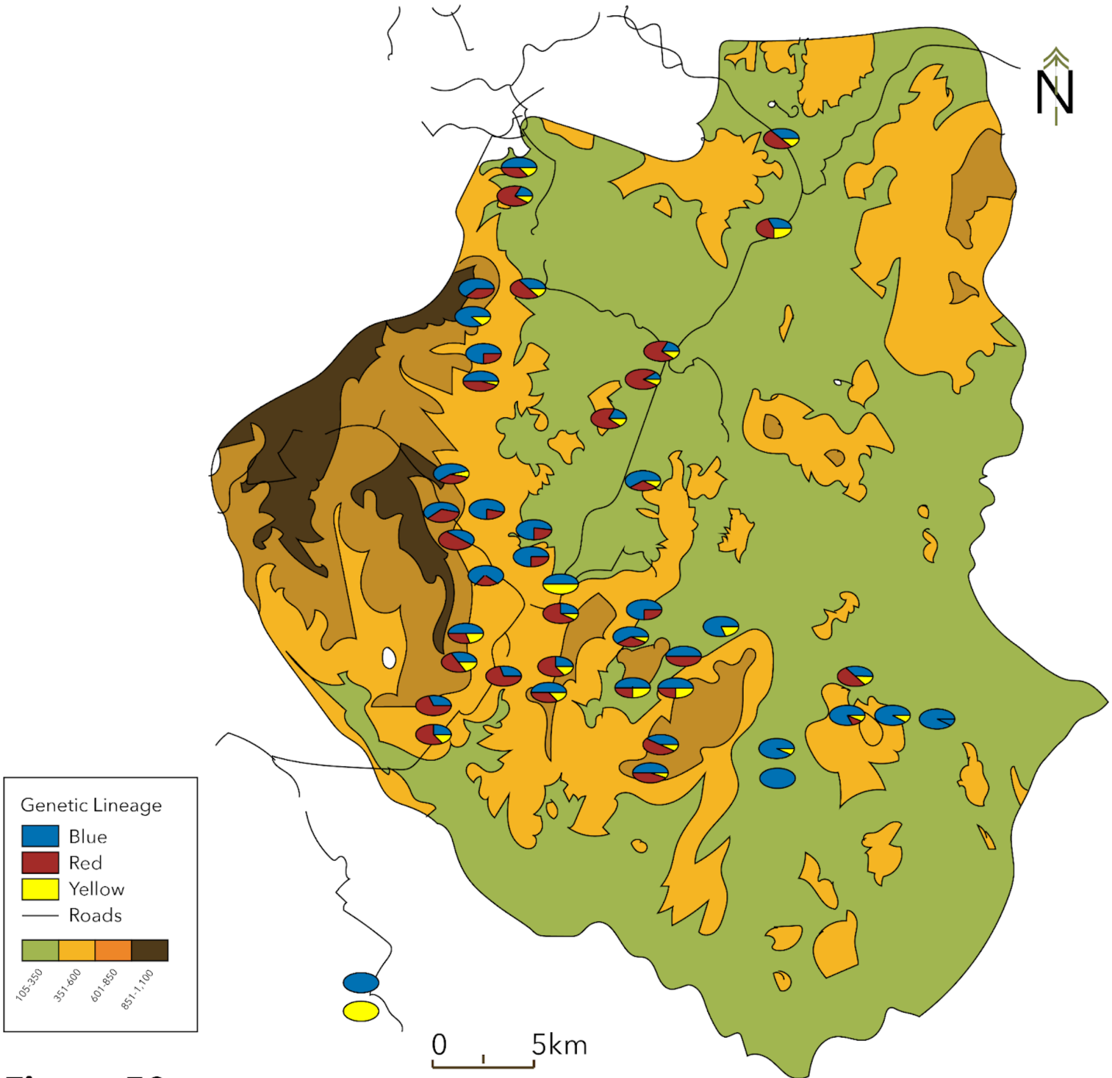


Figure 50

Sampling sites in Waslala of central northern Nicaragua
and the frequency of the three main genetic backgrounds for each farm.
Taken from Trognitz et al. (2011). Yellow represents presumed Criollo ancestry.

Flavor Quality

Cook (1982) stated that Nicaraguan cocoa as native Criollo had large, lightly colored beans that could be eaten as raw or lightly roasted nuts. Nicaragua is an 80% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Trognitz et al. (2013) assessed 100 trees from Waslala and found that 68% had a theobromine:caffeine ratio typical of Trinitarios. Trognitz et al. (2013) assessed flavor quality by major genetic group in their highly admixed samples and found that this significantly affected theobromine:caffeine ratio, astringency, global score and dry fruit aroma. However, these authors did not report on flavor profile by farm or county or on the region as a whole. Nevertheless Trognitz et al. (2013) reported scoring fresh fruit, dry fruit, fresh seed, dry seed, floral aroma, woody and spiciness, with spiciness only being significantly correlated to sweetness in a positive relationship.

Over the period from 2010 to 2021, chocolate samples from Nicaragua were selected for the best 50 International Cocoa Awards in 2013 (one batch), 2015 (one batch), 2017 (one batch), 2019 (one batch) and 2021 (one batch), with wins being secured in only 2015 and 2021. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch from Comunidad El Balsamo, Municipio de Matiguás, Departamento de Matagalpa, Region Centro, had strong cocoa flavor; moderate roast, bitterness and astringency; and low acidity, sweet, fresh fruit, brown fruit, floral, spice, woody and nutty flavours (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Comunidad La Tronca, La Dalia, Bocas del Toro, was given the following flavor profile description: "Intense dark-red colour. Chocolate and spice (cinnamon, pepper) notes appear immediately along with browned fruit and floral earthy and green herbal. Spice becomes more predominant into the aftertaste along with slightly increased bitterness and astringency. Unique." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

PANAMA

Overview

Panama (#7 in Fig. 37; Fig. 51) is in Central America and is bordered on the northwest by Costa Rica, on the north/northeast by the Caribbean Sea, on the southeast by Colombia in South America and on the southwest/west by the Pacific Ocean. Panama produced 662 metric tons of cocoa in 2021, ranking 36th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Panama exported US$1.76 million in cocoa beans, making it the 43rd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/pan).

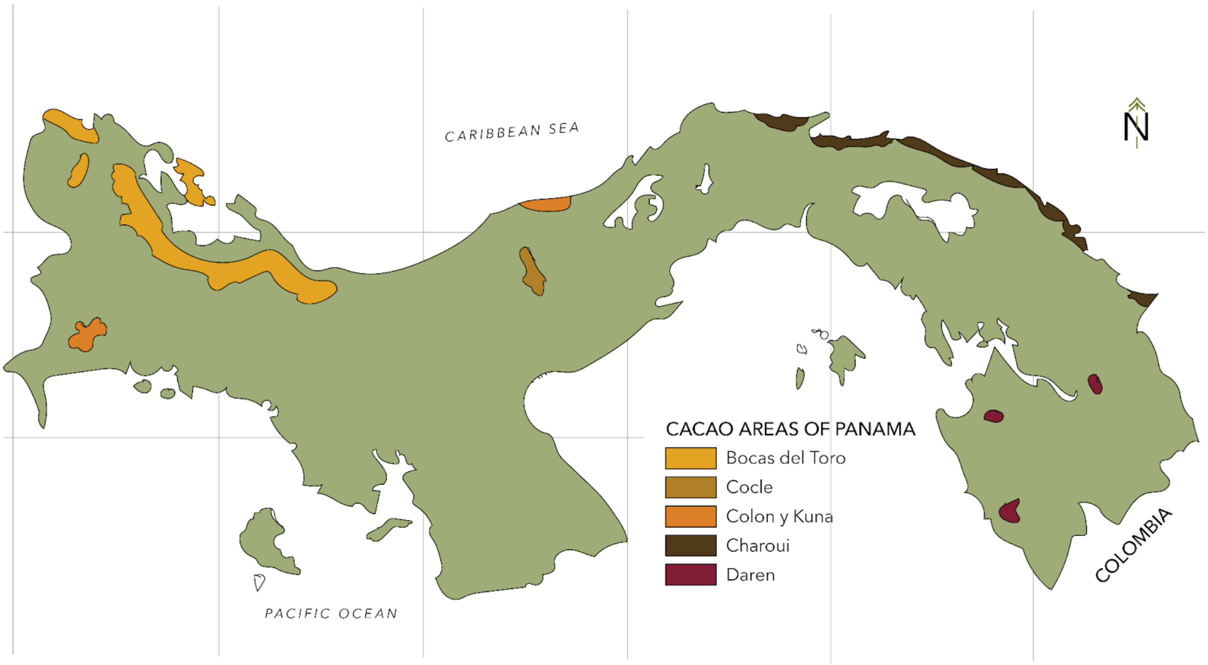


Figure 51
Map of the cocao areas of Panama (Miranda 1992)

Historical Introductions

In colonial times, cocoa in Panama was produced mainly in the northern (Atlantic-influenced) part of the country, in Bocas del Toro, which by that time was part of Talamanca, Costa Rica (Somarriba and Beer 1999). Hart (1900) reported 40-foot-tall trees were found in 1885 in the province of Veragua, Colombia, now Panama.

Recent Cultivation

The Choco Indians in Darien, Panama, were reported by Covich and Nickerson (1966) to have a low incidence of cacao trees along the Rio Chucunaque (one of 13 sites) and the Rio Chico (two of 13 sites). These cacao trees were said to be introduced instead of being native forest trees (Covich and Nickerson 1966). Likewise, the San Blas or Cuna Indians, who have few habitations on the mainland of Comaraca de San Blas and predominantly live on its associated islands in the Caribbean Sea, are said to cultivate cacao trees on the mainland (Jelliffe et al. 1961). Cocoa production zone by the early 90s when the production started to fall was still in Bocas del Toro (Changinola, Almirante y Chiriqui), from the Costa Rican border to the Cricamola river basin; up and down the coast of Colon and Kuna Yala, in limited sectors from Belen river to the west to Obaldia port close to the Colombian border; and in Coclesito, between Cocle and Colon. Also, in the Pacific influence zone: Progreso, Bugaba, Yaviza y Jaque en el Darien, close to the Colombian border (Miranda 1992). In 2007, about 4,850 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Flavor Quality

Panama is a 50% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Over the period from 2010 to 2021, three batches of chocolate samples from Panama were selected for the best 50 International Cocoa Awards in 2021, each of which secured a win. A winning entry from Los Caucheros, Antes del Centro de Salud, Los Caucheros, Bocas del Toro, was given the following flavor profile description: "Dark reddish-brown colour. Flavour emerges slowly then deepens with chocolate, herbal, mild fruit acidity, earthy, slight overripe browned fruit (prunes) notes, then trace orange and banana skins, slightly elevated bitterness and a velvety, balanced astringency." (CoEx 2021). The second winning entry in 2021, from Almirante, Comunidad de Nuevo Paraiso, Quebradas Limon, Nuevo Paraiso, Bocas del Toro, was given the flavor profile description: "Dark brown colour. Soft, smooth mouth melt with early chocolate note blended with fruit acid and trace acetic (balsamic), browned fruit, mild fresh fruits, dark wood notes. Cocoa is balanced and blended with bitterness and astringency. Long chocolatey finish." (CoEx 2021). The third winning entry in 2021, from Ojo De Agua, Almirante, Bocas del Toro, was given this description: "Medium dark brown colour. Soft, smooth mouth melt with early chocolate note blended with fruit acid and trace acetic (balsamic), browned fruit is prune-like and accompanied by bitterness and astringency (banana fresh fruit notes). Some floral herbal and flowers in the center taste." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

SOUTH AMERICA

South America (Fig. 52) is the ancestral home of cacao, with suitable growing regions across the width of the continent. The largest country, Brazil, is home to Amelonado, the most dispersed bulk variety. Fine flavor cocoa as Criollo and Nacional is found in Venezuela and Ecuador. Rare or newly recognized clusters like the Chuao in Venezuela, Beni in Bolivia and Chucho in Peru are present.

1. Ecuador
2. Colombia
3. Peru
4. Venezuela
5. Brazil
6. Bolivia

Figure 52 Cocoa countries in South America.
Adapted from http://chocolatecodex.com/portfolio, countries-of-origin/

Groups of cacao trees are often found as part of the forest vegetation of the upper and middle tributaries of the Amazon and upper tributaries of the Orinoco, and along some river systems in the Guyana shield (Patiño 2002, cited in Somarriba and Lachenaud 2013). The term "wild cacao" is used to describe trees arising out of natural dispersal via seeds or plants and trees that arise from the practices of early human civilization (Somarriba and Lachenaud 2013). Bartley (2005) stresses the difficulty in determining whether a given cocoa stand is wild or semi-wild and indicates that the former may remain for more than two centuries at any one site.

Ecologically, wild cacao is a riparian species that grows well (but not exclusively) on the alluvial river banks, especially on the high terraces of large rivers rather than of small rivers up to 600–900 m altitude or higher near the equator (Somarriba and Lachenaud 2013). Wild cacao will also grow in lowland humid places (Myers 1930; Lachenaud and Sallée 1993) and semi-wild cacao may be found on "elevated islands" (relics of Precambrian shield domes) in the seasonally flooded plains of Moxos, Bolivia (see Somarriba and Lachenaud 2013).

The habit of wild cacao can occur as individual trees each with one trunk, but this habit is seldom found (Somarriba and Lachenaud 2013). Sibling individuals, each with several trunks (up to 50 or more; Allen 1988), that form patches of genetic sub-populations (Lachenaud and Zhang 2008) are usually found. Another common habit is that of genetically homogeneous clonal stands that develop from chupons anchored to the ground independently of a fallen cacao tree, and after the latter rots, the old chupons are separated as if they are different trees (Myers 1930; Allen and Lass 1983; Allen 1987; Sabatier and Prévost 1987; Lachenaud and Sallée 1993; Bartley 2005).

Cocoa population densities in the wild vary from five to 10 trees per hectare in Ecuador and Colombia (Allen and Lass 1983; Allen 1987) to 31 trees per hectare along the high Camopi river in French Guiana (Sabatier and Prévost 1987; Lachenaud and Sallée 1993). In the mountains and valleys along the Jí-Paraná river, a tributary of the Madeira, wild cacao stands may cover several hectares and have "high tree densities" (Bartley 2005).

At least 30 collection expeditions have been undertaken in South America since 1930 (Tables 3 and 4; Lockwood and End 1993; Zhang and Motilal 2016). Collections were predominantly along the river systems and basins within the Amazon Basin where wild cacao populations were present. The Upper Amazon region that stretches from the Marañn River to Brazil is a collection point for many rivers, and groupings of wild cacao populations have been found on a number of riverbanks. These include the Santiago, Morona, Pastaza, Nucuray, Nanay, Urituyacu, Chambira, Tigre, Napo, Huallaga, Ucayali, Javary, Putumayo, Japura, Purus and Rio Negro systems (Zhang et al. 2011a).

Pound discovered fruits that he called "Criollos de la Montagne" on the banks of the Napo and Ortegaza rivers. These varieties had "blanco, warty lagarta, with splashes of red pigmentation on the ridges." Pound was convinced that this population represented the wild cocoa population from the Rio Napo to the foothills of the cordilleras north of there (Lachenaud and Motamayor 2004). Describing cocoa in the Amazon river valley, Pound claimed that all fruits in the valley were either green or "blanco" and only when it was near to Colombia did the fruits gain some pigmentation (Lachenaud and Motamayor 2004).

Some of these more recent collections include the French Guiana collections and the ICT-USDA collections (Zhang et al. 2011a). The French Guiana collection took place in 1987, 1990 and 1994. Material from 215 mother trees was collected from along the Camopi and Tanpok rivers. This material would eventually be distributed to Cameroon, Costa Rica, Côte D'Ívoire, U.K., Philippines, Togo and Trinidad and Tobago. In 1990, a second expedition to the Upper Oyapok and Kérindioutou rivers was done to collect material from 27 mother plants from the Borne 7, Kérindioutou and Pina populations. In 1995, 46 pods were collected from 34 mother trees along the Eulepousing, Oyapok and Yaloupi rivers. All the material was eventually planted in plots in Sinnamary, French Guiana (Zhang et al. 2011a).

Table 3 Cacao collection expeditions from Lockwood and End (1993)

Collector	Year	Area explored	Number of accessions	Location of primary collection	ICGD survivors	ICGT survivors
Myers	1930	Surinam	2 pods	Trinidad	1	1
Pound	1937-38	W. Ecuador	80 half-sib families	Trinidad	-	1185
Pound	1937-38	Peru, Colombia	25 half-sib families	Trinidad	587	486
Pound	1942	Peru	32 clones	Trinidad	28	19
Desrosiers, von Buchwald	1949	Ecuador Oriente	26 clones	Pichilingue	3	0
Anglo-colombian	1952-53	Colombia	17 populations	Trinidad	15	45
Doak, Ampuero, von Buchwald	1958	Ecuador Oriente	4 clones	Pichiligue	2	0
Doak, Zambrano	1961	Ecuador Oriente	46 clones	Pichilingue	2	0
Soria	1964	Peru, Bolivia	5 clones, 5 pods	Alto Beni, Turrialba	0	0
International	1965	Brazil: Para, Amazonas, Rodonia, Acre	55 clones	Belem or Santarem	38	4
Brazilian	1967	Brazil: Amazonas, Acre	34 clones	Belem	22	4
Chalmers	1968	Ecuador Oriente	51 clones, 12 half-sib families	Pichilingue	13	11
Smithsonian	1969	Colombia	9 clones	unknown	1	0
Chalmers	1969	Ecuador Oriente	23 clones, 12 half-sib families	Pichilingue and Trinidad	9	8
Chalmers	1970	Ecuador Oriente	53 clones, 32 half-sib families	Pichilingue and Trinidad	12	19

Collector	**Year**	**Area explored**	**Number of accessions**	**Location of primary collection**	**ICGD survivors**	**ICGT survivors**
Chalmers	1972	Ecuador Oriente	54 clones, 7 half-sib families	Pichilingue and Trinidad	22	3
Chalmers	1973	Ecuador Oriente Brazil, Peru Peru	54 clones, 22 half-sib families 35 clones, 17 half-sib families	Pichilingue and Trinidad Pichilingue and Ecuador	35 32	2 9
Besse	1973	Ecuador Oriente	16 clones, 4 half-sib families	Pichilingue Brazil, France	0	0
ICA	1978	Colombia	75 trees?	Palmira	unknown	unknown
Allen	1980–1985	Ecuador Oriente	417 trees as budwood or seed	281 at San Carlos	255	103
IBPGR	1983	Colombia, Pacific	76	Palmira	49	0
Corporacion de Araracuara, Allen and others	1984	Colombia, Rio Caqueta	99 clones, 33 half-sib families	Palmira	0	9
IRCC	1984	French Guiana	149 accessions	Montpellier	142	0
IBPGR/ICA	1986	Colombia	293	Palmira	93	0
Venezuela/France	1986	Venezuela	38	FONIAP	14	0
IBPGR	1987	Bolivia	21	La Joto & La Paz	0	0
IRCC	1987	French Guiana	248	Montpellier	223	0
IBPGR	1988	Venezuela	26	FONIAP	1	0

Table 4 Cacao germplasm groups collected from major Amazonian expeditions.
Modified from Zhang and Motilal (2016) and CacaoNet (2012)

Major Collecting Expeditions	**River Basins**	**Number of mother trees**
Refractario (1937)	Upper Amazon in Ecuador	80
Pound (1938–1943)	Marañon, Morona, Nanay, Ucayali	32–48
Anglo-Colombian (1952–1953)	Apaporis, Caguán, Caquetá, Cauca, Inírida, Negro, Putumayo, Vaupés	191
Chalmers (1968–1973)	Curaray, Coca, Napo, Putumayo	184
IBPGR-Bolivian (1974)	Rio Beli	21–43
Brazilian (1965–1967; 1976–1991)	36 river basins including Acre, Amapá, Amazonas, Baixo, Iaco, Jamarí, Japurá, Jarí, Ji-Paraná, Maicuru, Pará, Purús, Rondônia, Solimões, Tarauacá	144; 940
LCT EEN (1979–1987)	Curaray, Coca, Napo, Putumayo	255
Peruvian (1987–1989)	Ucayali	51
French Guiana (1990, 1995)	Camopi, Euleupousing, Oyapok, Tanpok, Yaloupi	187
ICA and IBPGR	Colombia	151
UWE Guyana (1998)	Guyana	31
ICT (Peru), INCAGRO/USDA (2008v)	Aypena, Madre de Dios, Marañon-Charupa, Morona, Nanay, Napo, Nucuray, Pastaza, Putumayo, Santiago, Tigre, Ucayali, Ungumayo, Ungurahui, Urituyacu, Urituyacu Chambira,	540–666
Cacao Ancestors of the Nacional Variety Collection (CAN) (2010) (Silvestres Aromáticos)	Southern Ecuadorian Amazonia	71

The ICT-USDA Collection of 1998 collected 198 samples along seven rivers in the Peruvian Amazon (Rio Marañon, Rio Santiago, Rio Pastaza, Rio Nucuray, Rio Urituyacu, Rio Tigre and Rio Putumayo). The trees propagated from this material were planted in Tarapoto, Peru, but evaluations were not conducted at the time (Zhang et al. 2011a).

The collected germplasm is an important source of genetic material for breeding for superior varieties. Material was initially collected based on productivity and resistance to diseases. In an analysis of 816 accessions at the ICGT between 1998 and 2004, the Forastero population was found to contain more varieties with resistance to black pod disease (18%) than the material from the Trinitario population (4.8%). Most of this resistance in the Forastero material was from the Parinari accession group in the Marañon genetic group (Zhang et al. 2011a). Zhang and Motilal (2016) indicated that a total of 520 wild tree samples were collected from 19 river basins in the Amazon. These samples are part of an ongoing experiment in Tarapoto, Peru, to investigate flavor and disease resistance (Zhang and Motilal 2016).

BOLIVIA

Overview

Bolivia (#6 in Fig. 52) is in South America and is a landlocked nation bordered on the north by Colombia, on the northeast to southeast by Brazil, on the southeast by Paraguay, on the south by Argentina, on the southwest by Chile and on the northwest by Peru. Bolivia produced 5,518 metric tons of cocoa in 2021, ranking 26th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Bolivia exported US$1.01 million in cocoa beans, making it the 52nd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/bol).

Historical Introductions

Hvistendahl (2008) reports thousands of forest islands called chocolatales in the Bolivian Amazon as in the Llanos de Mojos in the Beni with cacao trees that may have been cultivated by the early natives. Jesuit missionary records from 1772 indicate that the Baure people in Llanos de Mojos were renowned for their chocolate. Introduced cacao cultivation from the colonials in Bolivia dates from the 18th century from the Jesuit and Franciscan missionaries (Romina Villegas and Carlos Astorga 2005; Somarriba and Trujillo 2005; Bazoberry Chali and Salazar Carrasco 2008). The missionaries then spent the next 150–200 years assisting the locals in the colonial-introduced methods of cacao cultivation. The Bolivian National Cacao (CNB), locally called "criollo," was cultivated by the Mosetene natives in Alto Beni for more than 100 years (Alvim y Machicado 1962 cited in Romina Villegas and Carlos Astorga 2005). From 1960, hybrids and international clones were introduced, leading to many abandoned CNB plantations (Romina Villegas and Carlos Astorga 2005). Hybrid seeds from two crosses (SILECIA 1 × SCA 6 and SILECIA 5 × SCA 6) were imported from Ecuador, Peru, and Trinidad and Tobago and used to establish the first modern plantations (Somarriba and Trujillo 2005). Later budwood from the international collection that became the ICGT was imported, and hybrid seeds were produced from manual pollinations when these varieties became established and germplasm at the Sapecho Experimental Station (Somarriba and Trujillo 2005). In 1980 and 2001 germplasm was introduced from CATIE in Costa Rica and the Intermediate Quarantine Station of the University of Reading in the United Kingdom (Somarriba and Trujillo 2005). Between 2002 and 2005, CCN 51 from CATIE and local superior material were also introduced to the gene bank (Somarriba and Trujillo 2005), and hybrid seeds from controlled crosses using the germplasm from Trinidad, CATIE and U.K. were produced and disseminated (July Martinez 2007).

Collections

July Martinez (2007) undertook three collection expeditions between December 2006 and October 2007 (Fig. 53). The first expedition was in the towns of Tumupasa, San Silvestre, Ixiámas, Macagua and Santa Fe, north of the Department of La Paz, Abel Iturralde province. All belong to communities of the Community Lands of Origin (TCO) of the indigenous Tacanas. The second expedition was along the Beni River and some of its tributaries in the communities of Copacabana, Altamarani, Cachichira, San Marcos, Tequeje, Carmen del Emero, Golondrina, Rodales de Isla del Oro and Paltal in the Departments of La Paz and Beni. The third expedition was in 11 communities (Covendo, San José, San Miguel de Huachi, San Antonio, Mototoy, Cocochi, Covendo, Inicua Bajo, Santa Ana, Sararia and Muchane) of Alto Beni in the Department of La Paz. Samples of CNB were collected from
original communities of the Mosetén ethnic group, and in plots thought to derive from those of the Jesuits and Franciscans in the 18th century. Fifty-seven wild CNB and 107 Cacao Criollo (CNB that has been cultivated for at least 200 years) samples were collected (July Martinez 2007).

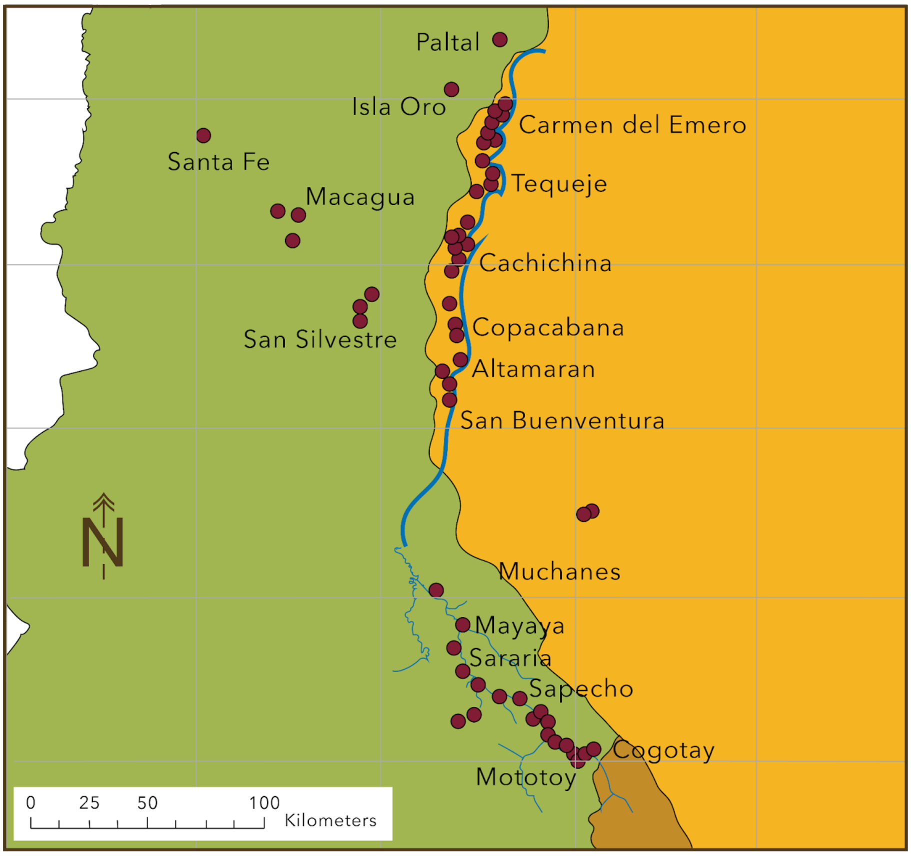


Figure 53
Collection sites in the departments of Beni and La Paz, Bolivia.
Adapted from (Zhang, Martínez, et al., 2010).

From 2000 to 2010, the Central Cooperative Ceibo collected 60 elite genotypes from 500 farmer selections, which are conserved in the Cooperative's germplasm collections (July Martinez 2007).

Recent Cultivation

Hvistendahl (2008) indicates that the locals of Baures (Iténez Province, Beni Department, northern Bolivia) harvest wild cacao that is so abundant that ownership is not an issue.
Wild groves of CNB cacao stand in the transitional region known as the "Yungas" of the Andes foothills (specifically along the banks of the Beni and Ichilo), from which Bolivian farmers regularly harvest cacao to supplement their crops (Zhang et al. 2012). In general, cacao areas usually have three genetic types: national (locally "criollo"), hybrids and clones (grafts) (Somarriba and Trujillo 2005). Trees indicated as "criollo" are in the minority and come from seeds from the old plantations of Mostenes and Franciscan missions (Somarriba and Trujillo 2005). "Criollo" as a word form means local, native, indigenous or the first introduced variety that is different from "Forastero" taken as foreign, of the forest or later introduced varieties (Bartley 2005; Lachenaud and Motamayor 2017). The local criollo varieties are therefore not from the Criollo population group. Zhang et al. (2012) differentiated among wild CNB and cultivated CNB (local "criollo") while noting that the two could be used interchangeably as previously mentioned in Romina Villegas and Carlos Astorga (2005) and July Martinez (2007). In 1993, almost one million (950,317) cocoa grafts of 114 clones (25 international and 89 local selections from El Ceibo) were produced and disseminated among 1,792 smallholder farms (Somarriba and Trujillo 2005). Most of the grafted cocoa plantations (550 plants each) were planted between 2003 and 2005, and the most distributed clones were ICS 1, ICS 6, ICS 8, ICS 95, ICS 111, TSH 565, TSH 792, IMC 67, EET 19 and 80 local selections from El Ceibo (Somarriba and Trujillo 2005). Cacao from the Alto Beni region is considered organic under USDA and EU requirements (Andres et al. 2016).

Genetic Studies

Romina Villegas and Carlos Astorga (2005) morphologically characterized 73 genotypes of Nacional Boliviano cacao from nine farms in four localities of Alto Beni, Bolivia. They reported similar grouping with Forastero cacao from Rio Beni, and the farm samples also differed sufficiently from the Forastero-Trinitario references. In addition, although four sites were sampled, only two subgroups (Fig. 54) were found, suggesting that the plantations were developed from a few mother trees and with seed exchanges among the sites (Romina Villegas and Carlos Astorga 2005).

Figure 54
Fruit and seed morphology from the two clusters of Nacional Boliviano cacao in Alto Beni, Bolivia. Modified from Romina Villegas and Carlos Astorgas (2005).

July Martinez (2007) compared 164 CNB genotypes (57 wild and 107 cultivated) to 61 elite selections of the cooperative El Ceibo, Bolivia, using 13 fruit and seed traits, and to 11 reference clones, using 184 alleles from 14 microsatellite markers. Similar to Romina Villegas and Carlos Astorga (2005), two main groups were found. One group is composed of samples collected north of the Beni River, from Isla del Oro, Paltal, Tequeje and Carmen del Emero. The second group is composed of samples from the south of the Beni river (Cachichira and Copacabana) and North of La Paz (San Silvestre, Tumupasa, Santa Fé, Macagua) that show molecular similarities to the cultivated genotypes of the Alto Beni Region (Covendo, San Miguel de Huachi, Cocochi, San José, Remolino, Mototoy and San Antonio). Further, the greatest diversity was found along the Beni River, suggesting that the original genotypes likely entered Bolivia from the Brazilian Amazon opposite to the direction of the river current (July Martinez 2007). The cultivated CNB germplasm was introgressed with other genotypes that distanced it molecularly and morphologically from the wild CNB germplasm. This distinction was greatest in the case of elite selections obtained on producer farms, due to the increasing presence of imported cultivars (July Martinez 2007).

Zhang et al. (2012) re-assessed Bolivian cacao collected by July Martinez (2007) against a more diverse reference set of 78 accessions using 15 microsatellite markers and confirmed the uniqueness of Bolivian CNB cacao (wild and cultivated) from the reference accessions. However, the wild and cultivated CNB populations shared a similar genetic profile, suggesting that cultivated CNB cacao originated from the native wild CNB cacao of Bolivia (Zhang et al. 2012). In contrast, de Schawe et al. (2013), using multivariate analysis and ancestry determination from nine microsatellite markers, corroborated the separation of the wild and cultivated CNB found by earlier workers (Romina Villegas and Carlos Astorga 2005; July Martinez 2007).

Highlighted Cultivars

The CNB variety has purple staminodes, green fruits that ripen to yellow and which are ovoid or Amelonado shaped with small apex and slight-moderate surface roughness, slight ridges, and purple seeds (Romina Villegas and Carlos Astorga 2005; July Martinez 2007). CNB plantations escape black pod disease because the variety sets fruit early and there is also a low incidence of witches' broom disease in CNB plantations (Romina Villegas and Carlos Astorga 2005; July Martinez 2007). A short fermentation period and early maturity were also favorable traits (July Martinez 2007). The CNB variety is well-adapted to the conditions in the local river valleys, having survived without management for several hundred years (Zhang et al. 2012).

Flavor Quality

Some of the wild CNB materials were said to have remarkable sensory profiles (July Martinez 2007). However, of the 12 samples presented with sensory profiles only seven appeared acceptable and it appeared that better fermentation would have helped the sensory profiles. Nevertheless, green grass/floral notes coupled with orange blossom notes (two samples); woody bark notes (two samples); fruity, dried fruit, raisin notes (two samples); mild spicy, peppery notes (one sample); and earthy, mushroom, herbal notes (one sample) were present in the acceptable samples (July Martinez 2007). Over the period from 2010 to 2021, chocolate samples from Bolivia were selected in the best 50 International Cocoa Awards (CoEx) for 2010 (one batch), 2011 (two batches), 2013 (one batch), 2015 (two batches), 2017 (one batch), 2019 (two batches) and 2021 (two batches) with 0, 0, 1, 2, 1, 1 and 2 winners respectively.

In the best 50 of the International Cocoa Awards 2019, chocolate made from a wild cacao batch from Estancia El Pilar, Carretera Baures, Municipio de Huacaraje, Iténez Province, Beni, had strong cocoa flavor; moderate roast bitterness, astringency and fresh fruit flavor; and low acidity, sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019). Another qualifying best-50 in 2019 was chocolate made from a Forastero batch from Santa Rosa del Apere - Territorio Indígena Multiétnico TIM, Beni, that had a strong cocoa flavor; moderate roast, bitterness, astringency and brown fruit flavor; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from Comunidad San Juan del Urucú, Beni, Municipio de Riberalta, Beni, was given the following flavor profile description: "Medium-dark brown colour. Clean fruit acidity and fresh fruits (ripe banana, tropical sweet) blended with chocolate note. Center has browned fruit (dates, light raisins) with dark fresh cherry and a floral note with earthy, green herbal, and flowers (honeysuckle). Woody. Balanced, complex, unique." (CoEx 2021). Another winning entry in 2021, from Santa Anita, Yuracaré, D8/Cochabamba, TCO – Yuracaré, was given the description: "Dark brown colour. Smooth mouth melt. Early fruit acidity combines with chocolate note along with trace fresh tropical fruit notes (berries, banana). Center taste is brown fruits (raisin, dates) with green herbal and earthy with a mild spice and trace nut character. Very balanced." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

Brazil

Overview

Brazil (#5 in Fig. 52) is the largest country in South America and has its eastern shore on the Atlantic Ocean. The northern end of Brazil is bordered by French Guiana, Suriname, Guyana, Venezuela and Colombia. The western side is bordered by Peru and Bolivia. The southern side is bordered by Paraguay, Argentina and Uruguay. Brazil produced 235,809 metric tons of cocoa in 2021, ranking 6th out of 59 cocoa producing countries (World Population Review 2022). This ranking agrees with that of the Chocolate Codex. In 2020, Brazil exported US$2.75 million in cocoa beans, making it the 42nd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/bra). About 62% of cacao production in Brazil occurs in southern Bahia (IBGE 2013) and of which 70% occurs in Cabruca agroforestry systems (Araújo et al. 1998).

Historical Introductions

Forastero varieties are indigenous to Brazil and were found in abundance in the State of Pará around 1540–1550 (Cook 1982). The first importation of cacao plants into the state of Bahia was variously reported as in 1746 (Vello and Garcia 1971; Urquhart and Wood 1954 cited in Wood 1991), in 1750 (Erneholm 1948 cited in Toxopeus 1971) or in 1780 (Van Hall 1914). Toxopeus (1971) also indicated that the germplasm originated from the Amazon Delta regions and that the cacao was taken to be closely related to the wild cocoa from the eastern jungle area of Guyana. A Spanish map printed in 1775 has labels of "Montes de cacao" in Brazil (Fig. 55; David Rumsey Map Collection; www.davidrumsey.com/luna/servlet/s/zjikxt)

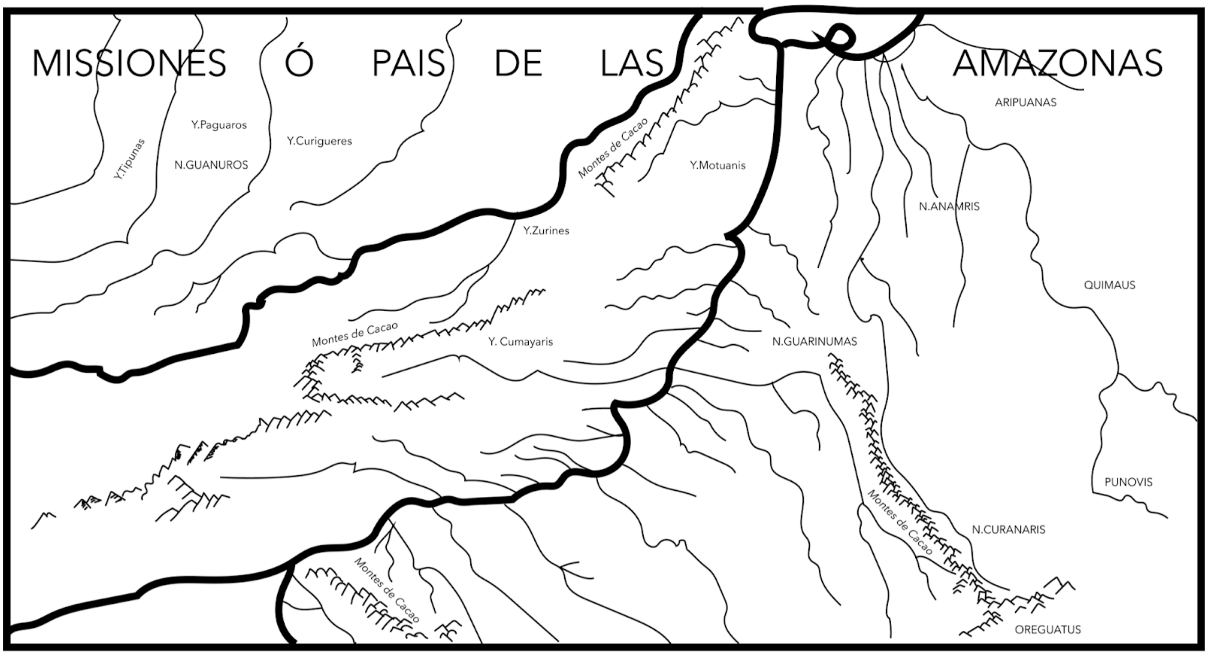


Figure 55
Montes de cacao labels in Brazil on a 1775 Spanish map of South America.
Adapted from (David Rumsey Map Collection)

It is suggested that the seeds first imported to Bahia came from the Comum variety from Pará State (Vello and Garcia 1971; Urquhart and Wood 1954 cited in Wood 1991). The French settler Luiz Frederico Warneau from Pará planted seedlings in Canavieiras on the banks of the Pardo River and gave seeds to Antonio Dias Rubiesco, who planted them at Cubiculo de Almado on the banks of Rio Pardo, not far south from Ilhéus (Cook 1982; Urquhart and Wood 1954 cited in Wood 1991; Presilla 2009). Descendants of these varieties spread throughout Bahia and Espírito Santo State (Santos et al. 2015).

Between 1874 and 1876, the Maranhão and Pará cultivars from Pará State were also introduced (Vello and Garcia 1971; Bartley 2005; Santos et al. 2015). The Comum, Maranhão and Pará cultivars differ from other each other based on fruit characteristics (Vello and Garcia 1971; Bartley 2005; Arevalo-Gardini et al. 2019). Spontaneous mutants of these founder types generated the anthocyanin mutants ALMEIDA and CATONGO (Vello et al. 1972), which have white seeds but are not from the Criollo population.

Collections

From the 1930s to 1950s, the first selective breeding for productivity was performed in farmers' fields in Bahia resulting in the SIC and SIAL series (Cacao Institute Selection and East Agronomic Institute Selection, respectively) in Bahia and EEG (Selection of the Goitacazes Experimental Station) clones in Espírito Santo (Yamada et al. 2001; Monteiro et al. 2009). Since 1965, the Brazilian research institute CEPLAC (Executive Commission for Planning Cacao Culture) has been preserving over 2,000 cacao accessions from the Brazilian Amazon region in various gene banks (Almedia and Almedia 1987; Almedia et al. 1987; Barriga et al. 1985). The variability of this natural cacao material has been noted to include plant vigor, yield, witches' broom resistance and desirable seed/fruit characteristics (Dos Santos Dias et al. 2003). The germplasm bank in Belem, Brazil, claims to have derived 90% of its germplasm from wild collections (Monteiro et al. 2009). The gene bank of cacao of the Experimental Station in Ouro Preto (ESTEX-OP), of CEPLAC, was planted in 1977 and holds 615 accessions. These accessions originated from the state of Rondônia from mostly wild populations from the region, which is where the germplasm collection is also situated (Almeida et al. 2005). Related Theobroma species and their hybrids are also present in two collections in the state of Pará (Silva et al. 2004). The collection established at the "Estação de Recursos Genéticos do Cacau José Haroldo" (ERJOH), located in Marituba, Pará state, contains more than 1,800 accessions (940 clones and 877 open-pollinated seedlings), denominated as the Cacao Amazon Brazil (CAB) series, representing 36 river basins of the 186 Brazilian Amazon basins (Almeida et al. 1995, cited in Sereno et al. 2006).

Recent Cultivation

The SIAL and SIC clones are considered common varieties cultivated for centuries in Bahia and were used as parental types to produce hybrids (Yamada et al. 2001). In the 1960s, large quantities of CATONGO seed were distributed (Toxopeus 1985b) and clones were imported from several countries to produce interclonal hybrids for planting (Yamada et al. 2001). From the 1960s to 1983 most of the plantings were from hybrids involving the three common cultivars (SIC, SIAL and EEG clones) and introduced germplasm from Peru (IMC and SCA clones), Trinidad (ICS clones) and Costa Rica (UF clones) (Vello et al. 1969, 1972).

Expansion of cacao farming until the 1960s was principally by seeds from selected accessions, and from 1970 to 1990 it was by hybrid seeds, including from SCA 6 and SCA 12 mother trees (Leal et al. 2008). In 1986, the mixtures of crosses were restricted to SIAL and SIC with ICS clones, but these were susceptible to witches' broom disease (Anonymous 1989 cited in Yamada et al. 2001). In 1989 and 1999, the production in Brazil was reduced by 70% due to the effects of witches' broom disease, and this has been a deciding factor in the varieties cultivated since (Zhang and Motilal 2016). In 1994, hybrid varieties derived from SCA 6 × ICS 1 and later from ICS 6 × SCA 6 and ICS 8 × SCA 6 were produced for dissemination (Yamaga et al. 2001).

In 2018 and 2019, thousands of cacao seedlings were planted in the forests near Waikás and other villages in the remote Yanomami indigenous reserve by the Ye'kwana and Yanomami peoples (Phillips 2020b). The traditional cocoa agroforestry system with plantation crops (Alvim and Nair 1986) under variable and sometimes dense shade remains due to many farmers failing to fully adopt shade reduction policies (Johns 1999). Rolim and Chiarello (2004) argue that management practices of thinning and clearing native trees are counterproductive to maintaining biodiversity and may jeopardize the long-term survival of the forests.

Genetic Studies

Cacao populations have been differentiated by river basins (Pound 1938; Almeida et al. 1987) and this continues in recent times (Bartley 2005). Dos Santos Dias et al. (2003) from a study of 64 progenies (total 320 trees) from four Brazilian Amazon basins (Amazon, Jápura, Ji-Paraná, Purus) using 15 fruit and seed traits established that differentiation occurred among river basins with diversity being found within and among the basins. The recommended practice is to sample as many trees as possible starting from few progenies in many river basins (dos Santos Dias et al. 2003). The Parinari clones (PA accession series) were genetically similar to cultivated Lower Amazon Forastero material imported from the Ji-Paraná river in Brazil (Zhang et al. 2009b).

Yamada et al. (2001) assessed the parents used to generate the hybrids distributed to Brazilian farmers from 1960 to 2001 using three isozymes and 11 random amplified polymorphic DNA (RAPD) primers. A total of 80 polymorphic bands were scored (10 isozyme markers and 70 RAPD markers), enabling the identification of three clusters: SCA 6 and SCA 12 accessions; SIC, SIAL and UF accessions; and ICS 1, PA 30 and PA 150 accessions. Four other accessions (ICS 6, ICS 8, IMC 67, SIC 19) were in their own singlet groups with ICS 6 and IMC 67 being the immediate sister groups to the ICS 1 cluster and the SIC/SIAL/UF cluster respectively. The ICS 8 accession was the most distinctive of all the accessions that were studied.

Sereno et al. (2006) using 94 cacao accessions from four populations (Acre, Rondônia, lower Amazon and upper Amazon) with 47 alleles from 11 microsatellite markers demonstrated that most of the diversity was within the populations and that the Upper Amazon had the greatest genetic diversity. Further the accession CAB0015, one of the only two accessions originally collected at river Xeriuini (state of Roraima), had two rare alleles.

Leal et al. (2008) assessed the genetic diversity of 120 farm selections from 17 farms in seven counties (Camacã, Ilhéus, Itabuna, Itajuípe, Jussari, S.J. Vitória, Uruçuca) in southern Bahia with 30 RAPD markers. There was high diversity among the farm accessions with 89% grouping with members of the reference accessions (Leal et al. 2008) into subclusters with Trinitario/Contamana (most of the grouped samples), Amelonado/Iquitos and Marañon based on the accession names that were used in the study. There were seven unmatched subclusters, six of which had only one farm accession. The unmatched subclusters were drawn from the Conjunto Camaça farm in Camaca (three samples); Leolinda farm and América farms in Uruçuca (one sample each); Futurosa farm in Jussari (one sample); and in one subcluster farm selections obtained from Uruçuca (Brasileira farm, two samples; Santa Rosa farm, one sample) and Ilhéus (Brasil farm, one farm; Sao Pedro farm, one farm) districts.

Santos et al. (2015) genotyped 176 trees from seven farms of four municipalities (Camacan, Canavieiras, Uruçuca, Gandu) and two research centers in Bahia, 31 SIC clones, 20 SIAL clones and 52 reference clones (11 of which are present on farms) with 209 alleles from 30 microsatellite markers. In general, cacao from Bahia could be separated from the reference clones but while the SIAL, SIC and EEG samples clustered with the farm selections, the greatest genetic diversity was from the group of farm selections. Furthermore, Santos et al. (2015) point out that the on-farm diversity was not represented by the three reference Amelonado accession series and represented a valuable resource for phenotypic and agronomic evaluations.

Highlighted Cultivars

Red fruits have been found by R. de Lemos Froes near the river Jandiatuba in Amazonas state, and the Museu Goeldi in Belem hosts a tree with red fruits as part of its Amazonian collection (Lachenaud and Motamayor 2004). Also, the Red Amelonado variety, of Belem and Amazonian origin (Lachenaud and Motamayor 2004), is entirely red on both ridges and furrows fruits throughout fruit development.

Santos et al. (2015) described several of the unique cacao cultivars that appear in the Bahia region of Brazil (Figs. 56, 57). The Parazinho type has ripe fruits that are small and orange, and they contain few seeds. The rounded pods have a thin exocarp with superficial unpaired ridges. The Tomate variety displays ripe pods with small, rounded and reddish-orange skin with a thick exocarp. Fig. 56 shows the unripe and ripe pods of these two varieties (Santos et al. 2015).

Figure 56
Ripe and unripe pods of Parazinho (Left) and Tomate (Right) Cacao collected in Bahia, Brazil.
Adapted from Santos et al. (2015)

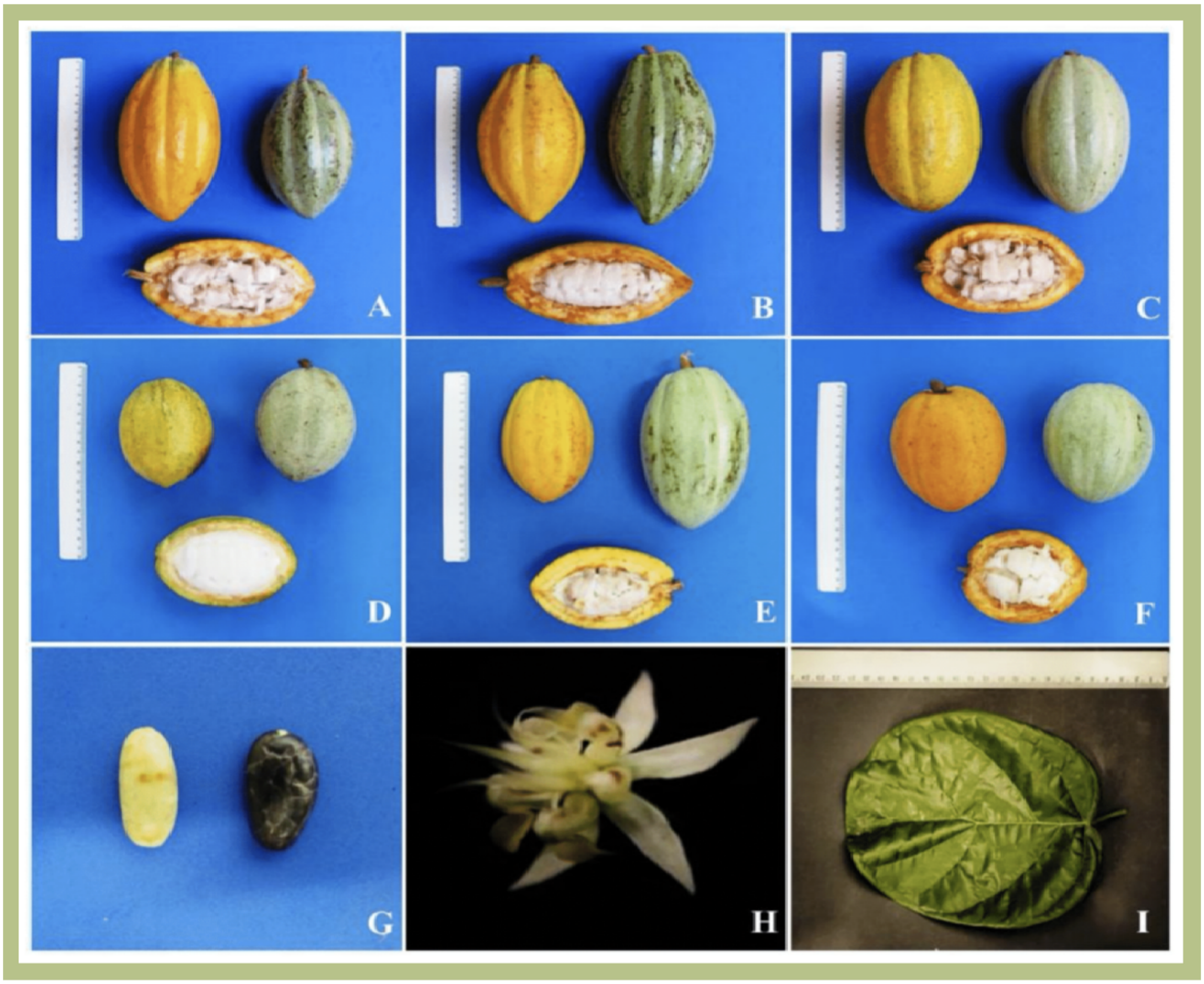


Figure 57
Morphological Characteristics of Cacao Varieties from Bahia, Brazil.
(A) Comum, (B) Maranhão, (C) Pará, (D) Almeida, (E) Catongo, (F) Laranja, (G) Catongo seeds
(H) Catongo flower (I) leaf of Jaca cacao.
Taken from Santos et al. (2015)

Ripe fruits of the Comum variety are yellow, medium-sized and elongated Amelonado shape, with thick exocarp and deep paired ridges. It is susceptible to witches' broom. This variety has been used to start plantations in Asia and Western Africa since 1822. First introduced in 1746, likely from the Pará region, this was the first cacao used in Brazil. Comum produces many beans and has good yield overall. It is considered to have acceptable sensory qualities and produces chocolate with inherent sweetness. The Comum type has medium-sized fruits with yellow ovoid pods showing unpaired ridges and medium exocarp thickness. It is susceptible to witches' broom.

The Maranhão variety is a spontaneous mutant of Comum, and it was introduced in Brazil after this mutation in 1874–1876. Fruits are shaped like Amelonados but with pronounced basal constriction. When ripe, they are large, pale orange, with a very thick exocarp showing shallow, paired ridges. Although susceptible to witches' broom, it is used in the fine-cacao market (Santos et al. 2015). The Catongo mutants of Brazil were first identified by the Bahia Cocoa Institute (ICB) (Monteiro et al. 2009) and produce white seeds and has flowers of unusual shape (Santos et al. 2015). Sold as fine cacao, Catongo makes chocolate that is less astringent and more flavorful than many varieties. When ripe, the pod is small, yellow and slightly elongated with gentle basal constriction (Fig. 57). Another mutant of Comum, Almeida, also produces white seeds. The pod is small and rounded and turns a pale yellowish-green when ripe (Santos et al. 2015). Laranja is a mutant of Pará that grows small fruits and small seeds. It was found on a farm in the municipality of Gandu. Locals sometimes use the fruit ornamentally. It is rounded like an orange. "Laranja" means "orange" and refers to the shape and color of the pod. Jaca cacao is a highly unusual variety. The name refers to "jackfruit" and indicates the shape of the leaves, which are small and rounded and similar to jackfruit leaves. This variety has three plagiotropic branches instead of five. It also has unusual flowers.

Morphological evaluation was performed on fruits of 207 plants within the ESTEX-OP collection over five sampling periods from 2001 to 2003 (Almeida et al. 2005). Data were collected on five fruit and seed characteristics. Results identified high performers in each category. IMC 67, BE 9, STM 66/04 had mean fruit weight above 900 g per fruit. STM 66/04, MA 12, POUND 12, EEOP 5, IMC 67, MA 15, EEOP 3, EEOP 18, EEOP 17, RO 263 all had high average seed weight per fruit. A high average number of normal seeds per fruit (>46) was found in EEOP 9, RO 168, RO 192, POUND 7, EEOP 7, EEOP 14 and MA 15. A mean individual wet seed weight above 4g was demonstrated by EEOP 17, RO 263, ICS 9. A mean individual dry seed weight above 1g was seen in EEOP 11, IMC 67, EEOP 16, STM 61/01, STM 66/05, RO 263, STM 63/01, EEOP 18, STM 62/03, STM/CASA, EEOP 5, ICS 100, EEOP 17 and ICS 9 (Almeida et al. 2005).

Flavor Quality

Brazil is a 100% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Moreira (2017) demonstrated that chocolates prepared from four different hybrid varieties (CEPEC 2004, PH 15, PS 1319 and SJ02) differed in acceptability with chocolates from CEPEC 2004 being most preferred, higher values of sweet and nut taste from PH 15 and coffee and fruit taste in PS 1319. Similarly, Menezes et al. (2016) using CCN51, PS1030, FA13 and CEPEC 2004 cultivars showed that there was a varietal effect on chocolate quality with dominance of sweet (CCN 51, PS 1030), fruity (PS1030, FA13 and CEPEC 2004), astringent (FA13 and CEPEC 2004) and caramel (PS 1030) attributes.

Chocolate from Yanomami cacao had notes of almond oil and flowers, light acidity and sweetness (Phillips 2020b). Chocolates from CATONGO cocoa are said to have a floral note that settles into clear ripe red raspberries with a tang of acidity (Lewis 2014). Leite et al. (2013) showed that cocoa mass from susceptible or resistant cultivars to witches' broom disease were similar in phenolic content whereas chocolates from a blend of the susceptible Pará, Parazinho and Maranhão cultivars were higher in phenolics than chocolates from two resistant cultivars. However, the catechin and epicatechin content did not show any general trend but was highest in just one resistant cultivar, SR162, which is a mutant with white seeds. A similar study with four cultivars resistant to witches' broom disease showed that variety had an influence on quality attributes and one variety (PS1030) had a perceptible caramel flavor.

Over the period from 2010 to 2021, chocolate samples from Brazil were selected in the best 50 International Cocoa Awards (CoEx) for 2010 (seven batches), 2011 (five batches), 2013 (four batches), 2017 (one batch), 2019 (two batches) and 2021 (two batches) with 1, 1, 0, 1, 0 and 3 winners respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a hybrid Trinitario cacao batch from Vila Alvorada, Uruará, Pará, had moderate cocoa, roast bitterness, astringent; and low acidity, sweet, fresh fruit, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019). Another qualifying best-50 in 2019 was chocolate made from a Trinitario cacao (SJ 02 variety) batch from Catolé, Uruçuca, Bahia, that had moderate cocoa, roast, bitterness, astringency and floral; and low acidity, sweet, fresh fruit, brown fruit, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from Br 101, After Santo Antonio Gas, First Right, Uruçuca, Bahia, Northeast, was given the following flavor profile description: "Very light colour — like a dark milk chocolate. Creamy, smooth fast melt. Low chocolate note, mild bitterness and astringency, mild fruit acid with clear and bright sweet caramel / panela character. Mid taste is nuts and nut skins with a hint of floral flowers. Long, unique finish. Balanced, mild but complex. (CoEx 2021). The second winning entry in 2021, from Pov. Banco do Pedro, Uruçuca, Bahia, Northeast, was given this flavor profile description: "Dark brown colour. Chocolate note builds with mild bitterness and velvety astringency. Blends mild fruit acidity, mild citrus and yellow fruits, dried-browned fruit (light raisin) note. Floral appears in center taste (green grass and floral flowers-jasmine). Finishes with mild wood and trace spice. Unique, balanced." (CoEx 2021). The third winning entry in 2021, from Vicinal Tc 02 - Km 27 Região Tuerê, Novo Repartimento (Tuerê), Pará, North, was given this description: "Burgundy-dark brown colour. Smooth mouth melt. A mélange of chocolate, fruit acids, mild fresh fruits moving to a clear browned fruit center note. Has a bright fragrant floral with green grass, earthy, and floral flowers. Astringency increased to the finish. Long finish. Balanced." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

COLOMBIA

Overview

Colombia (#2 in Fig. 52) is in South America connected to Central America by Panama on the northeast. The Caribbean Sea is on the northern side and the Pacific Ocean on the western side. Colombia shares borders with Venezuela (northeast/east), Peru (south/southwest) and Ecuador (southwest). Colombia produced 56,808 metric tons of cocoa in 2021, ranking 10th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Colombia exported US$28.6 million in cocoa beans, making it the 22nd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/col). Colombia has four cacao-producing regions, distributed between 0 and 1,200 m above sea level: the tropical rainforest zone (Arauca, Nariño, the Pacific coast), the drier Andean valleys (Huila, Atlantic Coast), the Andes zone (Antioquia, Tolima) and the most productive region, the Santanderean mountains (Santander and Norte de Santander) (de Walque 2018). The departments of Santander, Arauca and Boyacá in the northeastern region of Colombia account for 40% of the cacao production (Bravo et al. 2018).

Historical Introductions

According to Wood (1959), Colombia was considered as the origin of cocoa, specifically, the forest to the east of the Andes, near to the border with Ecuador. Knapp (1920) indicated that Francisco de Orellana, a Spanish explorer, observed cacao growing in El Dorado (Gutavita Lagoon, Colombia). The earliest known cacao plantation is in 1622 from the department of Valle del Cauca near the city of Cali (Patiño 2002 cited in Rodriguez-Medina et al. 2019).
Later in 1636 as wild cacao trees in the forest of Zaragoza de Antioquia were recorded (Erneholm 1948 cited in Bergmann 1969).

Prior to 1930 only Criollo, also known as Común or Real, was typically found in Colombian plantations (Wood 1959). Rodriguez-Medina et al. (2019) indicate that the main cacao type was Criollo until 1885, at which time Forastero type(s), called Pajarito" (little bird), were introduced in Antioquia of northwest Colombia (Chavarriaga and Ochoa 1940; cited in Rodriguez-Medina et al. 2019). Garcés (1939; cited in Rodriguez-Medina et al. 2019) suggested that the better disease resistance of the Forastero cacao led to the displacement of the Criollo trees. Criollo of the Cauca valley seemed similar to Venezuela Maracaibo according to Cook (1982). After 1930, more Trinitarios Amelonados or Calabacillos known as Pajarito were found within plantations (Wood 1959). Trinitario is reportedly the predominant type of cacao in Colombia (de Walque 2018) but this is probably meant to be farmed cacao. Common cacao comes from natural hybrids (Sanchez and Rojas 2013 cited in de Walque 2018).

Collections

Cacao clones were collected in the early 1940s as Selection Cacao Palmira (SCP) clones (Oicatá 1986, cited in Rodriguez-Medina et al. 2019) and around 1948 with the Selection
Cacao Cauca (SCC) and Selection Cacao Tuluá (SCT) clones (García 1997; cited in Rodriguez-Medina et al. 2019). These three accession series were all lumped into the SC accession group (García 1997; cited in Rodriguez-Medina et al. 2019).

The Colombian Ministry of Agriculture, with the partnership of the Imperial College of Tropical Agriculture, embarked on an expedition in 1952 and 1953 to collect samples of wild and cultivated cacao. Collection was focused along the banks of the Apaporis, Caquetá, Caguán, Guaviare, Inirida, Putumayo and Vaupés rivers, in the departments of Amazonas, Vaupés, Caquetá and Putumayo (Cope 1952; Baker et al. 1953; Fig. 58). The expedition also focused on some of the areas of the Valles de cacao and El Choco departments. The expedition team collected 191 cacao accessions from both the wild and cultivated areas, 63 of which were sent to Trinidad (Rodriguez-Medina et al. 2019).

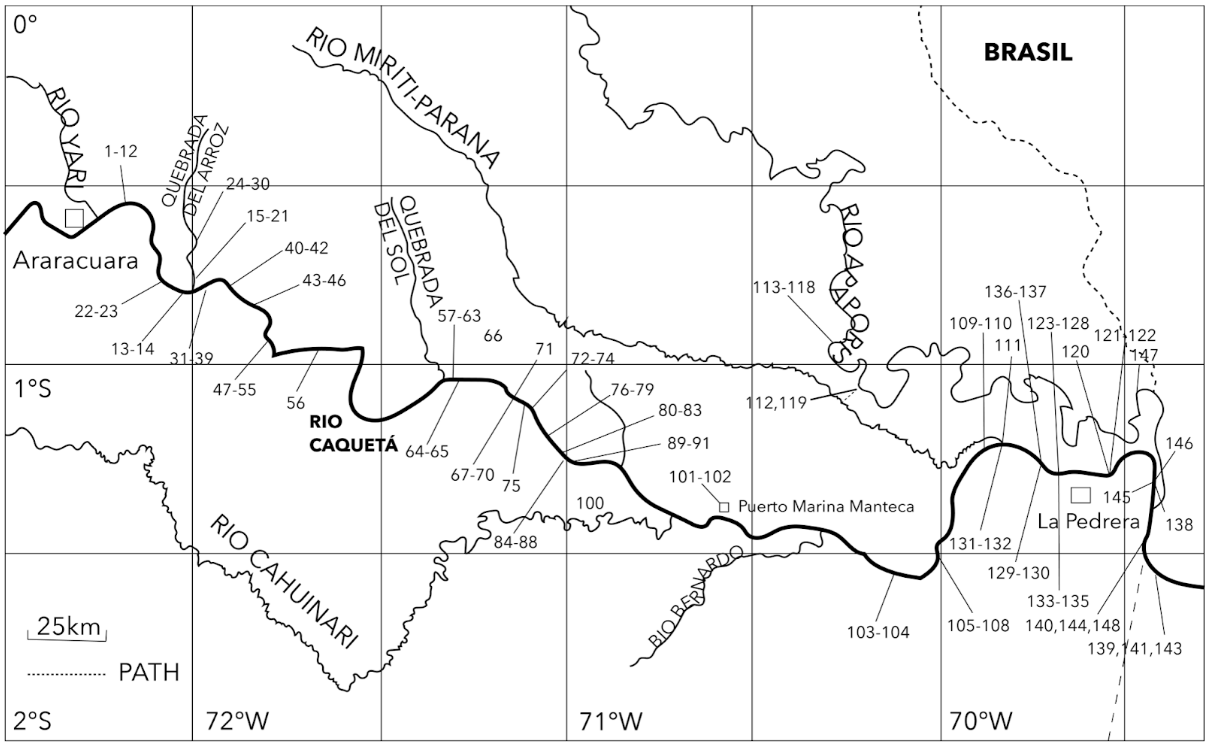


Figure 58
Map of Rio Caquetá in Colombia, showing locations of EBC collections (Theobroma wild species in Colombia). Adapted from Cope (1952).

In 1977 another expedition was carried out in the Cagúan river basin in the Caquetá department to collect material resistant to witches' broom (Buriticá 1985; cited in Rodriguez-Medina et al. 2019). The material gathered from the wild trees was sent to the ICA gene bank in Palmira, Colombia. The team also collected new accessions in Huila, Putumayo and Amazonas departments (Rodriguez-Medina et al. 2019). In 1983 and 1984, further collection took place in the Pacific region, particularly in the Nariño and Choco departments (Rodriguez-Medina et al. 2019). In the mid-1980s, more surveys were performed along the Caquetá River banks from Puerto Santander to Isla Colombia on the border with Brazil and along a stretch of the Apaporis River. Around 151 accessions grouped as the EBC (Caquetá Botanical Expedition) series were collected (Rodriguez-Medina et al. 2019). Another expedition, in 1986 and 1987, focused on the departments of Cundinamarca, Antioquia, Magdalena, Guajira, Huila, Norte de Santander and Tolima and led to the ICA (ICA 861307 to ICA 861769) series (Rodriguez-Medina et al. 2019). The various collection expeditions in Colombia are given in Fig. 59.

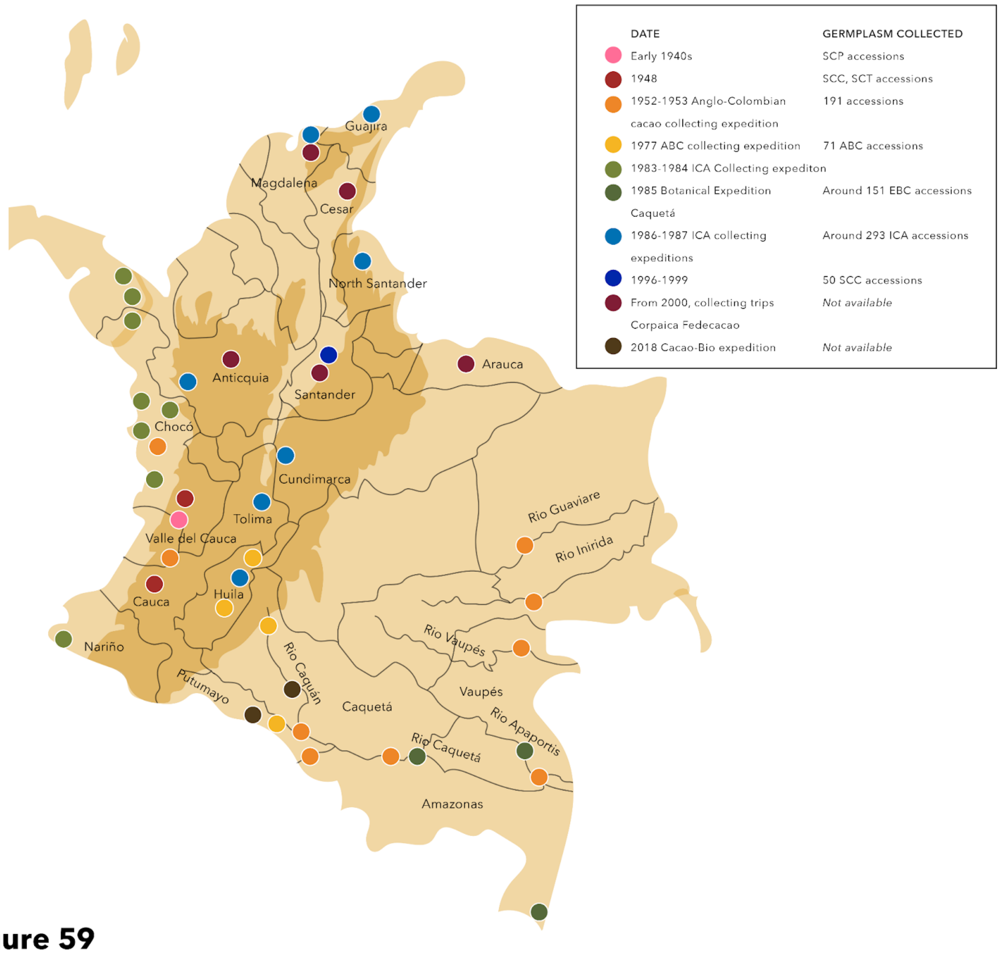


Figure 59

Germplasm collecting expeditions and selection programs of cultivated trees in local plantations in Colombia.
Adapted from Rodriguez-Medina et al. (2019).

There have also been private cacao breeding initiatives in Colombia from companies such as Luker, Compañia Nacional de Chocolate, and Fedecacao. In 1983, Luker and Compañía Nacional de Chocolate prepared a report highlighting the local Criollo cacao trees in the region of the Tumaco Nariño department. They reported that the Criollo cacao in this region had outstanding features (Rodriguez-Medina et al. 2019). Another private company, Fedecacao, started a tree selection program in 2001 that focused on the Santander, Arauca and Antioquia departments. The program favored cacao that was disease-resistant, high-yielding and otherwise superior.

Criollo cacao germplasm was collected from the Serranía del Perijá and Sierra Nevada de Santa Marta in 2006 and 2007 (Aránzazu et al. 2009 cited in Rodriguez-Medina et al. 2019 and Erazo et al. 2014). Efforts to collect and preserve Colombian cacao germplasm have stepped up since 2006. The Colombian Corporation of Agricultural Research (CORPOICA) held about 700 germplasm accessions in the early 2000s (Osorío-Guarin et al. 2017).

González-Orozco et al. (2020) carried out two expeditions, in 2018 and 2019, with the aim of documenting wild relatives of cacao in unexplored regions. The expedition covered the southern area of the Serrania de Baudo in central Choco and the upper Caguan and Caqueta Rivers in the upper Amazon basin. These areas are difficult to access because of their remoteness. There were also four samples collected in the South of Remolino del Caguan. The samples were growing near a population of a very productive set of wild trees. Interestingly, they were in a riverbank that remained flooded for at least three months, so this germplasm could possibly help with finding cacao that could be adapted to flooding conditions (González-Orozco et al. 2020). A total of 174 samples of cacao (as well as many cacao relatives), 73 of which they classified as non-domesticated, were collected and compared to a historical dataset (376 samples) that was generated using both national and international museum and herbarium samples. The results showed that the data in the historical databases had lower species diversity than was reflected in the surveys. This was probably due to the lack of expedition to the recently collected geographic areas. The authors suggest that more expeditions need to be carried out in the Upper Apaporis River and the lower Caqueta, in the Amazon basin in Brazil, in the unique climate conditions of the lower Amazon, in the western slopes of the eastern mountain ranges, and in the San Jose del Guaviare region. The urgency of collection in this last region is particularly vital, as this area is not protected and deforestation there is limiting opportunities for germplasm collection (González-Orozco et al. 2020)

Recent Cultivation

The best introduced Trinitario in Colombia (ICS 1, ICS 6, ICS 39, ICS 60 and ICS 95) are used to obtain hybrids and clones (FNC and UIS 2013 cited in Erazo 2014). The SCP (Palmira Colombian Selection) clones were selected from 1943 (Aránzazu et al. 2009 cited in Erazo 2014). Hybrid seeds derived from EET, ICS, IMC, TSH and UF accessions have been produced since 1960 (FNC and UIS, 2013 cited in Erazo 2014). Since 2000 the industry has been modernized with clonal plantations from a "small number of individuals," most of which were introduced (Erazo 2014). In 2004, Fedecacao and CORPOICA signed a technical-scientific cooperation agreement for a five-year breeding program to enhance cacao's productivity. This program has seen the creation of four clonal cultivars (TCS01, TCS06, TCS13, and TCS19). TCS01 and TCS06 were given to farmers to propagate in 2014, while varieties TCS13 and TCS19 were introduced in 2017. The TCS19 variety gave an average yield of 1.8 kg per tree per year, and the variety TCS01 was at 3.3 kg per tree per year. TCS01 is now used in the Agrosavia breeding program (Rodriguez-Medina et al. 2019). However, farmers in the main cacao-producing municipalities of Teorama, Bucarasica, Cúcuta and San Calixto in the Norte de Santander department tended to have unsustainable systems with degrading soil and water resources and without adoption of recommended best practices (Ramírez Sulvarán et al. 2014). FEDECACAO distributed eight primary clones to the farmers from its tree selection program: FLE 2, FLE 3, FSV 41, FEC 2, FTA 2, FSA 11, FSA 12 and FEAR 5 (Perea et al. 2013 cited in Rodriguez-Medina et al. 2019). In 2007, about 26 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Genetic Studies

Ramos Ospino et al. (2020) indicated that the highest diversity of cacao is concentrated in the northwestern part of the Amazon in Colombia, Ecuador and Peru. Sánchez et al. (2007) in their analysis of accessions from germplasm bank of Corpoica with 25 microsatellites found two main groups with one group containing accessions from Colombia, Trinidad, Peru,
Costa Rica and Brazil, while the other group contained accessions from Ecuador, Peru and Colombia. In addition, these workers found that the Colombian clones SC4 and SC6 were duplicates of each other as were SPA10 and SPA11.

Erazo (2014) and Morillo C et al. (2014) assessed 93 samples from the municipality of Tumaco on farms located in San Luis Robles, Río Rosarío, Río Mejicano, Río Chagüi and Mascarey with six random amplified microsatellite markers. Of the 93 samples collected, 54 were considered elite trees based on morphology, 35 were suggested by the farmers, and five were commercial clones from the Cocoa Germplasm Bank of CORPOICA. These commercial clones included CCN 51, ICS 60, IMC 67 and TSH 561 material. Fig. 60 shows a map of farm collection sites. The collected germplasm was genetically close to but distinct from germplasm from CORPOICA and FEDECACAO (Erazo 2014). The samples showed intermediate genetic diversity and formed six main groups (Morillo C et al. 2014). Group 1, consisting of 76 genotypes, included 40 genotypes that were collected in San Luis Robles and was characterized by greatest fresh seed weight (5.21 g), greatest bean width (average 1.39 cm) and length (average 2.98 cm), and large (average 9.97 cm) pods in the Cundeamor shape, with little to no anthocyanin on the flower bud. Some plants in this group had no pulvini in the leaf petioles and no anthocyanin in the staminodes. Sample IDs 22, 69 and 73 displayed resistance to *M. perniciosa* (Morillo C et al. 2014). The second group was composed of genetic material recently introduced to the zone by government institutions and collected from the village of Nerete in San Luis Robles. Samples in this group were 74, 75, 77, CR 4, CR 5, CR 6, CR 9 and CR 11. This group showed the most separation from the traditional local farmed varieties, and there is concern that if widely adopted, they could displace local germplasm. Group 3 contained only the clone CCN 51 from CORPOICA, Tumaco. Group 4 was made up of the genotypes 76 (small beans, few flowers and leaves, high field tolerance to *M. perniciosa*) and one of the two varieties collected as TSH 561. Group 4 was an immediate sister group to Group 5 and these two could be allocated to the same cluster. In Group 5, genotypes 42 and 23, collected in the Río Chagüi, at La Ceiba and La Sirena, respectively were present. These genotypes have Cundeamor-shaped pods and no anthocyanin on the flower bud. Group 6 involved Trinitario clones (ICS 60, ICS 90 and TSH 561) and IMC 67 from the CORPOICA Germplasm Bank in Tumaco (Morillo C et al. 2014).

Ballesteros et al. (2016) sampled trees in the villages of San Luis Robles, Mascarey, Carretera, and in the river basin of Rosario Mejicano, and Chagüí. All 102 cacao trees were morphologically typed according to farmer's selection by the following characteristics: (1) older than 15 years; (2) produces more than 50 pods per year; (3) tolerant to frosty pod rot and witches' broom disease. Pods were grouped by multivariate analysis into four clusters. Group 1 and Group 3 had greater size and quantity of beans, plus larger weight of fruit overall; these groups showed some resistance to pests. Groups 2 and 4 both had Cundeamor-shaped fruits with bottle-shaped basal constriction, attenuated apex, and resistance to frosty pod rot and witches' broom. Cluster 5 showed high anthocyanin content in pods, stalks and buds. Pods were Angoleta-shaped. However, Ballesteros et al. (2016) did not identify which trees were associated with which characteristics.

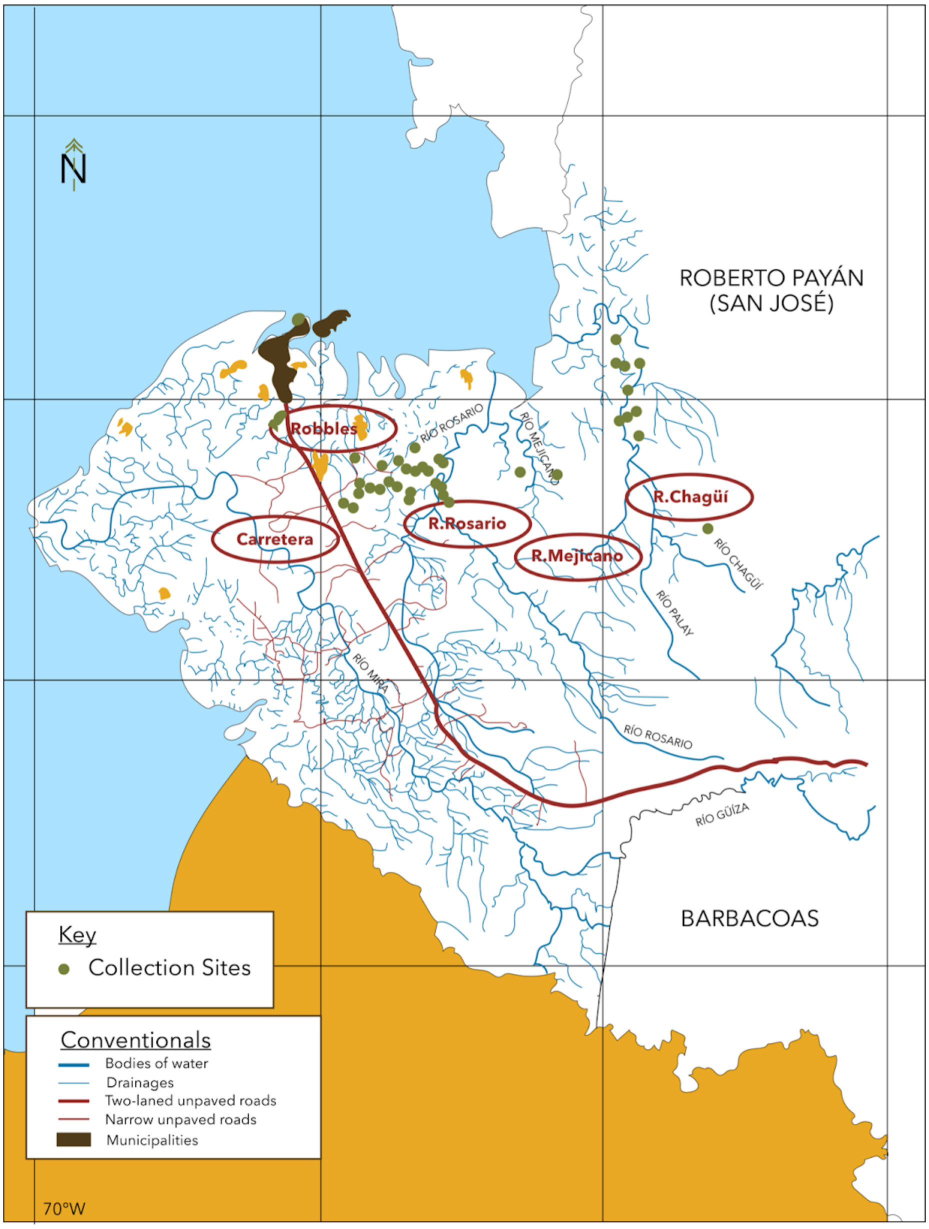


Figure 60
Cacao sampling sites on farms around Tumaco, Colombia.
Adapted from Morillo et al. (2014).

Later, Osorío-Guarin et al. (2017) worked on characterizing the population diversity of CORPOICA using 87 SNP markers on a Fluidigm platform and identifying accessions that might be useful for Colombia's breeding program. Genetic material from leaves from 450 of the CORPOICA accessions thought to represent Colombian cacao were tested against 115 accessions from a breeding collection. Phylogenetic data in this study showed that Colombian cacao samples appeared on branches associated with the Criollo, Amelonado, Iquitos, Nacional and Curaray groups, indicating that many different genotypes are well-represented within Colombian cacao. Records show that those samples grouping clearly as Colombian Criollos were collected in the northern region of Cesar, near the Serrania del Perijá and the Sierra Nevada de Santa Marta. In addition, two groups of mostly Colombian samples were obtained that were distinct from the reference populations, indicative of unique genetic diversity in Colombia. However, the structure output may have been suboptimal, and the allocation of new cacao groups is to be confirmed. Phenotypic evaluations were carried out on 141 accessions. Fruit shapes were mainly elliptic (46%), oblong (40%) or obovate (14%). Exocarp thickness was generally medium (52%) or thin (18%). Basal constriction was either absent (15%), slight (47%), moderate (34%) or strong (4%). Seed length and seed width ranged from 1.85 to 2.86 cm and from 0.75 to 1.56 cm respectively (Osorío-Guarin et al. 2017).

A farm survey was conducted by de Walque (2018) from August to October 2017 in Santander immediately preceding a major cocoa harvest. The survey sought to determine the prevalence of major foreign germplasm types. It included the municipalities of San Vicente de Chucurí (coded SV) and Río Negro (RN). They found CCN 51 in 95% of the farms in San Vicente and 80% of the farms sampled in Río Negro. ICS cultivars were widespread in those two regions (61% in SV and 76% in RN). All principal genetic varieties were found in both municipalities. Low altitudes showed a predominance of CCN 51 and hybrid varieties, while at mid to high altitudes, less hybridized forms could be found. The authors suggested that because disease and pest susceptibility is greater at lower altitudes, hardier varieties predominate there, and higher altitudes can accommodate a broader range of cultivars (de Walque 2018).

Most recently, 10 cacao plants from the farm known as Association of Organic Producers of the Municipality of Dibulla (APOMD) 10 km northeast of the town of Mingueo, in the district of Dibulla, La Guajira, Colombia, were sampled by Ramos Ospino et al. (2020). Five commercial and five native cultivars from the farm were assessed along with a known Criollo reference cultivated in Becerril, Cesar. The genetic and morphological analyses separated the 11 samples into two clades or groups: the Criollo types group together, and all the others group together (the ICS clones, the hybrid types, the non-Criollo types and the CCN-51 clone). Several of the Criollo types, including the reference sample, were almost certainly not pure Criollo, and further work was recommended (Ramos Ospino et al. 2020).

Highlighted Cultivars

According to Rondon Carvajal (1993), cacao varieties specific to Colombia include the Comum cacao, Garzon Trinitarios, Cacao del Pais, Comun del Valle, Parajito and Cacao Vegetal. The following information on these varieties were obtained from Rondon Carvajal (1993). The Comum cacao, found in the Huila region and which has also been described by Santos et al. (2015) as a Brazilian variety, is described as "Criollo-type" with white cotyledons and a soft husk; however, it is said to be highly variable and eroding quickly as a genetically distinct category. The Garzon Trinitarios are a population of old plantings around the town of Garzon. Fruits of Garzon Trinitarios are quite variable. The shape ranges from being sharp to blunt, color from white to green with red pigmentation, surface texture ranging from warty to smooth and glossy, and the apex is any shape from large and quite bent to small and indistinct. Cacao del Pais is found in the Santa Marta region. These are said to be Criollo-types because of their white cotyledons. They present white pigmented "rugoso" pods showing a large apex and a bottleneck. Some of the trees have white pods with very deep furrows. The young flush of most trees is covered in short hairs (Rondon Carvajal, 1993). Comun del Valle is found along the Cauca River and appears to be morphologically Trinitario. Parajito, found in the Uraba and Choco regions, is an Amelonado variety with small pods of very uniform shape. This variety is distributed from the Pacific coast of Colombia from Buenaventura port, following the border with Panama northward to the Gulf of Uraba. The pacific lowlands of Choco have a particular concentration of this variety. Cacao Vegetal, found in the Tumaco region, is said to have been recorded by farmers in the latter half of the 19th century who settled in the area and cleared the forest, noting the cacao trees growing there and planting their offspring. Cacao Vegetal is usually a large white Amelonado with a distinct bottleneck (less distinct in some cases) and a shoulder that ranges from narrow to broad. The surface may be smooth or slightly warty. It always displays the point form, but this ranges from indistinct to very distinct and may sometimes be very bent and sharp. This population is described as indigenous and semi-wild. The trees are high-producing (no numbers are given) enough to cast suspicion on the possibility of their being a wild population. Finally, Rondon Carvajal (1993) notes the very old populations situated between the cordilleras of Colombia, as well as the "well-described" Amazonian populations.

Flavor Quality

Colombia cacao is generally considered fine-flavor cacao, making up 5% of world cacao production (Osorío-Guarin et al. 2017). Colombia is a 95% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Traditional cacao in Tumaco is reportedly low-yielding with floral notes (Morillo C et al. 2014). Criollo and Trinitario varieties are said to be responsible for the fine or flavor cocoa (De Walque 2018). The municipalities of San Vicente de Chucurí and Rionegro located in Santander had a high-quality cacao but Rionegro was suboptimal in terms of fermentation index and moisture content (De Walque 2018). However, San Vicente de Chucurí had high cadmium with beans exceeding permissible limits whereas Rionegro had almost no cadmium in the beans (De Walque 2018). Although de Walque (2018) found that the cacao beans were significantly heavier and larger at higher altitudes, the genetic mix across farms was not established and the attribution of bigger seeds due to higher altitude is therefore preliminary. Five cacao clones (ICS 1, ICS 95, ICS 39, TSH 565 and CCN 51) from the Department of Huila, Colombia, differed in fermentation time and yielded liquor that had lowest acidity and highest cocoa flavor (CCN 51), and low walnut flavor (ICS 1and TSH 565) (Horta Téllez et al. 2019).

Over the period from 2010 to 2021, chocolate samples from Colombia were selected in the best 50 International Cocoa Awards for 2010 (one batch), 2011 (three batches), 2013 (four batches), 2015 (one batch), 2017 (three batches), 2019 (one batch) and 2021 (one batch) with 1, 1, 0, 1, 0, 1 and 1 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Criollo cacao batch (FSV 1, FSV 41, FSV 155 and FCHI 8 cultivars) from Granja Villa Mónica, San Vicente de Chucurí, Santander, had strong cocoa flavors; moderate roast, bitterness, astringency, acidity and fresh fruit flavors; and low sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Vereda Bijagual, Valencia, Cordoba, was given the following flavor description: "Dark brown colour. Mild fruit acidity with blend of fruits. Browned and dried fruits present. Moderate floral dried green herbs. Light wood and trace resin notes with trace spice and nut notes. Mild caramel. Balanced, clear, unique, and mild overall." (CoEx 2021). Calvo et al. (2021) found that although the cocoa liquor from the Departments of Antioquia, Huila and Santander all had fruity and floral notes, the liquor from Huila had a better sensory profile than that of Antioquia and Santander, with a strong cocoa aroma, nutty notes, less astringent sensation, and neither sour nor bitter taste.

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

ECUADOR

Overview

Ecuador (#1 in Fig. 52) is in South America with the Pacific Ocean on the western side. Ecuador shares borders with Colombia (northeast/east) and Peru (south/southeast). Ecuador produced 205,955 metric tons of cocoa in 2021, ranking 7th out of 59 cocoa producing countries (World Population Review 2022). The seventh-place ranking is in agreement with the Chocolate Codex. In 2020, Ecuador exported US$823 million in cocoa beans, making it the 3rd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/ecu). Ecuador is a principal producer of specialty or fine flavor cacao (Cadby and Araki 2020), holding 50% of the global share of fine flavor cacao export (Rottiers et al. 2019).

Historical Introductions

Specialty cacao production in Ecuador places particular emphasis on the Nacional variety, the domestication of which pre-dates the Spanish conquest of the region. Cacao was cultivated in Ecuador during the Incan period since the 12th century (JaimeVera 1993 cited in Lerceteau et al. 1997). Nacional cacao is thought to be either indigenous to Ecuador or introduced from wild Amazonian cacao populations bordering the Andes of Ecuador (see Lerceteau et al. 1997). Evidence suggests that small plantations of Nacional cacao existed along the upper Guayas River in the 17th century in a region called "ARRIBA" that spread in its tributaries to the Daule and Babahoyo upward rivers (Loor et al. 2009; Loor Solorzano et al. 2015) and continued into the 19th century (Lehmann and Springer-Heinze 2014). In fact, Nacional was the only significant variety grown in Ecuador until the 1890s, when other genetic material was introduced (Loor Solorzano et al. 2012; Van Hall 1932). The province of Esmeralda was reportedly the exception with cacao other than Nacional prior to 1890 (Van Hall 1932). Around 1890, fruits from a variety known as Cocoa Venezuela were introduced from Trinidad to Ecuador and became predominant because of their high productivity, even on a poor soil, and their tolerance to frosty pod rot and witches' broom disease (Lerceteau et al. 1997). The "Cocoa Venezuela" variety also known as "Venezolano amarillo" is considered a Trinitario (Lerceteau et al. 1997).

Collections

Ecuador is home to the Refractario variety that originated from a field screening in the 1920s for witches' broom disease (Moniliophthora perniciosa) (Zhang et al. 2008). Trees that appeared resistant to the disease were selected from unknown locations along the coastal valley of Ecuador in 1923 and then raised in nurseries where they were exposed to the diseases. Those trees that survived the nursery screening were established on farm sites. In 1938, Pound collected seedlings from approximately 80 of these trees across various farms. The collected seedlings were quarantined and budwood transferred to Marper Farm in Trinidad. In the 1980s, all the Refractario germplasm from Marper was transferred to the ICGT (Zhang et al. 2008). Monteiro et al. (2009) mentions that the collections of "Refractarios and Silecia" from Ecuador were attempts to collect pest-resistant genetic material. The Silecia varieties are said to be resistant to witches' broom according to Hyland's (1968) Plant Inventory. Wild samples were collected in an early survey by Allen and Lass (1983) that linked some wild trees to the Nacional variety, particularly in the southern Ecuadorian Amazon.

Loor Solorzano et al. (2015) reported on two surveys (in August of 2010 and 2013) of the woodlands that have survived the extensive deforestation along the valleys of the Yacuambi, Zamora and Nangaritza rivers in the Zamora-Chinchipe province (Fig. 61).

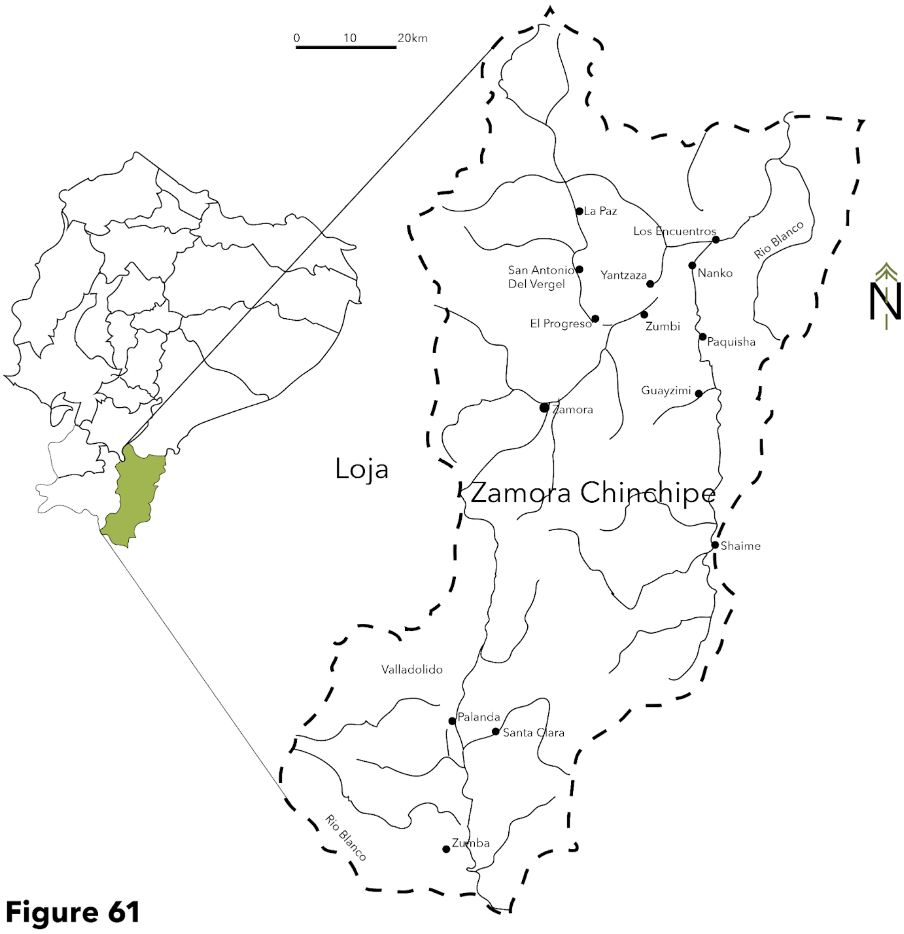


Figure 61
Areas surveyed by Loor Solorzano et al. (2015) in the Zamora-Chinchipe region of Ecuador. Adapted from Loor Solorzano (2015)

The 2010 survey collected budwood, pods and leaves from six districts of Zamora-Chinchipe: El Pangui, Yantzaza, Yacuambi, Centinela del Cóndor, Zamora and Nangaritza. Surveyors first collected from the valleys of the Yacuambi, Zamora and Nangaritza rivers (near La Saquea, La Paz, Zumbi, El Pangui, Paquisha, Bella Vista and Nankais) and then finished in the villages of Shaime and Nuevo Paraiso, along the Nangaritza, Numpatakaime and Shamatak rivers. All sources of genetic material from this survey were stored at the Granja Domono experimental farm near Macas (Morona-Santiago province). Some of the budsticks were also sent to the Pichilingue tropical experimental station near Quevedo. In total, material from 83 mother trees was collected (Loor Solorzano et al. 2015). The 2013 survey collected pods, leaves and budsticks from 48 mother trees from the cantons of Palanda and Chinchipe, near Palanda and San Francisco del Vergel, then in Zumba and Chito. Genetic material was sown and grafted at Pichilingue after collection. Material from a total of 48 mother trees was collected. Some Trinitario-type trees were discovered, but no genetic material was gathered from these trees (Loor Solorzano et al. 2015).

As a result of the pods and budsticks collected from the two surveys, 1,370 grafts were enabled, and 1,106 open progenies were planted at Granja Domono and Pichilingue (Loor Solorzano et al. 2015). The authors reported that most samples showed a green-to-yellow pod and a Nacional-shaped pod (characterized by pointed ends). Seed color and shape were highly variable, even within a single pod. They note that many samples were collected from trees plagued with disease and parasites, indicating that this genetic material is unlikely to show much resistance to pests (Loor Solorzano et al. 2015). However, while the authors claim that the survey material likely included both cultivated and wild samples, they note that it is impossible to ascertain the degree of cultivation of a given sample; they also warn that many cultivated samples showed signs of having been recently trimmed or cut back, threatening the life of the tree (Loor Solorzano et al. 2015).

Of particular note from the samples collected in 2010 and 2013 were accessions Zamo-014, 015; Pang-008, 024; Yacu-021; Nank-005; and Pal 1, 2, 4, 10, 11, 14, 25, 26, 27, 34, 35, 44 and 45; which displayed the pod and flower phenotypes most similar to those associated with Nacional. Additionally, accessions Zamo-001, Zamo-007, Zamo-009 and Nank-004 are worthy of mention for having entirely white seeds. Fig. 62, taken from Loor Solorzano et al. (2015), displays noteworthy features of these accessions.

Recent Cultivation

In the early to mid-1990s it was estimated that Nacional hybrids (Cacao Venezuela and Nacional) accounted for 93–97% of the total growing area as opposed to 2% for Nacional cacao (Petithuguenin and Roche 1995). Cacao is mostly grown as agroforestry systems and other traditional production systems on about 202,343 ha, of which 5,560 have organic certification and about 6,550 have fine aromatic cocoa (Lehmann and Springer-Heinze 2014). There are three main cacao growing regions — north (mainly progenies of Nacional and Venezolano), central (old plantations with Arriba variety) and south (recent replanting 1980s –1990s) — with limited cultivation in the eastern Andes (Lerceteau et al. 1997).

Figure 62
Examples of cocoa fruits and pods collected in 2010 and 2013 surveys. Adapted from Loor Solorzano (2015).

Nacional cacao averages a yield of 550 kg/ha, which is about half that obtained with the bulk cultivar CCN 51. Nacional trees also tend to be older than other varieties (averaging almost 30 years old) and grown on farms using intercropping strategies (Cadby and Araki 2020).

Mixed progenies, variable genetics and preferential planting of CCN 51 clones threaten to dilute the Nacional population in Ecuador to the point that it is at significant risk of extinction (Loor Solorzano et al. 2015). Modern Ecuadorian cacao plantations (as opposed to traditional farms) make up about 70% of the country's cocoa export. Usually, they contain a genetic admixture of Nacional and highly productive disease-resistant foreign cultivars such as CCN 51. CCN 51 is notable for its very high butter content, low flavor intensity, and high bitterness and astringency. It is considered a bulk variety and does not contribute to the country's fine-flavor export quantity (Rottiers et al. 2019). The development of the CCN 51 clone has increased the total production of cacao in Ecuador and accounts for about 80,000 ha of the total 400,000 ha of planting space (Boza et al. 2014). This hybrid variety was reportedly developed from ICS 95, IMC 67 and a Criollo type variety referred to as Oriente 1 from the Canelos Valley in the Ecuadorian Amazon (Boza et al. 2014). In 2007, about 22,308 ha were under organic cocoa cultivation (Garibay and Ugas 2010).

Genetic Studies

Lerceteau et al. (1997) evaluated 60 Ecuadorian genotypes with 14 RAPDs, 45 RFLPs and 26 morphological traits. Accessions were from the EETP (Estacion Experimental Tropical Pichilingue of Ecuador) collection (33) and from the Sebastian Arteaga (11) and Balao Chico (16) plantations that were 80 to 100 years old in the regions of Manabi (north Ecuador) and Guayas (south Ecuador) respectively. These two plantations are approximately 450 km apart and were established from a limited number of fruits (Lerceteau et al. 1997). Trees from the two plantations were more related to each other and had lower levels of heterozygosity than the EETP collection. The low heterozygous trees in EETP were suggested to be genetically related to the on-farm cacao, and the high heterozygous trees probably originated from hybridizations between Nacional germplasm of Ecuador and genotypes imported from Trinidad at the beginning of the century (Lerceteau et al. 1997).

Crouzillat et al. (1998) analyzed 416 genotypes clones housed at CATIE (Costa Rica), INIAP (Ecuador) and Mexico's Instituto Nacional de Investigaciones Forestales, Agricolas, y Pecuarias (INIFAP) with 50 RFLP markers. In this sample set, 140 were Ecuadorian clones which were said to come from old plantations, but no further information about their source was given. Fifty Ecuadorian clones were found to be pure Nacional with very low levels of heterozygosity. The rest of the samples were more mixed and varied and were thought to be the result of hybridization between the Nacional and imported genotypes (Crouzillat et al. 1998).

Deheuvels et al. (2004) clonally propagated 115 Nacional trees between 1996 and 2000 from the Ecuadorian coastal plain that had high yield, resistance to diseases (moniliasis and witches' broom disease) and intense floral flavor, and evaluated these plants at two different sites. These workers found that 11 cultivars had early fruiting and 10 had very low susceptibility to witches' broom disease, with one cultivar in common between these two groups. Furthermore, the flavor characteristics were the same as those of the mother tree for eight of the nine cultivars that were tested.

Zhang et al. (2008) studied 482 Refractario accessions in Ecuador using 15 microsatellites. The Refractario cacao group has a genetic composition of hybrid origin between the genetic cluster "Nacional" with others from the Upper Amazon origin (Zhang et al. 2008). The Refractario group was different from the Marañon, ICS, French Guiana, Criollo, Forastero, Trinitario and pure Nacional samples tested. However, hybrid Nacional clones such as EET 96 [ECU], UF 705, NAL 1, NAL 2, NAL 3 and NAL 4 showed genetic similarity, strongly indicating that Nacional is one of the parents of the Refractario group. The results of Zhang et al. (2008) and Motilal et al. (2012) support the separation of the Refractario accessions into two main groups. One group contained germplasm from the AM, CL, CLM, LP and MOQ accession groups, which were collected from Haciendas Amalia, Clementia (CL and CLM), La Paz and Moquique respectively. The other group contained germplasm from the B, JA, LV, LX, LZ, SJ, SLA and SLC accession groups, which were collected from Haciendas Balao, Javilla, L (LV: Large Vuelta; LX, LZ: Limoncillo), San Juan and Santa Lucia (SLA, SLC) respectively. Hacienda L lacked background information in the original collection report (Pound 1938, 1943). Bekele et al. (2020) found that the Refractario germplasm at the ICGT comprised 36% of the 254 accessions with best pod index from the 1,900 diverse accessions that were studied.

Loor et al. (2009) attempted to trace the ancestral genetics using 40 microsatellites on 322 cacao trees on the Central Coast region, managed by the Instituto Nacional de Investigaciones Agropecuarias (INIAP) and Colección del Centro del Cacao de Aroma Tenguel (CCAT) on the South Coast region, organized by the Universidad Técnica Estatal Quevedo. These are samples of germplasm material that were collected at unspecified locations along the Pacific coast of Ecuador and are maintained as living collections at these two germplasm banks. There were seven samples considered to be "high-homozygosity individuals (HoN)" since these shared a close genetic ancestry with the old Nacional reference. The "Arriba" character is present in all HoN accessions, except for the unevaluated accession L39-H66. These results could suggest that the HoN individuals represent the Native Nacional cacao before the introduction of other international varieties. Even with the vast region where the samples were taken, the HoN population seemed to have high genetic similarity, perhaps indicating a bottleneck effect on the original Nacional cacao population. The high level of homozygosity in the old Nacional cacao is suggestive of self-compatibility (Loor et al. 2009).

The Nacional variety had a high level of heterozygosity due to several historical introductions of foreign germplasm. Most of the samples appeared to be hybrids that shared alleles with the Trinitario type UF 676 and with the old Nacional reference B 240, which supported the hybrid nature of the modern Nacional cacao. Modern Nacional cacao reportedly developed from a mix of crossbreeding and backcrosses among homozygous Nacional genotypes, foreign genotypes inclusive of Trinitario trees and SCA 6 (Loor et al. 2009). A later study by Colonges et al. (2021) using genotyping by sequencing on 152 Nacional cacao trees from INIAP and CCAT demonstrated a similar distribution among Amelonado, Criollo and Nacional clones. Rottiers et al. (2019) using 14 microsatellite loci showed that four EET accessions (Nacional hybrids) clustered apart from CCN 51 but that three of the EET accessions (EET 103, EET 576, EET 577) were identical to each other.

Loor Solorzano et al. (2012) assessed trees from different geographical origins including seven putative ancient Nacional from the coast; and 65 wild trees from the north, central and south regions of the Upper Amazonian region of Ecuador with 80 microsatellite loci. These authors found that the trees from the north and central Amazonian regions of Ecuador were similar and clustered mainly amongst themselves. However, the samples from the southern Amazonian regions clustered together with the ancient Nacional and reference Nacional samples from the Morona river valley in Peru. Similarly, Nieves-Orduña et al. (2021) found two natural populations based on chloroplast microsatellite haplotype for the Nacional group. One population was along the Napo River in Ecuador and the other along the Morona River in Peru. The southern Amazonian region is geographically close to the Guayas basin where the first Nacional cacao plantations were established. Several accessions (LCT EEN 85, LCT EEN 86 and LCT EEN 91) found along the Nangaritza, Yacuambi and Zamora riverbanks were suggested as possible ancestors of the Nacional variety. Loor Solorzano et al. (2012) suggested that the Amazonian region located in the Province of Zamora Chinchipe could be the center of domestication of the Nacional variety and recommended that future cacao expeditions should be carried out in the southern Amazonian area of Ecuador.

Carranza et al (2020) used 95 SNPs to assess 80 Nacional genotypes and 19 introduced accessions revealing 16 groups of identical samples with two to 13 members per group and genetic similarity with the introduced accessions (CCN 51, Trinitario and Forastero).

Sankar et al. (2018) assessed 500 wild LCT EEN accessions collected in The Oriente with 82 SNPs and found evidence for identical samples, about 100 samples with high homozygosity, two subclusters, spatial structure with isolation by distance and relatedness to the Nacional, Ucayali and Purús clusters.

Highlighted Cultivars

Rondon Carvajal (1993) describes a variety known as Amicagales, found in the Pacific lowlands of Ecuador by Pound in 1938, that was linked to the Cacao Vegetal population of Colombia based on distribution and morphology.

The local Ecuadorian variety Sabor Nacional Arriba (SNA) has shown some resistance to the Ceratocystis fimbriata fungus (Delgado, 2007). In Delgado's (2007) study, 86 clones of SNA were analyzed for their resistance to Ceratocystis with IMC 67, ICS 1 and CCN 51 as controls. Most of the accessions were either susceptible or highly susceptible to the fungus. The clone that showed the most resistance was SNA 0106. It was more resistant than the resistant control IMC 67. The clones SNA 0106, SNA 0905, SNA 0430, SNA 0101, IMC 67, CCN 51 and SNA 0205 were somewhat resistant to perithecium formation of the fungus, while SNA 0106 and SNA 0905 proved to be highly resistant as no perithecium formation was observed (Delgado 2007). However, the clone CCN 51 was proven to be susceptible to the fungus (Delgado 2007).

Nevertheless, the CCN 51 cultivar has become one of the most planted cultivars in Ecuador, mainly as a result of its high productivity and low witches' broom disease incidence (Boza et al. 2014). Hermann et al. (2015) found genetic differences using microsatellite markers among CCN 51 cultivar samples. One reason advanced was seed propagation and distribution from fruits on CCN 51 plant. The seedling progenies would be different especially if the fruits were derived from open pollination but may have been attributed the name of CCN 51. In Rottiers et al. (2019), ripe pods of five cultivars (CCN 51, EET 103, EET 559, EET 576 and EET 577) were harvested in April 2018 from a certified clonal garden located in Milagro, Guayas Province, in the Coastal region of Ecuador. The bean count showed that all of the cultivars in this study had large beans, but CCN 51 had the largest beans, at 70 ± 3 per 100g. There was no significant difference in bean count between the EET cultivars, with values ranging from 75 to 78 beans per 100 g. Naula Laura (2016) showed that EET 95 and EET 103 were promising clones relative to CCN 51 for canton Arosemena Tola in the province of Napo, Ecuador. Manual, deliberate hybrids among Nacional and Alto Amazónico yielded 53 genotypes which when evaluated identified a cultivar INIAPT 484 (Alto Amazónico × Alto Amazónico) with a higher yield than CCN 51 or EET 103 (Sotomayor Cantos et al. 2017).

Flavor Quality

Fine aromatic cacao from Ecuador is obtained from the Nacional variety and to obtain the Arriba designation of origin must be grown at a maximum altitude of 1,200 meters above sea level, according to the Ecuadorian Institute of Intellectual Property (PROECUADOR, 2011 cited in Lehmann and Springer-Heinze 2014). Ecuador accounted for about 60% of the global aromatic cacao production in 2014 (Lehmann and Springer-Heinze 2014). Ecuador is a 75% fine or flavor cocoa producer from the December 2020 ruling (ICCO 2016–2020b). Nacional cacao is said to have very short fermentation, resulting in smooth chocolate with good flavor and aroma (Lehmann and Springer-Heinze 2014). Nacional Fine Aroma cocoa is reputed for its fruity and floral fragrances in modern Nacional varieties (Carranza et al. 2020) and the traditional Nacional Arriba flavor of intense floral with spicy and woody notes (Luna et al. 2002; Loor et al. 2009; Colonges et al. 2022). Traditional Nacional cultivars also have low acidity, bitterness and astringency, with violet, jasmine, lilac or orange blossom notes contributing to the floral flavor (Deheuvels et al. 2004).

CCN 51 reportedly has an average bean mass of 1.54 g, 50.3% fat, a high ratio of theobromine to caffeine (6.9), moderate to low cocoa flavor, and high levels of bitterness and astringency (Boza et al. 2014). The varieties CCN 51 and EET 103 gave cocoa liquors that were the most alkaline and most acidic respectively (Boza et al. 2014). Furthermore, the seven Nacional clones that were used (EET 63, EET 95, EET 103, La Gloria, Las Brisas, Santa Lucia and Voluntad de Dios) showed low (EET 103) to moderate-high (EET 62, La Gloria) cocoa flavor, low (EET 95, EET 103, Voluntad de Dios) to moderate (EET 62, La Gloria, Las Brisas, Santa Lucia) floral flavor and low fruity scores in the seven Nacional clones. Four Nacional hybrids (EET 559, EET 576, EET 577 and EET 103) had different volatile and sensory profiles even though three of these were identical from 14 microsatellites but in general had high fruity and floral volatiles (Rottiers et al. 2019).

Over the period from 2010 to 2021, chocolate samples from Ecuador were selected for the best 50 International Cocoa Awards for 2010 (five batches), 2011 (two batches), 2013 (five batches), 2015 (two batches), 2017 (three batches), 2019 (three batches) and 2021 (one batch) with 1, 1, 0, 2, 1, 1 and 1 wins respectively. There were three top-50 samples in the 2019 Cocoa of Excellence (CoEx 2019). One was chocolate made from a Nacional cacao batch (EET 95, EET 96, EET 103, EET 111 cultivars) from Atacames, Esmeraldas, with strong cocoa flavor; moderate roast, bitterness, astringency, fresh fruit and floral flavors; and low acidity, sweet, brown fruit, spice, woody and nutty flavors (CoEx 2019). The second chocolate was made from a Nacional cacao batch (Tipo Nacional cultivar) from Calceta, Manabi, Costa, with strong cocoa flavor; moderate roast, bitterness, astringency and fresh fruit flavors; and low acidity, sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019). The third was a Nacional cacao batch from Punta del Este, Vinces, Vinces, with strong cocoa flavors; moderate roast, bitterness, astringency, acidity and fresh fruit; and low sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019). A winning entry in the best 50 of the International Cocoa Awards 2021 from Via Febres Cordero Km 9.5, Babahoyo, Mata de Cacao, Costa, was given the following flavor profile description: "Dark brown-burgundy hue colour. Chocolate note runs deep in character and blends mild fruit acidity, fresh dark fruits, mild browned (date) notes. Center develops floral green grassy, mild earthy and floral flowers. Astringency is velvety. Complex, unique, but balanced." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved.

FRENCH GUIANA

Overview

French Guiana (Fig. 63) is in South America with the Caribbean Sea on the northern side and sharing borders with Brazil (east-south) and Suriname (west). French Guiana was not ranked on World Population Review (2022) list of 59 cocoa producing countries.

Historical Introductions

French settlers brought cocoa from Trinidad to this country in 1684. This cacao material resulted to be progeny of the Mexican Criollo (Cook 1982). Sabatier and Prevost (1987) stated that the old cacao plantations on the upper Campoi River were known since the 18th century. Clément (1986 cited in Sabatier and Prevost 1987) indicated that the old cacao populations originated from fruits brought back from the upper Campoi River. Lachenaud et al. (2005) indicated that the wild trees were discovered in 1729. Although data suggest that Amelonado was first cultivated in the Brazilian state of Pará, ethnographic evidence indicates evidence of very early Amelonado domestication in French Guiana (Arevalo-Gardini et al. 2019).

Figure 63
Map of French Guiana showing the river systems.

Collections

From 1720 to 1743, cacao collecting expeditions went up the Oyapok and the Camopi rivers looking for stands of wild cacao (Hurault 1972 cited in Sabatier and Prevost 1987). Wild cacao collected in 1987 near the stream Crique Cacao, Montagne Cacao hill, and Borne 6 (Fig. 64) near the border with Brazil occur as clumped stands with some slanting stems taking root several meters away from the mother plant (Sabatier and Prevost 1987). It is believed that these are more likely to be natural stands rather than of anthropogenic origin (Sabatier and Prevost 1987). Somarriba and Lachenaud (2013) describe the types of wild cacao stands in Guiana. The first type is a single individual tree with only one trunk. The second type is a group of siblings in which each sibling has multiple trunks. The last type is a homogeneous type; this occurs when the main trunk of the original tree touches the ground, and some suckers attach themselves to the ground independently.

Figure 64
Joint cocoa collection expedition by IFCC, CIRAD, ORSTOM and ENGREF for wild cacao populations in the upper reaches of the Campoi River.
Adapted from Sabatier and Prevost (1987)

Wild cacao trees of southeastern French Guiana were collected between 1985 and 1995 (Paulin et al. 2008). The GU genetic material (Guiana) has been documented to be originating from wild mother trees in the Camopi and Tanpok river basins, according to Lachenaud et al. (2007). Additional cacao varieties from French Guiana would have been collected from the Kérindioutou river basin (KER and B7 clones), Oyapok river basin (OYA and PINA clones), Euleupousing river basin (ELP clones) and Yaloupi river basin (YAL clones) as described above (Lachenaud et al. 2007). A survey carried out in 2006 found that there were 370 GU clones distributed across cacao-producing countries. This distribution included Cameroon, Costa Rica, Côte D'Ívoire, U.K., Philippines, Togo, Trinidad and Tobago, Brazil, Malaysia, India and Indonesia (Lachenaud et al. 2007).

Two expeditions were carried out by Lachenaud in the upper Oyapok and Tanpok river basins in 1987 (Lachenaud 1993). Between them, 176 mother trees were collected, comprising 15 geographic populations. Some of this material has been quarantined and planted in other locations: material from 92 mother trees in Cameroon, Cote d'Ivoire, Costa Rica, Great Britain, Philippines, Togo and Trinidad. On the whole, this material shows some phenotypic descriptors in common, including somewhat large pods of a unique shape (somewhere between Angoleta and Amelonado), frequently very distinct basal constriction (although it is not always present), obtuse apex form, rough pod surface with paired ridges, pods that ripen to yellow, and small purple cotyledons. All of these traits vary among the material collected, especially with regard to shape and surface rugosity of pods (Lachenaud 1993).

Lachenaud (2007) conducted a further expedition in 1990 covering the Oyapok River on the border between French Guiana and Brazil. Pods were harvested from seven mother trees belonging to four sub-populations (KER 1, KER 2, KER 8 and KER 11). The KER varieties displayed some uniformity in the appearance and the size of the pods. The seedlings were planted in 1992, resulting in 80 trees, which were then harvested from April 1995 to October 2000. By 2000 only 63 trees remained in the trial. Lachenaud later carried out a second survey of the Euleupousing and Yaloupi rivers in April 1995 (Lachenaud et al. 1997). These rivers are tributaries to the upper Oyapok and located in the extreme southeastern region of French Guiana. Three populations of cacao were collected.

The Euleupousing River population resulted in the ELP (1–41) collection after budsticks were grown in both French Guiana and one in Barbados (Lachenaud et al. 1997). The area with cacao trees begins just upstream of Boko falls and ends just upstream of Cambrouze falls. This stretch is around 10 km from point to point but covers a much larger distance following the meandering river. Material from 26 mother trees was collected. They were mostly (59%) Amelonado-shaped, but some had the classic Guianan shape (32%). Pod surfaces were slightly rough to completely smooth. Some pods had pale-colored beans. Trees ranged from a single stem to several to clusters, and while most trees were arranged in groups of three to 50, eight of the trees were growing isolated. There was a complete absence of witches' broom disease and very few rotten pods (Lachenaud et al. 1997).

The Oyapok River material resulted in the OYA (1–4) collection, which the authors suggest comparing with the PINA material that had been collected farther upstream on the same river a few years earlier (Lachenaud et al. 1997). One of these trees was fruiting, and its pods were of Amelonado shape. The rest of the material was collected as budwood. A suspected case of witches' broom was recorded here, but it was not collected (Lachenaud et al. 1997).

The Yaloupi River collection was smaller (Lachenaud et al. 1997). In this natural sanctuary where even local native populations do not venture, very few trees were found downstream, although more trees could exist near the river's mouth, where the researchers could not reach. Only five mother trees were collected here, resulting in the YAL (1–8) collection. Only half of the observed trees had pods, and the pods were half Amelonado shape and half Calabacillo shape. No witches' broom was observed in this area (Lachenaud et al. 1997).

The IRCC in French Guiana established an international germplasm collection in the 1990s. To this end, they selected Lower Amazon clones among semi-wild and old cultivated Guianese material and used them for breeding to enlarge West African germplasm possibilities. A number of clones were selected based on vigor and productivity from this parentage (Lachenaud 1993).

Lachenaud and Motamayor (2004) claim that after years of observation, open-pollinated trees from the basins of the Camopi and Tanpok rivers have only yellow pods, without any red, pink or purple tanning. This is also true of the "Borne 7" and "KER" populations of the Upper-Oyapok (Lachenaud and Sallée 1993). However, on the banks of the Euleupousing river during a 1995 expedition, pinkish fruits were observed on some mother trees and some also had pale beans (Lachenaud et al. 1997). Seedlings from the pods harvested in this expedition were planted at Paracou-Combi in 1996, and when the first pods appeared from these seedlings, they showed obvious red pigmentation in two of the progenies (ELP 28 and ELP 31). ELP 28 is particularly interesting because it came from a mother tree with pale beans. After 2001, a tree displaying entirely red pods was found from progeny ELP 28 (Lachenaud and Motamayor 2004).

A fourth expedition via The European Regional Development Fund (ERDF) "Dicacao" undertaken in May 2012 along the upper reaches of the Tanpok (a.k.a. Tampok or Tampock) river, a tributary of the Maroni river, collected 22 mother trees, of which nine came from two new sites (Lachenaud et al. 2016).

Recent Cultivation

Somarriba and Lachenaud (2013) suggested that the five classes of coffee and cocoa production systems (open sun cultivation, specialized shade, commercial shade, mixed shade, and rustic systems) should be expanded to include a sixth type, the "successional cocoa agroforest" based on studies in French Guiana.

Genetic Studies

A study on wild cacao trees from expeditions in 1987, 1990 and 1995 by Lachenaud et al. (2005) concluded that wild cacao trees from French Guiana had a promising value for yield, cropping efficiency, resistance to disease and cacao quality. Lachenaud and Oliver (2005) showed that fresh bean mass ranged from 2.20 to 3.82 g in 96 local wild cacao trees belonging to 10 populations from the Camopi and Tanpok rivers. Genetically, French Guiana varieties are more closely related to the Amelonado subtype and material collected from the Lower Amazon (Arevalo-Gardini et al. 2019). It was originally thought that wild populations of cacao, recorded since 1729, were the origin of cultivated Guianese cacao. However, it is now known that wild types are very distinct from cultivated material, and efforts have been made to preserve wild germplasm (Lachenaud 1993). The French Guiana cacao is represented by a single chloroplast microsatellite haplotype that could support human-mediated dispersal of a few individuals as the founder population (Nieves-Orduña et al. 2021).

The Euleupousing River is incredibly remote. Access is difficult and even native populations rarely venture there. For this reason, finding "Trinitario" material there is very unlikely. In order to confirm that the red-pigmented fruits found along the Euleupousing River were not Trinitarios, an assignment test based on allelic frequency from 13 microsatellites was carried out on 12 ELP progenies and 34 Trinitario-type accessions, including ICS 1 and ICS 95, which have red fruits. The results confirmed that the ELP progeny could not be assigned to the Trinitario group (Lachenaud and Motamayor 2004). Overall the Guiana germplasm has a low genetic diversity (Lachenaud and Zhang 2008; Lachenaud et al. 2016).

Highlighted Cultivars

Guiana genetic material is reportedly resistant to witches' broom disease (Ofori et al. 2020). Additional assessment of the Guiana clones from the five river basins (Oyapok, Camopi, Euleupousing, Yaloupi and Tanpok (see Fig. 11) during the 2011 to 2013 harvest years identified 17 clones that displayed moderate to high resistance to the causative agents of black pod rot. The three Phytophthora species that are of major interest to the cacao industry due to their damaging nature to the levels of pod production are Phytophthora capsici, P. palmivora, and P. megakarya. Resistance to these species is useful to breeders to produce enhanced varieties. The clones of interest are GU 265/V, ELP 9-A, ELP 11-A, GU 161/A, ELP 18-A, GU 262/A, ELP 8-A and GU 152/A (highly resistant to P. capsici) and ELP 9-A, ELP 8-A, ELP 15, ELP 16-A, ELP 22-A, GU 123/V, GU 156/B, GU 263-/ and GU 303/B (highly resistant to P. palmivora and P. megakarya) (Lachenaud et al. 2015).

Over a 10-year period, the GU trees in French Guiana and other countries were assessed for agronomic characteristics that would be of interest for plant breeders, including yield, pod and bean traits, and resistance to black pod rot (Lachenaud et al. 2007). It was found that the average bean production for wild French Guiana families was 342 kg/ha of fermented and dried beans. The survey also found that GU clones have few seeds per pod, and they are generally small (Lachenaud et al. 2007). Finally, the survey confirmed that the GU clones from the Tanpok river basin were susceptible but displayed more resistance than the clones from Camopi river basin (Lachenaud et al. 2007). The GU clones currently in use in Côte D'Ívoire, Ghana and France (at CIRAD) are also highly resistant to black pod rot (Lachenaud et al. 2007). Paulin et al. (2008) found that 36 of the 50 studied accessions from French Guiana were resistant to the most aggressive black pod rot fungus, Phytophthora megakarya, and 13 of these were more resistant than the reference resistance clone.

The GU germplasm in French Guiana was highly resistant to witches' broom disease whereas the clones in Trinidad, Brazil and Ecuador were moderately resistant (Lachenaud et al. 2007). Very low resistance to frosty pod rot was found among GU clones in all locations. GU clones in Côte D'Ívoire (CNRA), Cameroon and Ghana were resistant to mirid insect attacks (Lachenaud et al. 2007).

Crosses in the Côte D'Ívoire using GU clones (GU 123/B, GU 175/A, GU 284/A) as a parent showed good transmission of black pod disease resistance. In Trinidad, GU clones GU 175/P and GU 286/P transmitted moderate resistance to their progenies for black pod rot and witches' broom diseases (Lachenaud et al. 2007).

An overall assessment of these characteristics led Lachenaud et al. (2007) to identify three GU clones (GU 28/A, GU 134/B and GU 139/A) that would be most suitable for selection of superior traits in breeding programs. The KER material was self-compatible, and five of these (KER 3, KER 5, KER 6, KER 7 and KER 9) could be cloned to serve as parents in the breeding programs (Lachenaud 2007).

Paulin et al. (2008) conducted a study at CIRAD in Montpellier to assess the degree of resistance to P. megakarya in clones originating from several natural populations from French Guiana. The material used in this study had origins from wild trees in the basins of the Camopi, Tanpok and Kerindioutou rivers and the Oyapok, Euleupousing and Yaloupi rivers. The studied material included 10 clones from each of the populations Camopi 1, 7, and 9; seven clones from the Euleupousing population; six clones from the Kerindioutou and Camopi 3 populations; four clones from the Borne 7 population; and one clone from each of the Camopi 6, Camopi 12, Oyapok, Pina, Tanpok and Yaloupi populations. Twenty-two GU clones (Camopi and Tanpok) maintained in the greenhouse in Montpellier and 20 clones that came from other rivers provided a random sampling.

A total of four trials were carried out by inoculating the wild Guianian clones with strains of the disease from Cameroon (NS269). It was observed that a correlation exists between resistance on leaves and percentage of rotten pods. It was found that 61% of the samples (36 clones) were either resistant or highly resistant. IMC 47 was found to be resistant. The clone GU 265/V was found to be susceptible for the Camopi 1 population. For the Kerindioutou population, the clone KER 1/L was found to be susceptible. The findings suggest that the wild Guianan clones of French Guiana are an important source of resistance to P. megakarya. The author suggests that the clones resistant to P. megakarya identified in this study should also be resistant to P. palmivora (Paulin et al. 2008).

Flavor Quality

Bean physical and chemical analysis of these natural GU populations originating from the Camopi and Tanpok rivers (Fig. 11) determined that pods generally had a high bean count and a high caffeine content in the beans when compared to the reference West African Amelonado varieties (Assemat et al. 2005). It was also found that GU clones in French Guiana and Côte D'Ívoire had a high caffeine level compared with the African Amelonado. In Ecuador, the GU clone had a high fat content (average of 54.2%), moderate bean weight (1.09g) and a rich cocoa aroma (Lachenaud et al. 2007). A further study on wild Guiana cacao compared the chemical properties of its unfermented and fermented beans with that of beans of Forastero type (Jean-Marie et al. 2021). Guiana is considered a separate population, having originated from the Amazon basin and the Guiana Shield. Pods for these analyses were harvested from the CIRAD cocoa station in Sinnamary, French Guiana. Overall, Guiana clones were higher in antioxidant capacity than the Forastero clones, had 50% less caffeine but were 15% richer in theobromine than Forastero and were equal in content of epicatechin and procyanidins (Jean-Marie et al. 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cacao awards should also be collected and conserved.

GUYANA

Overview

Guyana is in South America with the Atlantic Ocean on the northern side and bordered by Suriname to the east, Brazil to the south and Venezuela to the west. Guyana produced 429 metric tons of cacao in 2021, ranking 40th out of 59 cocoa producing countries (World Population Review 2022).

Historical Introductions

A cacao plantation established in the 1730s at Coomacka, on the Berbice River, was found to have both Criollo and Forastero types with trees being of mixed origin (Myers 1930 and references therein).

Collections

Myers (1930) reported on correspondence that indicated wild cacao was present in Black creek, close to the mouth of the Rupununi river. Wild cacao was also observed on the Upper Pomeroon River in British Guiana (Myers 1930 and references therein).

Recent Cultivation

A 2001 survey was carried out to discover the genetic diversity of farmed cacao in North-West Guiana (Chesney 2007). The survey focused on the county of Essequibo, on the border with Venezuela. A total of 65 trees originating from 21 certified organic farms were sampled and characterized using 22 qualitative and quantitative morphological traits (Chesney 2007).
Results indicated that the dominant type of cacao grown in the area of study was Amelonado. The mean cotyledon weight was 1.04 ± 0.46 g and the mean pod index (PI) was 36.3 ± 21.96. Ten of the accessions had a cotyledon weight of more than or equal to 1.2 g and pod index of less than or equal to 21. Also, 14 of the accessions had pale-colored beans with little or no concentration of anthocyanin pigment (Chesney 2007). In a survey later the same season, 18 cacao farms were surveyed, and the trees were monitored for the common cacao diseases. Trees were evaluated for black pod rot using detached pod inoculation technique, and witches' broom was evaluated using a seedling inoculation technique. Based on the tests, 47% of the pods were infected in the field with black pod rot. The dry bean loss to disease was estimated to be 0.1 kg per tree sampled based on the pod and bean yield technical coefficients. All accessions sampled also developed symptoms of witches' broom disease when inoculated artificially; however, no symptoms of witches' broom disease were ever observed on any of the farms that were monitored during the study (Chesney 2007).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

PERU

Overview

Peru (#3 in Fig. 52; Fig. 65) is in South America. It is bordered on its western side by the Pacific Ocean and shares borders with Colombia (north/northeast), Brazil (east), Bolivia (east/southeast) and Chile (south). Peru produced 121,825 metric tons of cacao in 2021, ranking 8th out of 59 cocoa producing countries (World Population Review 2022). In contrast, Peru was listed as the 10th top cacao-producing country in the world in the Chocolate Codex. In 2020, Peru exported US$146 million in cocoa beans, making it the 9th largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/per). The northeastern region of Peru is considered a diverse area for cacao, with seven varieties having been identified, including the Chuncho type, which is described below (Evans et al. 1998).

Historical Introductions

In 1526 and 1527, the Spanish explored Peru and found many cacao plantations in Esmeraldas province. This cacao should correspond to the Nacional variety (Díaz-Valderrama et al. 2020). Peruvian farmers first began using foreign clones in the 1950s. These clones include the UF clones from Costa Rica, ICS clones from Trinidad, and the EET clones from Ecuador (Zhang et al. 2011b). On-farm samples in Peru consist of "improved" and "unimproved" genetic populations. Those "improved" populations belong to Criollo, which tends to be mainly self-compatible and homozygous, as well as Forastero and Trinitario, which comprise a large part of on-farm cacao. Amelonado is also considered an "improved" variety since it is at least partially domesticated.

A Peruvian Nacional variety also exists and is also considered "improved"; it has been domesticated in some cases. Early evidence of its domestication in Chinchipe-Zamorra exists at the Ana de la Florida archaeological site on early pottery remnants (Arevalo-Gardini et al. 2019). In Tumbes, the first cocoa plantations began in 1960 in small areas (traditional family gardens) with trees that had long yellow pointed fruits (M & O Consulting S.A.C. 2008)

Figure 65
Map of Peru showing administrative regions and departments
Adapted from Evans et al. (1998).

Collections

The outbreak of witches' broom disease in 1920 led to the collection of cacao varieties in Iquitos, Peru, to find resistant cacao. The result was Pound's Collection (Fig. 66), which was composed of six main accession series: Iquitos Mixed Calabacillo (IMC), Morona (MO), Nanay (NA), Parinari (PA), Pound (POUND) and Scavina (SCA) (Zhang et al. 2009b; Zhang and Motilal 2016). The POUND clones were collected from the same sites as NA, IMC and SCA. These were selected based on their agronomic traits and resistance to black pod rot and witches' broom diseases and were introduced into the germplasm collection in the ICGT (Zhang et al. 2009b).

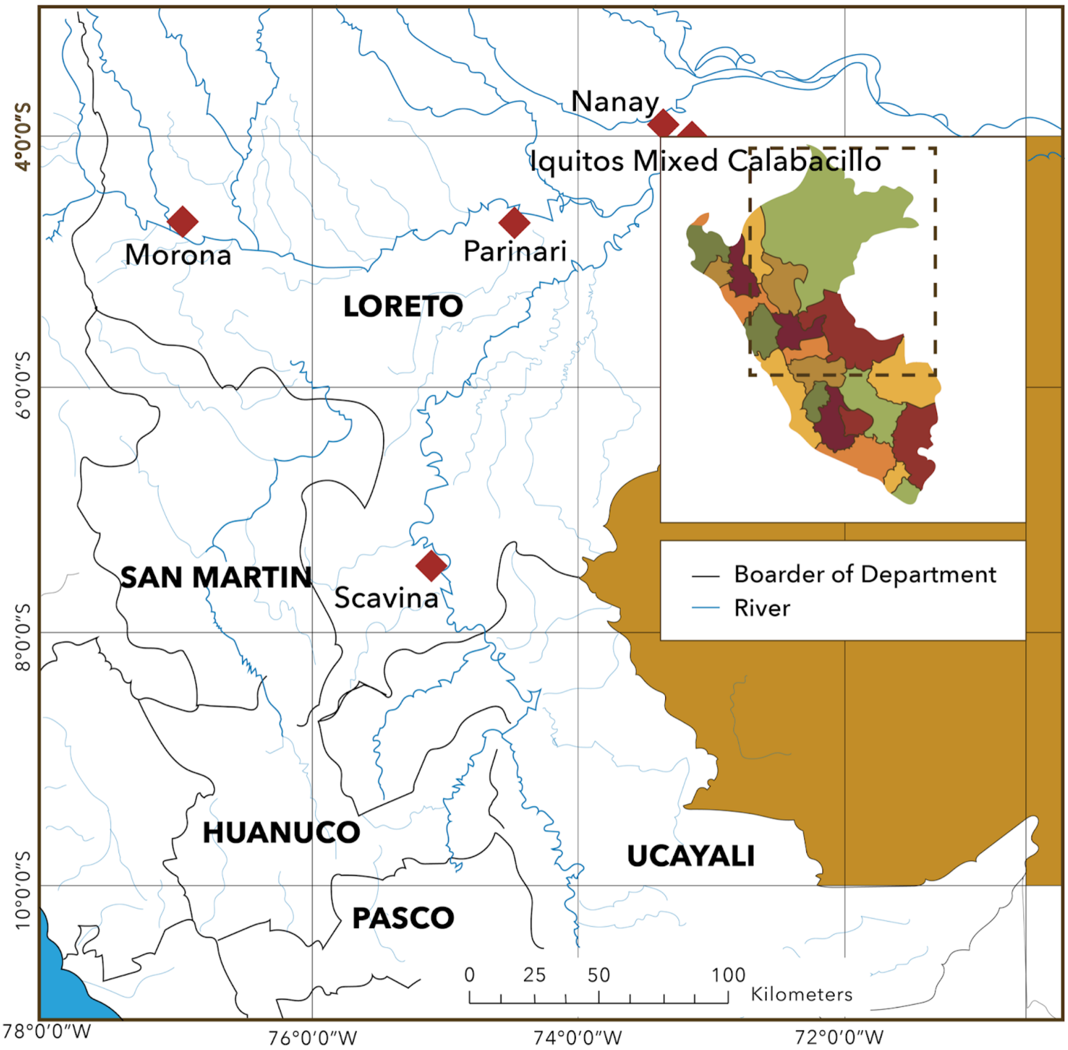


Figure 66

Collection of POUND cacao accessions from the Peruvian Amazon. Adpated from Zhang et al. (2009b)

Expeditions to the Huallaga, Ucayali and Urubamba river basins of the Peruvian Amazon were carried out from 1986 to 1989 (Macisco 2019). Cacao germplasm was later collected (1995–1999) in the areas of Jaén-San Ignacio (Cajamarca), Bagua, Utcubamba and Condorcanqui (Amazonas) and yielded 96 accessions that today constitute the "Marañon Collection" (see Macisco 2019). A collection of cacao germplasm from the Ucayali and Huallaga valleys of Peru was undertaken (Zhang et al. 2006; Fig. 67).

The Huallaga clones came from "Fundo San Jose," a cacao farm in Naranjillo – Tingo Maria, and they were collected from fields beset by witches' broom disease. The Ucayali clones were described as "wild" trees that came from Ucayali River as well as the Urubamba River and its tributaries Contamana, San Carlos, Ucayali, Cushabatay and Chiatipishca Lake (see Figure 66). The Ucayali group included two subgroups depending on the geographic area of collection. Lower Ucayali clones came from between 5°0'S and 9°10'S, while clones from the Urubamba subgroup were collected between 12°35'S and 13°01'S (see Fig. 66) (Zhang et al. 2006). Clones from the budwood collected from both of these subgroups were maintained in Tingo Maria and in Sahuayacu, near Quillabamba, Peru. Social unrest in Peru led to the loss of some of the collection in following years, but in 1998 re-collection was attempted and clones from Sahuayacu were used to restore the Tingo Maria collection. In the early 2000s the Tingo Maria collection maintained 62 Huallaga clones and 51 Ucayali clones (Zhang et al. 2006).

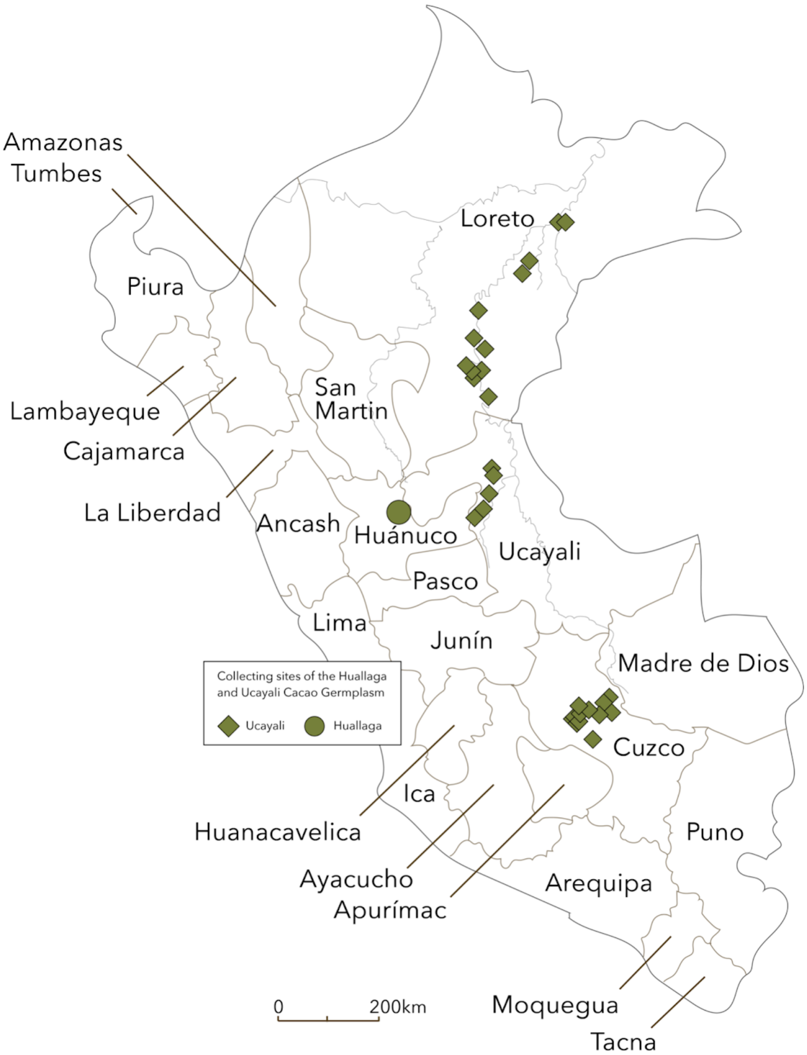


Figure 67
Wild cacao collection in Peru for Zhang et al. (2006) study.
Figure adapted from same study.

Céspedes Del Pozo et al. (2018) reported the selection of 72 trees of Chuncho cacao in the province of La Convención-Cusco for gene bank establishment. These authors claim that Chuncho cacao is native and unique to this province and recommended prospection in the Urubamba river valley in La Convención, Cusco-Perú. Chia Wong (2018) also indicated collection of 80 germplasm from the Piura, Cuzco, San Martín and Amazonas districts.

Arevalo-Gardini et al. (2019) collected wild cacao along the Santiago and Morona river valleys along the border between Ecuador and Peru (Fig. 68), some growing at an elevation over 1,000 m above sea level. Wood and Lass (1985) indicate that the altitude where cacao grows is governed by temperature, with cacao being established at 1,400 m in Colombia and 1,100 to 1,200 m in Uganda (Arevalo-Gardini et al. 2019).

Figure 68

Map of the Andean foothills of Northern Peru showing sites of cacao collection

Adapted from Arevalo-Gardini (2019)

Vargas and Vásquez (2018) collected 128 promising plants with fine aroma characteristics from 67 producers over 11 Regions (Tumbes, Piura, Ayacucho, Cuzco, Huánuco, Junín, Pasco, Iquitos, Ucayali, Amazonas and San Martin; Table 5). Oliva and Maicelo Quintana (2020) and Oliva Cruz (2020) reported the identification and selection of 146 ecotypes of fine flavor native cacao in northern Peru at various altitudes (Fig. 69). These reports identified 139 ecotypes from four provinces (Bagua, Utcubamba, Chachapoyas and Rodríguez de Mendoza) in the Amazonas Region, six ecotypes from Cajamarca Region and one from San Martin Region. Furthermore, there was greater phenotypic diversity at 800 m above sea level (Oliva Cruz 2020; Oliva and Maicelo Quintana 2020). The provinces of Bagua and Utcubamba differed in ecotype composition (Oliva Cruz 2020).

Table 5 Collection of fine aroma cacao germplasm in Peru. Excerpt and modified from Vargas and Vásquez (2018)

Region	Province	District	Number of Producers	Number of collected trees
Amazonas	Bagua, Utcubamba	Cajaruro, Peca	7	10
Ayacucho	La Mar	Santa Rosa	1	4
Cusco	Convención	Kimbiri, Pichari, Villa Virgen	5	11
Huanuco	Leoncio Prado	Daniel Alomías Robles, José Crespo y Castillo, Luyando, Naranjillo	7	15
Iquitos	Loreto, Requena	Jenaro Herrera, Nauta	2	2
Junin	Satipo	San Martin de Pangoa	2	10
Pasco	Oxapampa	Palcazu, Puerto Bermúdez	5	5
Piura	Morropón	Buenos Aires, San Juan de Bigote	7	18
San Martin	Mariscal Cáceres, Tocache	Juanjui, Pajarillo, Tocache	8	10
Tumbes	Zarumilla, Tumbes	Aguas Verdes, San Jacinto, Zarumilla	5	14
Ucayali	Atalaya, Padre Abad, Coronel Portillo	Calleria, Irazola, Neshuya, Raimondi	18	29
Total: 11	Total: 17	Total: 27	Total: 67	Total: 128

Recent Cultivation

A United Nations-led program that began in the early 2000s encouraged farmers to switch from coca farming to cacao. This drove production in the Amazonian departments of San Martin and Ucayali, which as of 2016 produced 42% of all cacao in Peru (Blare et al. 2020). This is heavily due to the adoption of the CCN 51 variety. The introduction of this and other hybrids has also affected Peru's export classification by the ICCO, moving it from 100% fine flavor export in 2008 to 90% by 2011 (Blare et al. 2020). Bamber and Fernandez-Stark (2012) reported a shift from conventional cacao farming to organic farming by 2012 for 1,200 farmers. In 2007, about 14,407 ha were under organic cacao cultivation (Garibay and Ugas 2010). Certified organic cacao is produced by 200 members of the Naranjillo Agroindustry Cooperative in the province of Tocache, Peru (Bamber and Fernandez-Stark 2014). These members produced about 35% of total organic cacao in 2014 (Bamber and Fernandez-Stark 2014). In the Irazola District (Padre Abad province, Ucayali Region) Criollo beans are used as rootstock on which desired hybrids are grafted (Emenius 2012). In northern Peru, thousands of hectares of primary forest were cleared since 2013 for a cacao plantation and this may be continuing despite alleged contravention of zonation policy (Erickson-Davis 2016).

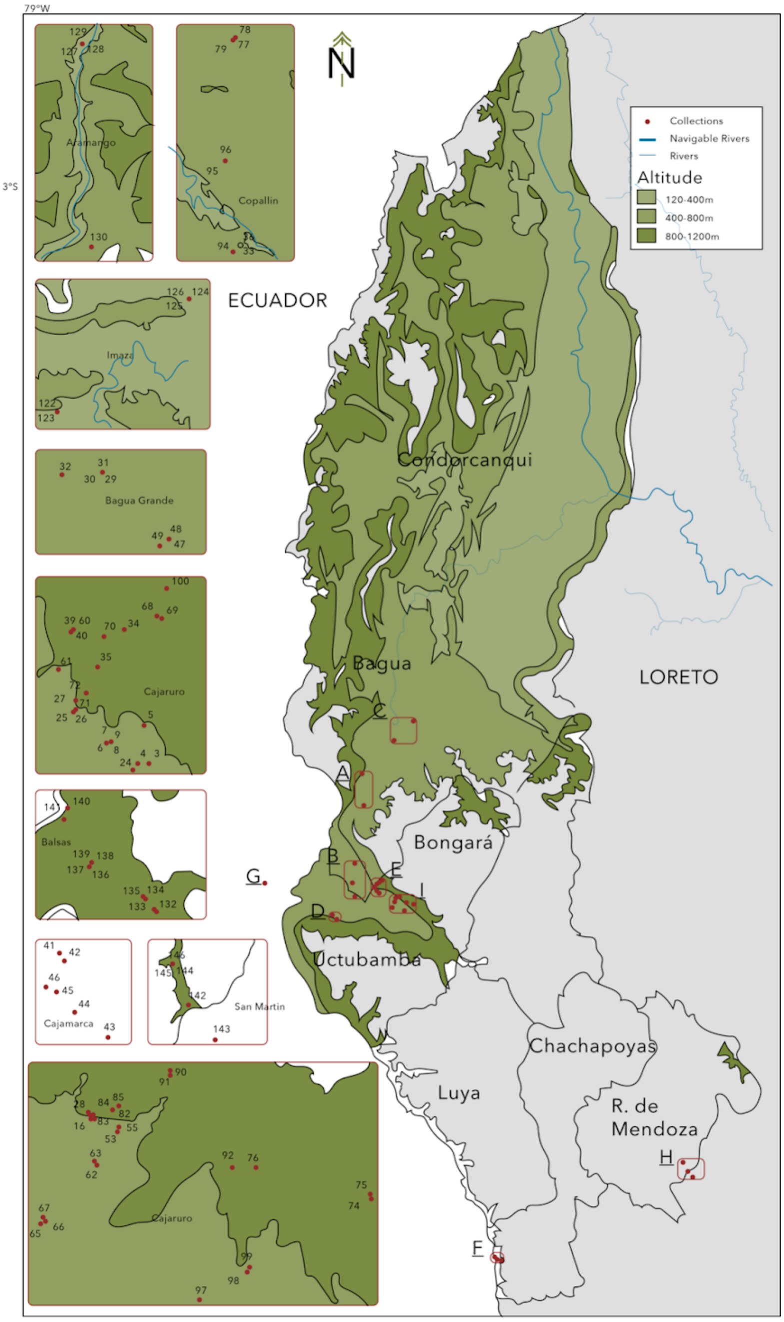


Figure 69

Collection map of native fine aroma cacao in northeastern Peru. Figure adapted from Oliva and Maicelo Quintana (2020)

In north Peru, traditional heterogenous hybrid varieties of Nacional × Trinitario crosses exist in Tumbes, whereas in Piura the phenotypically uniform but heterozygous Porcelana variety was established from seeds of few trees (M & O Consulting SAC 2008). Diverse cacao trees with local and foreign origins were present in the provinces of Jaén and San Ignacio (Cajamarca), and Bagua and Utcubamba (Amazonas) with fruits having white seeds being present in Bagua and Arriba types in Jaén (M & O Consulting SAC 2008). The Huallaga valley in San Martin (North Region) has a wide variety of hybrid types, clones and Trinitarios but the system in Huánuco (Tingo María; Central region), which also has a wide variation of morphological traits, is said to be due to the spread of mainly six interclonal hybrids (M & O Consulting SAC 2008). In Satipo (Central Region), red- and green-fruited hybrid Trinitario or Trinitario × Forastero crosses are present in Junín and Chuncho types in Coviriali (M & O Consulting SAC 2008). In the South Region, the Apurimac-Ene River Valley (Ayacucho) has a mixture of interclonal hybrids, unlike Cusco, which has the Chuncho variety and its hybrids (M & O Consulting SAC 2008). In the Zarumilla Province of Tumbes, two farmers in the Papayal sector reported that part of their plantation was from seed introduced from Ecuador and one farmer in the Las Plamas sector had clonally propagated cultivars from commercial plantations in Ecuador (M & O Consulting SAC 2008).

Genetic Studies

Zhang et al. (2006) fingerprinted 115 accessions from the Ucayali and Huallaga valleys of Peru. Results of a Bayesian assignment test showed that the germplasm group in the Huallaga valley was clearly separated from the group in Ucayali valley. Lower genetic diversity (allelic richness and gene diversity) was found in the Huallaga group. The Ucayali group showed genetic substructure with differences between the Lower Ucayali clones and the Urumbaya clones, although this difference was smaller than the difference between the Ucayali group and the Huallaga group. Results also indicated that there was spatial correlation between genetic distance and geographical distance (Zhang et al. 2006).

Zhang et al. (2009b) analyzed the genetic structure of POUND clones using 15 SSR primers to attempt to reconstruct the genetic identity of early cacao. The samples of existing Pound Collection were taken from the Marper Farm, Trinidad and the ICGT and reference accessions were from Peru and CATIE. There was a high level of allelic diversity in
the POUND collection from a large number of related family members collected from a few sites in the Ucayali and Nanay rivers, as well as the lower Marañon river near Iquitos. The SCA accessions and the POUND 31 clone were similar to the Ucayali reference accessions, confirming their original collection near Contamana along the Ucayali River (Zhang et al. 2009b). The MO accessions were also similar to the Ucayali clones, suggesting that these were also collected along the Ucayali River (Zhang et al. 2009b). Four of the POUND clones (POUND 4, POUND 18, POUND 21 and POUND 27) were genetically similar to the sampled IMC accessions with POUND 27 as a likely maternal parental type. The NA clones were also genetically similar to nine of the POUND clones (POUND 1, 2, 5, 7, 8, 10, 15, 21 and 26) which were reported to have been collected along the Nanay river area. These nine POUND were also identified as the likely maternal parental types of 83 of the 127 sampled NA accessions (Zhang et al. 2009b).

Zhang et al. (2011b) demonstrated that farmed cacao (220 samples) in the Juanjui region of the Peruvian Huallaga valley had a far higher proportion of Forastero and Trinitario hybrids, with 53.9% of the samples as Upper Amazon Forastero clones (NA, PA and POUND). Only a small portion showed a close relationship to the Trinitario ICS clones (Zhang et al. 2011b). Analysis grouped the samples into three clusters. The first cluster grouped 130 farmer selections with the Upper Amazon Forastero clones NA 33, PA 7, PA 150, POUND 7, POUND 12 and EET 400. The second cluster had 54 selections composed mainly of ICS Trinitario and UF clones. The last cluster comprised 23 selections of Upper Amazon Forastero clones containing SCA 6 and SCA 12, which both originated in Peru's Ucayali valley (Zhang et al. 2011b).

Fang et al. (2014) provided molecular support using 44 SNP markers for the differentiation of beans from a fine flavor Fortunato No. 4 against CCN 51 and other possible adulterants. CCN 51 is a likely adulterant to target because it is the bulk variety most widely grown in Peru, making up 50% of production in the region where Fortunato No. 4 is raised. It is also the major bulk variety in Ecuador, where the desirable Nacional variety is produced (Fang et al. 2014). Fortunato No. 4 is cultivated in the Cajamarca province of Peru. The 30 Fortunato No. 4 samples differed by at least three loci amongst each other indicative of unique mother trees but which form a homogenous genetic group. All the Fortunato No. 4 samples differed by at least six loci from the CCN 51 samples, indicating no contamination among the two groups. The collected cacao clustered with Piura Porcelana in the Nacional population with a Q-value of 0.934. The Nacional group and the Piura Porcelana group make up sister clades, while the wild population of the

Santiago-Morona is variably dispersed between both (Arevalo-Gardini et al. 2019). Piura Porcelana shows greater observed heterozygosity and gene diversity than the pre-Columbian landraces (Criollo, Amelonado, Nacional) but like wild populations, indicating that less inbreeding occurred in the origins of Piura Porcelana. The wild populations of the Santiago-Morona Valley cluster with the Nacional group with a Q-value of 0.951 (Arevalo-Gardini et al. 2019).

Chia Wong (2009) using 66 markers from five inter simple sequence repeat regions showed that a selection of eight cacao cultivars from Cusco were genetically closest to samples from Loreto (IMC 67, PA 150, POUND 7, SCA 6) and San Martin (five local selections), with Chuncho cacao being in the same clade as POUND 7. Céspedes Del Pozo et al. (2018) using 96 SNPs showed that Chuncho cacao was closest to the Ucayali, Beni and Madre De Dios groups and could be separated based on ancestry and multivariate analyses. A cultivar called Señorita in the Cusco region and locally called Chuncho formed its own group distinct from the 12 clusters of the other 49 samples including the samples from Cusco and the authentic Chucho (Chia Wong 2009).

Saavedra-Arbildo et al. (2018) demonstrated from fruit and seed morphology that the cacao in the regions of Amazonas, Cusco and Piura was similar in thickness of fruit wall, fruit length, water content of testa, and seed width but differed in depth of primary furrows, fruit mass, seed mass, fruit width, number of seeds, dry mass of seeds, seed length and seed thickness. In addition, the northern regions of Amazonas and Piura appeared more similar to each other than Cusco although all three areas were differentiated on the basis of number of seeds and seed length, with the Piura region having the greatest proportion of white seeds in fruits that were generally elliptic-obovate with obtuse apices and little to no rugosity (Saavedra-Arbildo et al. 2018).

Highlighted Cultivars

"Unimproved" varieties in Peru are not necessarily wild; both the Chuncho and Piura Porcelana varieties are cultivated and sold as fine flavor beans (Arevalo-Gardini et al. 2019). Chuncho is a small-seeded variety from the Urubamba valley in Southern Peru, in the Amazon area of the Cusco Department. Piura Porcelana is mainly grown in the Piura, Amazonas and Cajamarca districts of the North coast in the Piura Department. It has large, white seeds in a rounded pod that is green when immature, turning to orange at maturity (Arevalo-Gardini et al. 2019). Porcelana is a likely descendant of the (still extant) wild populations in the Santiago and Morona river valleys, independently domesticated in Northern Peru (Arevalo-Gardini et al. 2019).

Clones housed at the Universidad Nacional Agraria de la Selva (UNAS) in Tingo Maria, Huanuco (25 international clones, 62 Huallaga clones and 51 Ucayali clones) were assessed for disease resistance. The Huallaga clones are cultivated material collected from farms, both managed and abandoned, while the Ucayali clones are mostly rainforest germplasm from along the Ucayali and Urubamba River systems. These Ucayali clones were described as self-compatible with small ovoid pods and small seeds. Eight of the Huallaga clones were identified as high-yielding (H 9, H 12, H 34, H 35, H 45, H 47, H 54, H 60) while only one clone (H 24) showed promising results for resistance against *P. palmivora*, causal agent of black pod disease. Seven Ucayali clones were also high-yielding (U 8, U 12, U 26, U 38, U 39, U 65, U 68) and two clones (U 10, U 54) displayed good resistance to *M. perniciosa,* causal agent of witches' broom disease. The international clones included germplasm material from Costa Rica, Trinidad and Ecuador, and additional material is also present at Tocache, Chazuta, San Alejandro, Pucallpa, Shebonya (Huallaga Valley), Pichari (Apurimac) and Quillabamba (Cusco). Four of these clones displayed good resistance to the major diseases affecting cacao in Peru: SCA 12 was resistant to *M. perniciosa*; UF 913 showed resistance to *P. capsici*; UF 613 demonstrated resistance to *P. palmivora*, which also causes black pod rot, and ICS 95 showed resistance to *M. roreri*, the causative agent for frosty pod rot (Evans et al. 1998).

Chuncho cacao, when properly cultivated, is reportedly capable of high yield, and some Chuncho cacao trees also tolerate and resist the major diseases of cacao (Céspedes Del Pozo et al. 2018; Gill 2019). Most of the Chuncho cacao in southern Peru are hybrids but in Quillabamba (Santa Ana District, La Convencíon Province, Cuzco Region) it is reportedly pure with small and small beans that lack bitterness and have a high fat content (Gill 2019).

Flavor Quality

Peru is a 75% fine or flavor cacao producer from the December 2020 ruling (ICCO 2016–2020b). Chuncho cacao has a fine aroma and exceptional flavor: floral and fruity, sweet with low acidity, very low bitterness and astringency, herbal and nutty (Céspedes Del Pozo et al. 2018). Eskes et al. (2018) found 64 unique multi-trait sensory profiles in which 29 of the 40 flavors and aromas included mandarin, soursop, custard apple, cranberry, peach, banana, inga, mango, mint, cinnamon, jasmine, rose and lily from the pulp and raw bean of 226 farmer selections of Chuncho trees. The floral and fruity flavor of Chuncho cacao has attracted international cacao sourcers since 2015 (Blare et al. 2020). Piura Porcelana cacao gives a honey-like flavor that is attractive to European chocolate-makers (Blare et al. 2020).

Five groups of ecotypes (Bagüinos, Cajas, Indes, Toribianos, Utkus) based on sensory, productivity and morphological features were identified in northern Peru (Oliva Cruz 2020). The Bagua type cacao differed in sensory attributes from the native "Chuncho" cacao found in Quillabamba, Cusco (Céspedes Del Pozo et al. 2018; Mejía et al. 2021). The Indes and Bagüinos morphotypes had the best floral and fruity scores and the highest dry mass and number of seeds (Oliva Cruz 2020). Five dark chocolates (60–70% cacao) of single origin (Piura, San Martín [two samples], Amazonas and Cusco) had moderate-strong acceptability (Mejíaa et al. 2018). Furthermore, the two San Martin chocolates were different from each other, with chocolates from Amazonas, Piura and a San Martin sharing a similar multivariate cluster with a floral base while the other San Martin and Cusco shared a similar multivariate cluster with a fruity base. Floral odor notes of herbal, grass and hay were found in chocolates of San Martín and Piura while tobacco, earthy and wood notes were additionally used to describe the odor of chocolate from Amazonas. Fruity odor (yellow, brown and red fruit) was associated with the chocolates from Cuzco and San Martín. However, while the sensory attributes of fruity matched with the chocolate samples, the highest floral notes were in Amazonas and San Martin followed closely by the other samples (Mejíaa et al. 2018). Nottlemann et al. (2018) working with cacao samples from Amazonas, Piura and San Martin also showed that these regions differed in their volatile aroma-active flavor profiles.

Over the period from 2010 to 2021, chocolate samples from Peru were selected for the best 50 International Cocoa Awards in 2010 (three batches), 2011 (four batches), 2013 (four batches), 2017 (three batches), 2019 (two batches) and 2021 (three batches) with 0, 0, 1, 1, 0 and 3 wins respectively.

In the best 50 of the International Cocoa Awards 2019, chocolate made from a Trinitario cacao batch from Parcelación Pueblo Libre (Parcela Agricola) Ucayali, Padre Abad District, Curimana Region, had strong cocoa flavor; moderate roast, bitterness, astringency, fresh fruit and brown fruit flavors; and low acidity, sweet, floral, spice, woody and nutty flavors (CoEx 2019). Another qualifying best-50 in 2019 was a chocolate made from a Forastero cacao batch (Cacao native cultivar) from San Martin De Pangoa, San Martin De Pangoa, Pangoa, Junin, that had strong cocoa flavor; moderate roast, bitterness, astringency and brown fruit flavors; and low acidity, sweet, fresh fruit, floral, spice, woody and nutty flavors (CoEx 2019).

A winning entry in the best 50 of the International Cocoa Awards 2021 from C.P. La Libertad, San Rafael, Provincia Bellavista, San Martin, was given the following flavor profile description: "Medium-dark reddish brown colour. Starts with cocoa and browned fruit notes. Middle shows spices and tobacco, staying throughout. Fresh berries, citrus, dark, and yellow fruits then light nuts and wood arrive. The finale is acid and astringent, with nutty and fresh fruit lingering. Balanced, complex, unique." (CoEx 2021). Another winning entry in 2021, from La Quemazon, San Juan de Bigote - Morropon, Piura, was given this description: "Dark brown colour. Smooth, creamy mouth melt. Gradual flavour emergence, blending chocolate note, fruit acidity, a complex mix of fresh fruits. Brown fruit (date, raisin) in centre along with mild floral green herbal/grassy notes. Some dark woods and trace spice notes. Harmony of flavours." (CoEx 2021). The third winner in 2021, from Jiron Confraternidad U7, Koribeni, La Convencion Echarate, Cusco, was given this description: "Medium brown, golden yellow hue colour. Smooth mouthmelt. Smooth chocolate note blends mild fruit acidity, fresh fruits (citrus, tropical, berry and yellow), mild browned fruit (light raisin), center of green grass and trace earthy, spice (cinnamon, cardamom). Long spice/chocolate finish." (CoEx 2021).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cacao awards should also be collected and conserved.

SURINAME

Overview

Suriname (Fig. 70) is in South America with the Atlantic Ocean on the northern side and bordered by French Guiana to the east, Brazil to the south and Guyana to the west. Suriname produced 5 metric tons of cacao in 2021, ranking 58th of 59 cocoa producing countries (World Population Review 2022).

Historical Introductions

The first introduction of cacao to Suriname (Dutch Guiana) was in 1684 by Chevalier de Chatillon from the Orinoco basin (Van Hall 1914). However, cultivation was mostly abandoned until the middle of the 19th century (Van Hall 1914). Myers (1930) indicated that G. Stahel also examined and described wild cacao located by the Coppename river, looking for witches' broom and other pathogens' attacks within this population.

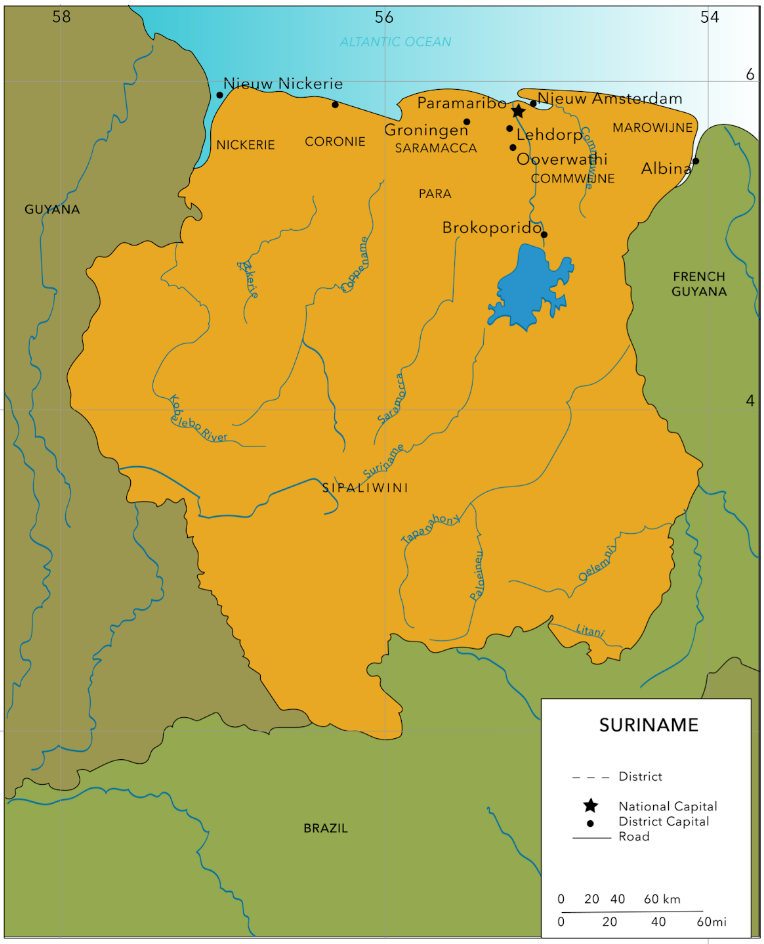


Figure 70
Physical map of Suriname in South America

Collections

An expedition described by Meyers (1930) along the Mamaboen Creek Valley during the late 1920s discovered cacao trees 10 to 25 feet in height with several young shoots originating from the base of the older trunks. The trees were growing singly but most were in groups of two to five. These trees were considered to be wild origin material since the area along the Coppename river bank has been entirely uninhabited with no cultivation. Wild cacao was also found along the upper parts of the Rewa and Quitaro creeks, which are branches of the Rupununi River (See Fig. 69). The ripe pods were of a bright yellow hue, without ridging and with 40 to 50 lilac-colored seeds per pod. The pods were described as Amelonado Forastero type. Two pod samples were collected from this site and taken to the Paramaribo Experiment Station, where the seeds were planted. This particular variety, which has not been fully genetically identified, displayed uniformity in the growth of all the seedlings, suggesting a homozygous variety of cacao from this area (Meyers 1930).

Wild cacao has also been reported in Black creek, a branch of the Essequebo, some distance above the mouth of the Rupununi River; on the Berbice River at a point due east of Black creek; near Primos Inlet; on the Kuduwini (Cuyuwini), Kassikedju or Dewar Wow, Kamu and Shewdikar creeks of the Upper Essequebo and the main river itself; the Quitari (Kwitari) River; the Capiwhuin (Kafuwini, a branch of the Trombetas, which is in its turn a tributary of the Amazon); on the Cutari (at the head of the Correntyne) and on the Upper Guidari (Quitaro).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved.

VENEZUELA

Overview

Venezuela (#4 in Fig. 52; Fig. 71) is in South America with the Atlantic Ocean on the northern side and bordered by Guyana to the east, Brazil to the south and Colombia to the west.

Figure 71

Administrative regions in Venezulea

Venezuela produced 23,349 metric tons of cacao in 2021, ranking 14th out of 59 cocoa producing countries (World Population Review 2022). In 2020, Venezuela exported US$28.5 million in cocoa beans, making it the 23rd largest exporter of cocoa beans in the world (oec.world/en/profile/bilateral-product/cocoa-beans/reporter/ven). Cacao is mainly grown in the northeast, north central coast and southwest (González-Jiménez 1999) with traditional areas of cacao cultivation in the northeastern (Sucre, Monagas and Delta Amacuro), northcentral-coastal (Miranda, Aragua, Carabobo, Guárico and Yaracuy), and southwestern (Apure, Barinas, Portuguesa, Mérida and Zulia) areas (Quintero and Garcia 2010). Old abandoned plantations could also be found at "Cacao" and "Palma Real" mountain of Isla Margarita, Nueva Esparta state (Tezara et al. 2016).

Historical Introductions

Wild indigenous cacao was reportedly used by the Cuica Indians in the lowland and foothill country of the southeastern Maracaibo Basin (Pédro de Simon 1882–1892 cited in Bergmann 1969). Ramírez Méndez (2015) indicated that cacao groves, cultivated by the natives, specifically by the indigenous peoples in the south of Lake Maracaibo, were found by the Spaniards, who subsequently propagated the seeds to expand cultivation. The origin of Criollo is suggested to have occurred south of Lake Maracaibo (Ramírez Méndez 2015). Van Hall (1914) stated that Criollo is mainly cultivated between Rio Yaracuy and Rio Tuy near the coast. Forastero in Venezuela was known as Trinitario or Carupano (Motilal and Sreenivasan 2012). One of the earliest records of cacao in Venezuela was in the early 1570s in Mérida (López de Velasco 1894 cited in Bergmann 1969; Ramírez Méndez 2015), specifically in the Caracas region (Alden 1976). However, Ramírez Méndez (2015), citing historical records, indicates that the Spanish merchant Galeotto Cey, who traveled in West Venezuela between 1549 and 1554, described how the natives grew wild cacao. The original location of the native cacao farms as a mountain of more than 100,000 cacao trees is suggested to be in Maruma and is thought to be located from "the boundary between Mérida and Trujillo, that is, between the banks of the Pocó River, the Buena Vista swamp to the Alguacil ravine precisely where it is currently La Dificultad (Sucre Municipality-Zulia State)" (Ramírez Méndez 2015 and references therein). The spread of cacao cultivation throughout Venezuela is suggested to be at the end of the 16th century or the beginning of the 17th century (Ramírez Méndez 2015). By 1663, Venezuelan cacao was being exported in large amounts from Curaçao to the Dutch Republic (Klooster 2014).

Pittier (1935, cited by Young 2007) affirmed that in the 17th century Spanish Capuchin friars imported Criollo cacao seeds into Aragua, Venezuela, from Nicoya Peninsula of Costa Rica or from Cuba. There is another theory that stated that these seeds came from Nicaragua (Soria 1967 cited in Marcano de Segovia 2007; Montal Montesa 1999). Montal Montesa (1999) stated that during the 17th century Benedictine monks from Venezuela visited Nicaragua and decided to import and reproduce these in Venezuela, yielding the famous Venezuelan white cacao. From 1620, cacao cultivation was recorded on the central coast, especially in Cuyagua, Choroní, Turiamo, Patanemo, Mamo, Caraballeda, Ocumare and Chuao. By 1706, the first cacao shipment from Maracaibo to the Netherlands occurred and Venezuela was considered as the line of cacao traffic between Colombia/Ecuador/Peru and Mexico (Cook 1982).

In 1825, Trinitario cacao was introduced on the coasts of Miranda state (Pittier, 1935). Quintero and Garcia (2010) point out from historical records that until 1825 only high-quality Criollo cacao was grown but from that year Forastero and Trinitario cacao were introduced. In 1913, a predominance of cacao with Calabacillo fruits was observed by Pittier in Barlovento (Marcano de Segovia 2007). In the 1940s, some of the accessions collected by Pound were imported primarily from the IMC, SCA, EET and ICS series (Marcano de Segovia 2007). According to Wood (1959), 1,821 Forastero plants were introduced from Trinidad.

Collections

In the 1940s, the "Colección del 45" was undertaken from outstanding trees in Aragua state and these were crossed with the clones distributed by Pound leading to superior progeny that was used to establish plantations throughout the country (Marcano de Segovia 2007).

Sanchez et al. (1989) explored the Territorio Federal de Amazonas and reported the presence of cacao in the areas of Cakuri, Wasihiña, Toki, Coyowateri and San Carlos de Río Negro. Interestingly, these workers reported that the indigenous tribes only sucked the mucilage or made a drink from mixing and macerating the mucilage and fresh seeds in water. Sanchez and Jaffé (1989) also reported cacao in Amazonas being present in Capibara, Chawaine, El Porvenir, Pantonoguey-teri, Pto Solano and San Fernanado de Atabapo regions. The cacao collected from the Amazonas regions all light green fruits and seeds with light violet cotyledons (Sanchez and Jaffé 1989). The thinnest fruit walls (11–17 mm) were recorded for the regions of San Carlos de Río Negro, Porvenir and Chewaine; the thickest fruit walls from Coyowateri and Toki (21–27 mm) and the widest range of fruit wall thickness (15–27 mm) from Pto Solano (Sanchez and Jaffé 1989). The lowest numbers of seeds were recorded in Cakuri (17) and Chewaine (27) and these had the lowest seed mass (46 and 57 respectively) as well with the other regions having 36 to 41 seeds per fruit and a range of 74 to 124 for seed mass.

There are four known types of Criollo in Venezuela: Porcelana, Criollo de Guasare, Criollos from the central region, and Criollo Andinos or Andean criollo (Fig. 72; Reyes 1993; Marcano de Segovia 2007). These all have different fruit morphologies (Marcano de Segovia 2007 and references therein). A rescue program was carried out by Reyes in the early 1990s that collected 231 Criollo and hybrid selections as farm selections across the northern coast from nine cacao-growing states of Aragua (Chuao, Choroni, Cata, Cumboto regions), Zulia (Río Escalante and Guasare regions) and Merida (Zea and Bocadillos regions) (Reyes 1993; Fig. 71; Table 6). Little is known about these selections and the four Criollo varieties are not described (Lachenaud and Motamayor 2017). Fruits, twigs and buds were taken from these sites based on the following criteria: pod traits typical of Criollo material such as sharp curved points, paired ridges with a rough surface texture, white or light purple cotyledons, good pod yield and disease resistance (Reyes 1993). Pure Criollo material was found in the Zulia state (northwestern area) while most of the plantations sampled had complex mixtures of Trinitario-type material (Reyes, 1993). Criollo de Mérida or Andean cacao trees are adapted to mountain areas, being found in isolated sites in the states of Mérida and Táchira, approximately 700 meters above sea level (Marcano de Segovia 2007).

Figure 72
Fruit morphology of the four types of Venezuelan Criollo.
Top left, Porcelana; Top right, Guasare; Bottom left, Andean; Bottom right, Pentagona.
Adapted from Marcano de Segovia (2007).

Recent Cultivation

Van Hall (1914) indicated that most Venezuelan Criollos are red-fruited although there are Criollos with yellow fruits or intermediate between these two types. Cook (1982) reported that Western Venezuela produced Criollo cacao, but, to the east, Forastero infusion was present in the fields. Criollo germplasm material in Venezuela has been included in several breeding programs in an effort to preserve its genetic variety. The northeast states of Sucre, Monagas and Delta Amacuro account for about 49% of production; the states of Miranda, Aragua, Carabobo, and Yaracuy in the central zone about 27% and the southwestern states of Merida, Zulia, Táchira, Apure, Barinas and Portuguesa about 24% (Marcano de Segovia 2007).

Table 6 Cacao germplasm focusing on Criollo selections in northern Venezuela.

State	Area	Number of Selections	State	Area	Number of Selections
Aragua	Cata	15	Merida	Bocadillos	10
	Choroni	21		Cano Tigre	2
	Chuao	28		Estanquez	2
	Cumboto	15		La Privincia	5
	Ocumare	6		Pamarito	2
Carabobo	Borburata	5		Zea	19
	Canaoabo	4	Tachira	Botijas	4
	Cariaprima	2		El Salao	8
	Patanemo	2		Hernandez	12
Federal District	Caruao	8		La Isla	3
	La Sabana	4		Mesa de costa	4
	Oritapo	1		Sardinas	1
Sucre	Mapire	2	Zulia	Rio Escalante	24
Trujillo	Monte Carmelo	2		St. Barbara	6
Yuracuy	Jobal-Zaragoza	12			

Alvaro Gómez and Azócar (2002) identified potential areas for cultivation of Criollo cacao in the state of Mérida to expand the then current 4,020 ha under production. The best areas were in the municipalities of Alberto Adriani, Julio César Salas, Tulio Febres Cordero and Caracciolo Parra Olmedo. Areas with slight agronomic limitations were in the municipalities of Sucre, Antonio Pinto Salinas, Zea and Alberto Adriani and there were more restrictions in the municipalities of Alberto Adriani, Obispo Ramos de Lora, Caracciolo Parra Olmedo and Julio César Salas. Marcano et al. (2007) indicated that a typical mix of Criollo/Trinitario trees was grown on a farm near Mérida (western Venezuela).

Marcano de Segovia (2007) stated that wild Forastero cacao was present in the Venezuelan Orinoquía, and that Criollos of high genetic purity could be found in isolated areas, especially in the western region. Quintero and Garcia (2010) indicated that the northeastern states have mainly Forastero; the north central coastal region has a mix of Criollo and Forastero with relic Criollo; and the southwest has diverse types of Criollo and Forastero with Amelonado being the dominant variety in Apure but Criollo types (Porcelana, Mérida, Ocumare and Guasare) dominant south of Lake Maracaibo. Soto (2017) agreed that the best fine aroma cacao in Venezuela was in the southwestern region, especially from Porcelana cacao.

Genetic Studies

Motamayor et al. (1998) reported evidence of Andean Criollo (long cylindrical pods with smooth to rough pod surfaces) in the states of Aragua, Tachira and Merida. Other areas had more Amelonado-type cacao material (Porcelana), Angoleta pods with rough green surfaces (Guasare in Guajira region) and Pentagona type pods in Tachir (Motamayor et al. 1998). Marcano et al. (2007) assessed 291 trees with 92 microsatellites and found both Criollo and Forastero contributions, with several trees being close to the Criollo reference type. The Criollo Guasare and many of the Pentagona cultivars are said to be highly homozygous similar to relic Criollos (Marcano de Segovia 2007). Ancestry determinations of two PENTAGONA accessions, however, have revealed the two accessions to be Criollo-Amelonado hybrids (Motilal et al. 2010) with about 52% Criollo ancestry (Lambert Motilal, pers. comm.). Porcelana cacao, originally called Maracaibo, is an heirloom variety that is based on hybrid Criollo trees (Daarnhouwer & Co. 2021).

Highlighted Cultivars

Two types of Criollos were identified in Venezuela from the exterior color of the fruit before maturity (Ciferri 1957): (a) violet Criollo or "Venezuelan Criollo," which is locally called "Criollo de concha morada," "Criollo morado," "Morado colorado" or "Criollo de Venezuela," and (b) green or "decolorized Criollo," "Criollo verde" or "blanco." "Porcelana" cacao, originally located south of Lake Maracaibo, near the Catatumbo and Escalante rivers [Zulia province], is a high-purity Criollo cacao with smooth unridged fruits and beans with excellent quality (Marcano de Segovia 2007). Porcelana fruits may be white (with attenuated curved apices), or green or red (both with attenuated apices) but smooth (primary and secondary furrows less than 2 mm) and without being basally constricted (Ramírez et al. 2011). Another high-purity Criollo, "Criollo Gusare," was originally found on the banks of the Guasare River in the state of Zulia and has had better performance in ecological conditions other than that of its original location (Marcano de Segovia 2007 and reference therein).

Three elite cultivars, OC 61, OC 77 and CHO 42, were identified on the basis of productivity, quality and acceptance among producers (Velasquez S et al. 2015). An eco-physiological survey of three Criollo cultivars in the Criollo germplasm bank of Centro Socialista de Investigación y Desarrollo del Cacao was undertaken by Ávila-Lovera et al. (2016). This survey investigated the cultivars Los Caños 001 (LCA 001), Sur Porcelana 010 (SP 010) and Escalante 001 (ESC 001) for their ability to adapt to changing climate conditions. ESC001 showed itself to be promising for distribution to areas with climate conditions like those at the Maracaibo Lake basin. It did well under these conditions because it responded well to drought, had excellent gas exchange performance, and had the best response of photochemical activity to light. More information about yield is needed. The other Criollo cultivars (LCA 001 and SP 010) would perform well in areas with periods of low rainfall throughout the year, but they were not as drought-tolerant as ESC 001 (Avila-Lovera et al. 2016). Similarly, Tezara et al. (2016) showed that Criollo and Forastero trees had similar photosynthetic capacity. However, since the study of Tezara et al. (2016) was on mature trees in the mountain at about 470 m altitude, the claim that both Criollo and Forastero are recommended for cultivation in similar environments needs further support.

Flavor Quality

Caracas, Carupano and Maracaibo were the most recognizable cacao varieties (Knapp 1920). The finest cacao in the world was reportedly produced in La Guayra, Caracas, as Venezuelan Criollo, "the bean with the golden-brown break" (Knapp 1920). Cook (1982) reported on the flavor profiles from Genuine Maracaibo (regal/real/royal cocoa), Puerto Cabello, La Guayra Caracas, and Carupano cacao. Genuine Maracaibo was reportedly big and bold of shape, light tan of color, well fermented and cured, and of deliciously mild nutty flavor. Puerto Cabello had a nutty/"Sweet Cheese flavor." La Guayra Caracas (darker than Puerto Cabello and lighter than Maracaibo) was popular for high-quality chocolate ice cream and milk chocolate because its vigorous flavor meant that a low percentage of chocolate needed to be used. Carupano cacao, later known as Rio Caribe, was weak in flavor but lighter-colored with a faint nutty flavor. Porcelana cacao, originally called Maracaibo, is said to have a light body; cherries and red fruit followed by notes of herbal green, nuts and a creamy finish (Daarnhouwer & Co. 2021).

Ramos et al. (2013) described the sensory attributes of Venezuelan cacao as an aromatic spectrum finding nutty, almond, wood, green beans, liquor, vitamins, yogurt, fresh grass, caramel, sugar cane juice, brown sugar, malt, orange blossom, cinnamon and chocolate aromas and oil, smoking, alcohol, cocoa, roasted coffee, citrus, chocolate, spicy, floral, dried fruits, fermented fruits, dairy, peanuts and medicine flavors. The following descriptions of fermented cacao from different areas in Venezuela are provided by Ramos et al. (2013). Criollo Guasare cocoa from the state of Mérida had the flavor of nuts, panela or malt and a moderate fruity flavor, with medium to low herbal, sour and bitter flavors. Criollo Mérida cocoa had flavors of nuts, panela or malt with little herbal flavor, low acidity and very low raw/green values. The Criollo Porcelana cocoa, from the Chama de Corpozulia Station, had flavors of nuts and panela or malt with very little herbal taste, acidity, bitterness, floral or raw/green notes. Cacao from Chuao (Santiago Mariño municipality of Aragua state) had panela, malt, walnut and peanut notes. Cacao from the central coastal strip in the Parish Choroní (Girardot municipality of Aragua state) had walnut, herbal and cocoa flavor with low bitterness, acidity and astringency. Cacao from Ocumare de la Costa Parish (Ocumare municipality of the Gold Coast of the state of Aragua) had a high cocoa flavor with bitter and astringent taste that was low in panela, malt, nut, floral, green and herbal flavors. Cacao from the Rio Caribbean (east Venezuela) had strong cocoa flavor with either nut or panela/malt flavor and fruity notes but with very low floral and raw/green notes. Cacao from the Yaguaraparo Sucre state had a good cocoa flavor with acidity, astringency and strong bitterness with a resin note and could have floral and nut notes but had very low fruity notes and lacked panela or malt flavors.

Over the period from 2010 to 2021, chocolate samples from Venezuela were selected for the best 50 International Cocoa Awards in 2011 (one batch), 2013 (two batches) and 2019 (one batch) with 0, 1 and 1 wins respectively. In the best 50 of the International Cocoa Awards 2019, chocolate made from a Criollo cacao batch (Brisas del Sarare cultivar) from Consejo Comunal Vuelta Redonda, Sector Caño Gaitan, Municipio Páez, Parroquia Urdaneta, Estado Apure, had moderate cocoa, roast, bitterness, astringency, acidity and fresh fruit flavors; and low sweet, brown fruit, floral, spice, woody and nutty flavors (CoEx 2019).

Recommended Collection

The oldest trees and the best-performing trees should be collected and conserved. The varieties or a representative set of the sampled trees entered into cocoa awards should also be collected and conserved. Reyes (1993) recommended collecting in Zuila state to obtain pure Criollo cacao in the foothills of the Andes and the Guasare River Basin and to obtain pure Porcelana cacao in the Escalante River Basin. Apart from these rivers, Reyes (1993) also recommended collecting from the regions of Aragua (Chuao, Choroni, Cata), Merida (Zea, Bocadillos) and Tachira (Hernandez, Salao).

FUTURE PROSPECTING

A Google survey form was administered and 51 returns were obtained from cacao collectors, sourcers, scientists and various organizations from over 25 countries. About 75% of the respondents actually collected germplasm principally from gene banks (43%) or farmer fields (41%). Formal explorations were planned or undertaken by 49% of the respondents, and collections via personal trips (16%), as an individual researcher (24%) or in groups as community-based organizations (30%), national governmental organization (25%) and non-profit organizations (14%) were indicated. Issues in obtaining germplasm were encountered by 19 respondents primarily due to lack of a material transfer agreement (42%), germplasm policy that prevented export (37%), or other host country restriction (21%). Only 11% and 5% of the 19 respondents with issues in getting germplasm attributed the cause to lack of access or no contact person respectively. Yet 53% of the respondents planned to obtain cocoa germplasm within the next five years, whereas 33% were unsure and 14% were not going to collect.

Factors driving collection were attributed to areas with a high risk of deforestation (73%), unknown or underexplored areas (71%), academic interest (69%), areas where cacao has high risk of being replaced by other crops or cacao varieties (68%), traits absent or underrepresented in existing gene banks (66%), areas absent or underrepresented in gene banks (59%) and germplasm in use by local communities (64%). The lowest influencers were having accurate coordinates of collection sites (45%), commercial interest (45%) and ease of access to collection site (32%). Characterization of newly collected germplasm was focused on flavor (77%), conservation (74%), ancestry (73%), disease resistance (71%), fruit production (70%) and seed number (65%) but not so much on pulp (52%), self-compatibility (57%) or other fruit characteristics (57%).

Collection guides were provided by the respondents who indicated areas in which they had already collected (39 respondents; 76%), preferred collection areas (41 respondents; 80%), and areas that may have unknown cacao germplasm (34 respondents; 67%). Previously collected areas were identified (Table 7) and preferred areas for collection (Table 8) that were predominantly involved the Amazon Basin although any cacao region worldwide could have been chosen. One respondent indicated a preference for collecting from all areas of all countries with fine or flavor aroma.

A total of 34 respondents indicated areas that may have unknown cacao germplasm (Table 9). While the majority of the responses were centered around the Amazon Basin, Asia/Pacific (two respondents, one of whom indicated remote islands for Malaysia), Grenada (one respondent) and Sierra Leone (one respondent) were also reported. Eight respondents provided general country names (Bolivia, Brazil, Colombia, Ecuador, El Salvador, French Guiana, Guyana, Mexico, Peru, Suriname, Venezuela) without specifying areas that could have unknown cacao germplasm. One respondent indicated that "several departments in Colombia that have not been explored due to violence" would be best to find unknown cacao.

Table 7 Localities of recent cacao collections provided by 39 respondents in Google Survey

Country	Area
Belize	Toledo district; BFREE Private Reserve
Bolivia	Beni Department, Caranavi in Alto Beni, Sud Yungas
Brazil	Amazon tributaries
Colombia	Caquetá, Cauca, Lower part of the Caguán river basin, Orinoco tributaries, Magdalena tributaries, Santander, Región Amazónica, Región Sierra Nevada, Santa Marta
Costa Rica	Provincia de Limón, Atlántico sur
Cuba	Baracoa: Aguadilla Abajo, Arrollo Hinojosa, Camarones, Cantarana, Capiro, Cayayal de Sabanilla, El Frijol, El Jamal, Güirito, La Aguadilla, Los Hoyos de Sabanilla, Miraflores, Ojo de Agua, Paso del Toa, Picoteo de Capiro, Sabanilla, San Germán, Santa María, Santa Rosa, Yagrumaje. Buey Arriba: Arrollón, Limones Arriba; Campechuela: Los Manantiales. Santiago de Cuba: Ceiba de Los Ramos, El Cristo, El Cujabo, El Pavón, El Socorro, Hongolocosongo, Ti Arriba; Ramón de las Yaguas. Cumanayagua: El Nicho, San Blas, Loma Los Blancos; Trinidad: Comunidad la 23, El Monumento a Manuel Ascunce, Polo Viejo, Topes de Collantes. Manicaragua: Jibacoa, Manicaragua
Ecuador	Amazon tributaries, Los Rios, Manabi, Palanda, Pichilingue, Piedra de Plata, Shaïme, Zamora, Zumba, Flavio Alfaro
El Salvador	Izalco
Guatemala	Alta Verapaz Izabal, Quiché, Suchitepequez, San Marcos
Guyana	Southeast, Kérindioutou rivers, Euleupousing, Tanpok
Honduras	Atlantida, Catacamas, Copan, Santa Barbara, Cortes, Olancho, Gracias a Dios, Copan Intibucá, Olancho, Yoro
India	Kerala, Karnataka
Indonesia	Java
Malaysia	Not indicated
Mexico	Chiapas esp. Soconusco area, Tabasco, Huimanguillo
Nicaragua	Managua km 33 carretera cebaco, Jinotega, RAAN, RAAS, Matagalpa, Río San Juan
Peru	Ayacucho-Vraem, Junin-Vraem, Amazonas, Cajamarca, Cusco, San Martin, San José de Sisa valley and Tingo Maria valley in Huaynuco, Madre de Rios river system including Tambopata, Amazon tributaries, Loreto, Aypena, Marañón, Urituyacu, Ungumayo, Ugumayo, Chambira, Pastaza, Morona, Tigre, Napo, Putumayo, Yavari; Ucayali; Santiago; Tambopata; Vilcanota, Urubamba; Huallaga, Utcubamba, Condorcanqui, Lumpay, Chachapoyas, Cajamarca, Yanuyacu, Jaen, San Martín, Hishpinguillo, Lamas, Soledad, Mariscal Cáceres, Tarapoto

Country	Area
Sierra Leone	Sandor Village
Trinidad	San Juan Estate
Venezuela	Yaracuy, Carabobo, Aragua, Mauraco, El Cuchape, Quebrada Seca, Las Conopias, Serrania de la Cerbatana, Agua Fría, Santa Isabel, Uquire, Don Pedro, Costa Norte de la Península de Paria, Municipio Arismendi, Macuro, Municipio Valdes, Estado Sucre

Table 8 Preferred areas identified by 41 respondents to collect cacao germplasm

Country	Area	Note
Belize	Maya Mountains: Cayo, Stann Creek, and Toledo Districts	Country also identified by three other respondents without giving specific area.
Bolivia	Amazonia; river systems; forest north of La Paz	Country also identified by one other respondent without giving specific area.
Brazil	Border region with Guyana	Country also identified by three other respondents without giving specific area.
Cameroon		Country identified by one respondent without giving specific area.
Colombia	River systems; Amazonia and coastal regions; Caquetá and Huila	Country also identified by five other respondents without giving specific area.
Costa Rica		Country identified by three respondents without giving specific area
Cuba	Guantánamo	
Ecuador	Foot of the Andes, Amazon Zone, coast of the country	Country identified by five other respondents without giving specific area.
El Salvador	Izalco	Country identified by two other respondents without giving specific area
Guatemala	Peten, Alta Verapaz Izabal, Quiché, Suchitepequez, San Marcos	Country identified by four other respondents without giving specific area
Guyana		Country identified by one respondent without giving specific area.
Honduras	Cortes	Country identified by two other respondents without giving specific area
India	Old plantations	
Ivory Coast		Country identified by two respondents without giving specific area

Country	Area	Note
Madagascar		Country identified by two respondents without giving specific area.
Mexico	Soconusco, Zona Zoque, Chontalpa and Selva Lacandona; Chiapas; Tabasco	Country identified by two other respondents without giving specific area
Nicaragua	Areas with Criollo cacao; Jinotega, RAAN, RAAS, Matagalpa, Río San Juan	Country identified by two other respondents without giving specific area
Panama		Country identified by two respondents without giving a specific area
Papua New Guinea	Plantations	Country identified by two other respondents without giving specific area.
Peru	Amazonia; all regions of the High Amazon; Alto Amazonas valley, San José de Sisa valley; Foot of the Andes; forests, reserves, farmer plots; Huallaga, Ucayali	San José de Sisa valley said to have "lot of incredible hibridos, native cocoa" by one respondent. Country identified by six other respondents without giving specific area.
Sri Lanka	Botanical garden	
Suriname		Country identified by one respondent without giving specific area.
Trinidad		Country identified by one respondent without giving specific area.
Venezuela	River systems; Sur de Lago de Maracaibo; Península de Paria including Macuro, Don Pedro, Uquire, Santa Isabel; Caripe in Serrania Del Tumiriquire; Caripito, Valle De San Bonifacio, & Cumanacoa in Delta del Río San Juan.	Country identified by two other respondents without giving specific area.

Nieves-Orduña et al. (2021) recommended collecting from river basins associated with geographically restricted chloroplast microsatellite haplotypes, in particular the Napo Basin of Ecuador, the Caquetá River in Colombia, and the Ucayali River in south and central Peru. These authors also suggested that new haplotypes (and hence previously uncollected germplasm) may be present in known cacao populations of the Upper Orinoco, Caquetá River in Colombian Amazon and Ecuadorian Amazon, Santiago and Morona rivers in northern Peru, Chuncho in southern Peru, Beni River in Bolivia, the Brazilian Amazon, and southwestern and southern Amazonia.

Table 9 Areas identified by 25 respondents that may contain unknown cacao germplasm

Country	Area
Asia-Pacific	
Belize	Maya Mountains; Toledo
Bolivia	Amazonia
Brazil	Madre de Dios, Purus; upper and lower Amazon; Madeira river; Rio Jari and its tributaries, near Guyana;
Cameroon	
Colombia	Santander and North of Santander; Sierra Nevada, Amazonas, Putumayo, Cauca; region between the Napo and Amazon rivers (tributaries of the Caquetá and Caguán rivers); Choco, Guaviare, Nariño, Vichada, Sucre, Caquetá, Casanare
Ecuador	Amazon region; Zona de Nanegal, Provincia de Pichincha, cacao cultivated over 1,000 m from sea level
El Salvador	
Grenada	
Guatemala	South Guatemala: Coatepeque, San Marcos, Retalhuleu, Suchitepéquez, Escuintla, Santa Rosa. North Guatemala: Petén, Izabal, Alta Verapaz, Baja Verapaz, Quiché
Guyana	
Honduras	Cortes
Mexico	Chiapas, Tabasco, Soconusco; Southeast Tabasco (Chontalpa and Sierra area), Chiapas (northern region, forest and Soconusco), Oaxaca (Coast, isthmus, southern Sierra and Papaloapan), Guerrero (coast and forest), Nayarit (coast)
Malaysia	Remote islands
Nicaragua	Jinotega, RAAN, RAAS, Matagalpa, Río San Juan,
Peru	San Martin region, San Jose de Sisa Valley, Ishichihui village, Capirona plantation, Amazonas, Madre de Dios, Cusco, Ayacucho, Junin; Rio Huallaga, Rio Ucayali, Rio Amazonas, Rio Marañón
Sierra Leone	
Suriname	high Maroni river
Venezuela	Península De Paria, Delta Del Río San Juan, Delta Del Río Orinoco; Falcon, Lara; South of Lake Maracaibo

CONCLUSIONS

A review of the available literature was conducted to get an up-to-date global picture of the cacao genetic resources within countries as a result of germplasm introductions, collections and breeding. There is a substantial number of known cacao cultivars, landraces and accessions dispersed worldwide. However, due to the limited number of introductions using few budsticks or seedlings in the early years, followed by distribution of seeds or otherwise from these few introduced plants, and the reliance on few cultivars for particular traits, there is a tendency to have a limited range of cacao diversity in countries where cacao was an introduced non-indigenous crop.

Nevertheless, many countries have assessed some part of their national cacao diversity, which will help in deciding how best to augment their germplasm. Collections within each country to supplement existing germplasm are required. Many countries have germplasm in abandoned areas or under forest regrowth in addition to farm material that is under-surveyed. Several countries have little available information and in these cases dedicated individuals have rescued abandoned trees in secondary forests to improve the cacao resources of a country, especially in the old world. Systematic surveys were lacking and should be undertaken. Areas that require particular attention are those that are difficult to access. Old, relic or landraces from countries which may have old trees or recent descendants of old trees seem to be present in the countries indicated from the historical germplasm records. This suggests that, in the main, the available cacao literature is a treasure trove from which to obtain information for planning collecting expeditions. Countries like Sri Lanka, the Philippines, India, Venezuela, and Mexico are good choices to obtain relic germplasm with Amelonado/Criollo background. Ecuador is the storehouse of wild Nacional material and the ICGT has a collection of this resource. However, the Nacional individuals within the gene banks represent a subset of those that were resistant to witches' broom disease. Systematic explorations within Ecuador are needed to complement this genetic diversity.

The South American countries remain a rich source of germplasm that is yet to be fully explored. At present there are 10 known populations of cacao, but as new areas are explored like Beni and Chuncho and within Colombia, there is an increasing likelihood that the 10-population picture will change. As more genetic stock is added in, a much clearer picture will emerge as to the real sub-clusters, clusters and meta-clusters in cacao. To this end, expeditions that explore every river system, within each river basin, within the cacao growing regions of the Central and South American continent are required. To obtain a good collection of genetic diversity, fruits of several trees should be collected as a genetic repository of the area. Collecting budwood conserves the genotype of the individual. Collecting seeds conserves the genetic diversity of the population. The general feedback was to collect primarily from Central and South America and it appears from the literature survey that many of these areas are yet to be fully and properly explored.

However, it appears that even within the scientific world there was a tendency to rely on outmoded descriptions and the improper application of what is called a cultivar or variety. Furthermore, some of the genetic studies may have been compromised by the inappropriate calling of alleles (e.g. the study of Johnsiul and Yazik (2019) with 990 alleles from just 11 microsatellites on 47 unique plants) and the lack of ancestral studies due to unavailable genetic group references. Furthermore, it appeared that seedling material collected and propagated from a clone may have been ascribed the same name when in fact it is not an identical copy of the mother tree. A good example of this was probably a study by Espino et al. (2017) where all 13 varieties had misidentified samples and that of CCN51 as reported by Herrmann et al. (2015). Yet overall a good picture of the genetic diversity was present and showed the movement and breeding of cacao germplasm.

It is recommended that collecting expeditions be done in a systematic manner and that primary germplasm within the South American Basin be targeted to best capture the real diversity that is yet to be fully documented.

BIBLIOGRAPHY

Abdul-Karimu A, Adomako B and Adu-Ampomah Y (2006) Cocoa introductions into Ghana. Ghana Journal Agricultural Science 39: 227–238.

Abdul-Karimu A, Butler DR, Iwaro AD, Sukha DA, Bekele FL, Mooleedhar V, and Shripat C. 2003. Farmers' perceptions of cacao (*Theobroma cacao* L.) planting material and factors affecting the cacao industry in Trinidad and Tobago. Trop. Agric. (Trinidad) 80(4): 261–266.

ACDI/VOCA (2021) Liberia–Livelihood Improvement for Farming Enterprises (LIFE) https://www.acdivoca.org/projects/liberia-livelihood-improvement-for-farming-enterprises-life/

ADC/IDEA (1998) A baseline survey on cocoa production in selected districts of Uganda. Development and Management Consultants International.
http://pdf.usaid.gov/pdf_docs/Pnadj521.pdf

Adenet S, Regina F, Rogers D, Bharath S, Argout X, Rochefort K and Cilas C (2020) Study of the genetic diversity of cocoa populations (*Theobroma cacao* L.) of Martinique (FWI) and potential for processing and the cocoa industry. Genetic Resources and Crop Evolution, 67(8), 1969–1979. https://doi.org/10.1007/s10722-020-00953-0

Adenuga OO and Ariyo OJ (2020) Diversity analysis of cacao (*Theobroma cacao*) genotypes in Nigeria based on juvenile phenotypic plant traits. International Journal of Fruit Science 20 (Suppl 3): S1348–1359. DOI: 10.1080/15538362.2020.1786487

Adewale B, Adeigbe O,Muyiwa A (2016) Cocoa seed garden: a means to disseminating improved planting materials for enhanced national productivity: a review. Agric Rev 37:205–212.

Aikpokpodion PO (2010) Variation in agro-morphological characteristics of cacao, *Theobroma cacao* L., in farmers' fields in Nigeria. New Zealand Journal of Crop and Horticultural Science 38(2): 157–170. DOI: 10.1080/0028825X.2010.488786

Aikpokpodion PO (2012) Defining genetic diversity in the chocolate tree, *Theobroma cacao* L. grown in West and Central Africa. In Genetic Diversity in Plants, Prof. Mahmut Caliskan (Ed.), InTech, Available from
http:///www.intechopen.com/books/genetic-diversity-in-plants/defining-genetic-diversity-in-the-chocolate-tree-theobroma-cacao-l-grown-in-west-and-central-africa.

Aikpokpodion PO, Badaru K, Kolesnikova-Allen M, Ingelbrecht I, Adetimirin VO (2003) Farmer–researcher participatory on-farm selection of improved cocoa varieties: the Nigerian experience. In: INGENIC International Workshop on Cocoa Breeding for Improved Production Systems held 19–21 October 2003, Accra, Ghana. pp. 183–188

Aikpokpodion PO, Motamayor JC, Adetimirin VO, Adu-Ampomah Y, Ingelbrecht I, Eskes AB, Schnell RJ and Kolesnikova-Allen M (2009) Genetic diversity assessment of sub-samples of cacao, *Theobroma cacao* L. collections in West Africa using simple sequence repeats marker. Tree Genetics and Genomes 5(4): 699–711. DOI 10.1007/s11295-009-0221-1

Aizat J, Nuraziawati MY, Haya R and Abdul Rahman R (2019) Preliminary evaluation of new local verification trial at farmer's field Serian, Sarawak. Malaysian Cocoa Journal 11: 76-78.

Alimin J (2021) The couple who gave up their legal careers to find happiness in Thai chocolate. CNA Luxury 10 Dec 2019 06:30AM (Updated: 21 May 2021 04:01PM) https://cnaluxury.channelnewsasia.com/remarkableliving/kad-kakao-bangkok-thai-chocolate-173531

Allen JB (1987) London cocoa trade Amazon project. Final report phase 2. Cocoa Growers Bulletin 39: 1–95.

Allen JB (1988) Geographical variation and population biology in wild Theobroma cacao. PhD thesis, University of Edinburgh, Scotland, UK.

Allen JB and Lass A (1983) London Cocoa Trade Amazon Project. Cocoa Growers' Bulletin, 34, 1–72.

Ali N, Sukha DA, Meerdink G and Umaharan P (2018) Fermentation progression and quality attributes of Trinitario and Refractario cacao (*Theobroma cacao* L.) hybrid groups at the International Cocoa Genebank Trinidad (ICGT) – Opportunities for genetic branding. In Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru.

Almeida CMVC and Almeida CFG (1987) Coleta de cacau silvestre no Estado de Rondônia. Rev. Theobroma 17: 65-92.

Almeida CMVC, Barriga JP, Machado PFR and Bartley BGD (1987) Evolução do programa de conservação dos recursos genéticos de cacau na Amazônia brasileira. Boletim Técnico, 5 (CEPLAC/DEPEA, Belém).

Almeida CMCV, Dias LAS, Okabe ET and Medeiros JRP (2005) Variability in genetic resources of cacao in Rondônia, Brazil. Crop Breeding and Applied Biotechnology 5(3): 318–324. https://doi.org/10.12702/1984-7033.v05n03a09

Alvaro Gómez M and Azócar A (2002) Areas potenciales para el desarrollo del cultivo cacao en elo estado Mérida. Agronomía Tropical 52(4): 403–425. Retrieved on March 18, 2022, from http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0002-192X2002000400001&lng=es&tlng=es.

Alvim R and Nair PKR (1986) Combination of cacao with other plantation crops: an agroforestry system in Southeast Bahia, Brazil. Agroforestry Systems 4: 3–15.

Andoh MA and Mbah MJ (2018) Poor rural cocoa producers in Cameroon. Universal Journal of Agricultural Research 6(6): 231-234. doi: 10.13189/ujar.2018.060605

Andres C, Comoé H, Beerli A, Schneider M, Rist S and Jacobi J (2016) Cocoa in Monoculture and Dynamic Agroforestry (pp. 121–153). Springer, Cham.
https://doi.org/10.1007/978-3-319-26777-7_3

Anon (1673) An Accurate Description of the Cacao-Tree, and the Way of It's Curing and Husbandry, & C; Given by an Intelligent Person Now Residing in Jamaica. Philosophical Transactions (1665–1678) 8: 6007-6009.

Anon (1987) Production et commercialisation du cacao au Zaire. Division de Strategie et de Planification Agricole Bureau d'Analyse Economique. Project 660-070/USAID/PRAGMA CORP

Anonymous (1896) German Colonies in Tropical Africa and the Pacific. Bulletin of Miscellaneous Information (Royal Botanic Gardens, Kew) 1896 (117/118): 174–185.
http://www.jstor.org/stable/4118338

Antheaume B and Pontie G (1990) Les planteurs-rénovateurs de cacao du Litimé (centre-ouest du Togo). L'innovation technique à marche force. Cah. Sci. Hum. 26(4): 655–677.
https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_4/sci_hum/35108.pdf

Anti-Slavery International (2004) The Cocoa Industry in West Africa:
A history of exploitation.
https://www.antislavery.org/wp-content/uploads/2017/01/1_cocoa_report_2004.pdf. Accessed 8 Sept 2021

Antony G, Kauzi GY, Loh DW and Anderson JR (1988) Returns to cacao research 1965 to 1980 in Papua New Guinea. ACIAR/ISNAR Project Papers No.9 September 1988.
https://ageconsearch.umn.edu/record/310797/files/Returns%20to%20cocoa%20research%201965.pdf

Anyanso HO (2014) A review on the impact of globlisation [sic] on the cocoa industry in Nigeria. MSc thesis, University of East London.

Appiah MR, Sackey ST, Ofori-Frimpong K and Afrifa AA (1997) The consequences of cocoa production on soil fertility in Ghana: A review. Ghana Journal Agricultural Science 30: 183–190.

Aragon Obando EM (2009) Genetic characterization of *Theobroma cacao* L. in Nicaragua. MSc thesis, Universityof Helsinkki

Araújo M, Alger K, Rocha R, Mesquita CAB (1998) A Mata Atlântica do sul da Bahia: situação atual, ações e perspectivas. Costa JPO, editor. Reserva da Biosfera da Mata Atlântica—MAB—UNESCO.

Arevalo-Gardini E, Meinhardt LW, Zuñiga LC, Arévalo-Gardni J, Motilal L and Zhang D (2019) Genetic identity and origin of "Piura Porcelana"—a fine-flavored traditional variety of cacao (Theobroma cacao) from the Peruvian Amazon. Tree Genetics and Genomes, 15(1).
https://doi.org/10.1007/s11295-019-1316-y

Aspinall A (1928) A wayfarer in the West Indies. London: Methuen & Co.

Assemat S, Lachenaud P, Ribeyre F, Davrieux F, Pradon JL and Cros E (2005) Bean quality traits and sensory evaluation of wild Guianan cocoa populations (Theobroma cacao L.). Genetic Resources and Crop Evolution, 52(7), 911–917. https://doi.org/10.1007/s10722-003-6117-2

Assiri AA, Deheuvels O, Kéli ZJ, Kébé BI, Konan A and Koffi N (2016) Identification de caractéristiques agronomiques pour le diagnostic et la prise de décision de régénération des vergers de cacaoyers en Côte d'Ivoire. African Crop Science Journal 24(3): 223–234 doi:10.4314/acsj.v24i3.1

Assiri AA, Yoro GR, Deheuvels O, Kébé BI, Kéli ZJ, Adiko A and Assa A (2009) Les caractéristiques agronomiques des vergers de cacaoyer (Theobroma cacao L.) en Côte d'Ivoire. Journal of Animal & Plant Sciences 2 (1): 55–66.

Attygale, R (2020) Sri Lankan cocoa – a promising inter-crop with coconut. The Island, 27 December 2020. www.island.lk/sri-lankan-cocoa-a-promising-inter-crop-with-coconut.

Avalos A, Porres MA, Pöll E, Dardón E, Arévalo LA and Rosales JA (2012) Caracterización agronómica, botánica y molecular de clones de cacao tipo criollo y mejorado de la zuna sur de Guatemala. Revista de la Universidad del Valle de Guatemala 24: 99–104.

Avendaño-Arrazate CH, López-Gómez P, Iracheta-Donjuan L, Vázquez-Ovando A, Bouchan R, Cortés-Cruz M and Borrayo E (2018) Genetic diversity and selection of a core collection for long term conservation of cocoa (*Theobroma cacao* L). Interciencia. Vol.43 No.11 pp.770–777

Avila-Lovera E, Coronel I, Jaimez R, Urich R, Pereyra G, Araque O, Chacón I and Tezara W (2016) Ecophysiological Traits of Adult Trees of Criollo Cultivars (Theobroma cacao) from a Germplasm Bank in Venezuela. Experimental Agriculture, 52(1), 137–153. https://doi.org/10.1017/S0014479714000593

Ayala HFC, Cruz DC, Castillo JCG and Uribe ST (2016) Cocoa diversity and quality in Southern Mexico. Presentation at Penn State's Symposium "Frontiers in Science and Technology for Cacao Quality, Productivity and Sustainability", May 31– June 2, 2016, The Huck Institute of the Life Sciences, Pennsylvania State University, PA, USA. Abstract retrieved from ResearchGate DOI:10.13140/RG.2.1.3337.9444 https://www.researchgate.net/publication/303783397_Cocoa_Diversity_and_Quality_in_Southern_Mexico

Ayenor GK (2006) Capsid control for organic cocoa in Ghana. Results of participatory learning and action research. PhD thesis, University of Ghana. https://www.researchgate.net/profile/Gk_Ayenor/publication/40112658_Capsid_control_for_organic_cocoa_in_Ghana_results_of_participatory_learning_and_action_research/links/5752c64808ae02ac1277fadb.pdf#page=103

Baker PL (1994) Centring the periphery: Chaos, order, and the ethnohistory of Dominica. McGill-Queen's University Press, Montreal, Quebec.

Ballesteros P, W, Lagos B, TC and Ferney LH (2016) Morphological characterization of elite cacao trees (Theobroma cacao L.) in Tumaco, Nariño, Colombia. Revista Colombiana de Ciencias Hortícolas 9(2): 313–328. https://doi.org/10.17584/rcch.2015v9i2.4187

Bamber P and Fernandez-Stark K (2012) Upgrading to organic cocoa cultivation in Peru. Center on Globalization, Governance and Competitiveness, Duke University.

Bamber P and Fernandez-Stark K (2014) Inclusive value chain interventions in the high-value agrifood sector in Latin America. In René A. Hernández, Jorge Mario Martínez and Nanno Mulder, "Global value chains and world trade: Prospects and challenges for Latin America", ECLAC Books, No. 127 (LC/G.2617-P), Santiago, Chile, Economic Commission for Latin America and the Caribbean (ECLAC), 2014.

Banbuck CA (1935) Histoire politique, économique et sociale de la Martinique sous l'Ancien Régime (Political, Economic and Social History of Martinique under the Ancien Régime) (1635–1789). https://issuu.com/scduag/docs/pap11052 (published online Jan 17, 2012). Accessed 13 October 2021.

Bardin A (1937) Le cacaoyer en Côte d'Ivoire. Annales Agricoles de l'Afrique Occidentale Française et Etrangère 1(2): 135–150

Barrett OW (1925) The food plants of Porto Rico. The Journal of Agriculture of the University of Puerto Rico 9(2): 61-208. https://doi.org/10.46429/jaupr.v9i2.15079. Accessed 17 October 2021.

Barriga JP, Machado PFR, Almeida CMVC and Almeida CFG (1985) A preservação e utilização dos recursos genéticos de cacau na Amazônia Brasileira. In: 9th Intl. Cocoa Res. Conf. London: Cocoa Producers' Alliance. pp. 73–79.

Bartley BGD (2001) Refractario—an explanation of the meaning of the term and its relationship to the introductions from Ecuador in 1937. INGENIC Newsl 6:10–15

Bartley BGD (2005) The genetic diversity of cacao and its utilization. CABI Publishing, CABI International, Wallingford, Oxfordshire

Bartley, B.G.D., and Chalmers, W.S. 1970. Germplasm collection. In Annual Report on Cacao Research 1969. Regional Research Centre, Imperial College of Tropical Agriculture, University of the West Indies, Trinidad. 8pp.

Batista L (2009) Guía Técnica el Cultivo de Cacao en la República Dominicana. Santo Domingo, República Dominicana. CEDAF. http://www.cedaf.org.do/publicaciones/guias/download/cacao.pdf. Accessed 1 October 2021.

Batista LJ (1985) Progreso en 10 años de investigación en el mejoramiento genético del cacao en Republica Dominicana. In Proc. 9th Intl. Cocoa Res. Conf., 12–18 February 1984, Lomé, Togo. Lagos, Nigeria: COPAL, pp. 263-267

Bazoberry Chali O, and Salazar Carrasco C (2008) El cacao en Bolivia una alternativa económica de base campesina indígena. La Paz: Centro de Investigación y Promoción del Campesinado.

Bekele F, James M and Bekele I (1999) An assessment of the phenotypic diversity of cacao germplasm in the Commonwealth of Dominica. Report of a study conducted July 12th – August 30th, 1999.

Bekele F, James M and Bekele I (2000) An assessment of the phenotypic diversity of cacao germplasm in the Commonwealth of Dominica. In Annual Report on Cacao Research 1999, Cocoa Research Unit, The University of the West Indies, Trinidad. pp. 19–27.

Bekele FL, Bekele I, Butler DR and Bidaisee GG (2006) Patterns of morphological variation in a sample of cacao (*Theobroma cacao* L.) germplasm from the International Cocoa Genebank, Trinidad. Genetic Resources and Crop Evolution 53(5): 933–948. https://doi.org/10.1007/s10722-004-6692-x

Bekele FL, Bidaisee GG, Singh H and Saravanakumar D (2020) Morphological characterisation and evaluation of cacao (*Theobroma cacao* L.) in Trinidad to facilitate utilisation of Trinitario cacao globally. Genetic Resources and Crop Evolution 67(3): 621–643. https://doi.org/10.1007/s10722-019-00793-7

Benoît C (2012) Pays, mouvements et sons dans la vallée de Grande-Rivière : pour une approche phénoménologique des paysages de Guadeloupe . VertigO - la revue électronique en sciences de l'environnement. URL: http://vertigo.revues.org/12381;
DOI: 10.4000/vertigo.12381; accessed 13 Oct 2021

Bergmann JF (1969) The distribution of cacao cultivation in pre-Columbian America. Annals of the Association of American Geographers 59(1): 85–96. doi:10.1111/j.1467-8306.1969.tb00659.x

Berry PE. (2015) "Malvaceae." Encyclopedia Britannica, May 5, 2015. https://www.britannica.com/plant/Malvaceae.

Berry SS (1968) Christianity and the rise of cocoa-growing in Ibadan and Ondo. Journal of the Historical Society of Nigeria, 4(3): 439–451

Bhat VR, Nair RV, Virakthmath BC, Balasimha D, Ananda KS, Subramonian N, Kumaran PM, Sujatha K, Rekha A and Rajan P (2005) Cocoa breeding – an experience at CPCRI. IN Proc. Intl. Cocoa Res. Conf., 13–18 October 2003, Accra, Ghana, Malaysia: COPAL, pp. 121–129

Bhattacharjee R, Aikpokpodion P, Kolesnikova-Allen M, Badaru K, Schnell R (2004) West African Cocoa: a pilot study on DNA fingerprinting of the germplasm from the Cross River State of Nigeria. INGENIC Newsletter 9:15–20

Bidot Martínez I, Riera Nelson M, Flamand MC, and Bertin P (2015) Genetic diversity and population structure of anciently introduced Cuban cacao *Theobroma cacao* plants. Genetic Resources and Crop Evolution 62(1): 67–84. https://doi.org/10.1007/s10722-014-0136-z

Bidot Martínez I, Valdés de la Cruz M, Riera Nelson M, and Bertin P (2017a) Establishment of a Core Collection of Traditional Cuban *Theobroma cacao* Plants for Conservation and Utilization

Purposes. Plant Molecular Biology Reporter 35(1): 47–60. https://doi.org/10.1007/s11105-016-0999-6

Bidot Martínez I, Valdés de la Cruz M, Riera Nelson M, and Bertin P (2017b) Morphological characterization of traditional cacao (*Theobroma cacao* L.) plants in Cuba. Genetic Resources and Crop Evolution 64(1): 73–99. https://doi.org/10.1007/s10722-015-0333-4

Billock J (2018) How Hawaii Became the North Pole of Cacao. https://www.smithsonianmag.com/travel/hawaii-north-pole-cacao-chocolate-tours-180967951/. Accessed 7 November 2021.

Blare T, Corrales I and Zambrino L (2020) Can Niche Markets for Local Cacao Varieties Benefit Smallholders in Peru and Mexico? . Choices 35(4): 1-7. https://www.jstor.org/stable/27098581

Boccara M, Motilal LA, Pierre C and Umaharan P (2018) Caractérisation morphologique et moléculaire de variétés de Cacaoyer cultivées dans le département de la Grand 'Anse à Haïti. In Proceedings of the International Symposium on Cocoa Research. November 13-17, 2017, Cusco, Peru. https://www.icco.org/wp-content/uploads/T1.153.-CARACTERISATION-MORPHOLOGIQUE-ET-MOLECULAIRE-DE-VARIETES-DE-CACAOYER-CULTIVEES-DANS-LE-DEPARTEMENT-DE-LA-GRAND-ANSE.pdf

Borome JA (1967) The French and Dominica, 1699–1763. Jamaican Historical Review, 7: 9–39.

Boza EJ, Irish BM, Meerow AW, Tondo CL, Rodríguez OA, Ventura-López M, Gómez JA, Moore JM, Zhang D, Motamayor JC and Schnell RJ (2013). Genetic diversity, conservation, and utilization of *Theobroma cacao* L.: Genetic resources in the Dominican Republic. Genetic Resources and Crop Evolution 60(2): 605–619. https://doi.org/10.1007/s10722-012-9860-4

Boza EJ, Motamayor JC, Amores FM., Cedeño-Amador S, Tondo CL, Livingstone DS, Schnell RJ and Gutiérrez OA (2014) Genetic characterization of the cacao cultivar CCN 51: Its impact and significance on global cacao improvement and production. Journal of the American Society for Horticultural Science 139(2): 219–229. https://doi.org/10.21273/jashs.139.2.219

Bravo D, Pardo-Diaz S, Benavides-Erazo J, Rengifo-Estrada G, Braissant O and Leon-Moreno C (2018) Cadmium and cadmium-tolerant soil bacteria in cacao crops from northeastern Colombia. Journal of Applied Microbiology 124: 1175–1194 doi:10.1111/jam.13698

Brown E and Hunter HH (1913) Planting in Uganda. Longmans, Green & Co., London

Bruno KK, Djaha K, Bertin GBZ, Aimé VBT, Claude KBJ and Yves AYC (2015) Typology of cocoa-based agroforestry systems in a forest-savannah transition zone: case study of Kokumbo (Centre, Côte d'Ivoire). International Journal of Agronomy and Agricultural Research 6(3): 36–47.

Burle L (1961) Le cacaoyer. (Tome premier). Paris (France): Maisonneuve et Larose, 316 p.

Bushnell, GHS, Sanders, WT, Soustelle, J, Patterson, TC, Hagen, VW von, Willey, GR, Coe, MD and Murra JV (2020, November 18). Pre-Columbian civilizations. Encyclopedia Britannica. https://www.britannica.com/topic/pre-Columbian-civilizations

Bymolt R, Laven A and Tyszler M (2018) Demystifying the cocoa sector in Ghana and Côte d'Ivoire. The Royal Tropical Institute (KIT). https://www.kit.nl/wp-content/uploads/2020/05/Demystifying-complete-file.pdf

Cacao Fiji (2021) Premium Fijian Cacao for Craft Chocolate. https://www.cacaofiji.com/

CacaoNet (2012) A Global Strategy for the Conservation and Use of Cacao Genetic Resources, as the Foundation for a Sustainable Cocoa Economy (B. Laliberté, compiler). Bioversity International, Montpellier, France.

Cadby J and Araki T (2020) Towards ethical chocolate: multicriterial identifiers, pricing structures, and the role of the specialty cacao industry in sustainable development. SN Business & Economics 1(44): 1–36. https://doi.org/10.1007/s43546-021-00051-y

Calvo AM, Botina BL, Garcia MC, Cardona WA, Montenegro AC and Criollo J (2021) Dynamics of cocoa fermentation and its effect on quality. Scientific Reports 11:16746 | https://doi.org/10.1038/s41598-021-95703-2

Camu N, De Winter T, Addo SK, Takrama JS, Bernaert H and De Vuyst L (2018) Fermentation of cocoa beans: influence of microbial activities and polyphenol concentrations on the flavour of chocolate. Journal of the Science of Food and Agriculture 88:2288–2297. DOI: 10.1002/jsfa.3349

Canale GR, Suscke P, Rocha-Santos L, Bernardo CSS, Kierulff MCM and Chivers DJ (2016) Seed Dispersal of Threatened Tree Species by a Critically Endangered Primate in a Brazilian Hotspot. Folia Primatol 87: 123–140. DOI: 10.1159/000447712

Carmichael G (1961) The History of the West Indian Islands of Trinidad and Tobago, 1498–1900. London: Alvin Redman.

Carranza MS, Zapata YP, Gallego G, Rodríguez JN, Carriel JM, Rosero NC, Jara SM and Muñoz JE (2020) Genetic diversity of Ecuadorian cocoa from the germplasm bank of Tenguel-Guayas Ecuador based in SNP's. Bioagro 32(2): 75–86.

Casas A, Blancas J, Lira R (2016) Mexican Ethnobotany: Interactions of People and Plants in Mesoamerica. In: Lira R., Casas A., Blancas J. (eds) Ethnobotany of Mexico. Ethnobiology. New York, NY: Springer, pp. 1–19. https://doi.org/10.1007/978-1-4614-6669-7_1

Celestino CP and Garrido ES (2013) Estudio sobre el Cacao de Comercio Justo en República Dominicana. La experiencia de Cooproagro. Oxfam Intermón. https://cdn2.hubspot.net/hubfs/426027/Oxfam-Website/oi-informes/El cacao en República Dominicana.pdf

Céspedes Del Pozo W, Blas Sevillano R and Zhang D (2018) Assessing genetic diversity of cacao (*Theobroma cacao* L.) Chuncho in La Convención, Cusco-Peru. In Proceedings of the International Symposium on Cocoa Research. November 13-17, 2017, Cusco, Peru. p. 1-8. https://www.icco.org/wp-content/uploads/T1.84.-ASSESING-GENETIC-DIVERSITY-OF-CACAO-Theobroma-cacao-L.-NATIVO-CHUNCHO-IN-LA-CONVENCION-CUSCO-PERU.pdf

Chalmers WS (1972) Germplasm collection. In Annual Report on Cacao Research 1971. University of the West Indies, Trinidad. 7pp.

Chalmers WS (1973) Germplasm collection. In Annual Report on Cacao Research 1972. University of the West Indies, Trinidad. 7pp

Champaud J (1966) L'économie cacaoyère au Cameroun. Cah. ORSTOM, Sér Sci hum III (3):105–124

Chan M (2020) LACRA seeks to improve Liberian cocoa sector. https://bartalks.net/lacra-seeks-to-improve-liberian-cocoa-sector/. Accessed 15 August 2021.

Chaves-López C, Serio A, Grande-Tovar CD, Cuervo-Mulet R, Delgado-Ospina J, Paparella A (2014) Traditional fermented foods and beverages from a microbiological and nutritional perspective: the Colombian heritage. Comp Rev Food Sci Food Safety 13:1031–1048.

Cheesman EE (1932) The economic botany of cacao. A critical survey of the literature to the end of 1930. Supplement to tropical agriculture. Port-of-Spain, Trinidad: Government Printing Office.

Cheesman EE (1934) The botanical programme of 1933. In Third Annual Report on Cacao Research, 1933, 1–2. Port-of-Spain, Trinidad: Government Printing Office.

Cheesman EE (1944) "Notes on the Nomenclature, Classification and Possible Relationships of Cacao Populations." Tropical Agriculture 21 (No.8): 144–59.

Chery W (2015) Factors Influencing Sustainable Cocoa Production in Northern Haiti. MSc thesis, Louisiana State University. https://digitalcommons.lsu.edu/gradschool_theses/3083

Chesney PEK (2007) Preliminary characterisation and evaluation of cocoa on-farm genetic diversity in the north-west region of Guyana. INGENIC Newsletter Issue 11: 2-4.

Chia Wong JA (2009) Caracterización molecular mediante marcadores issr de una colección de 50 árboles clonales e híbridos de cacao (*Theobroma cacao* L.) de la unas – Tingo Maria. Master thesis, Universidad Nacional Mayor De San Marcos

Chia-Wong JA, Márquez-Dávila KJ, Cárdenas-Salazar H, Hurtado-Gonzales OP, Huaman-Camacho T, Céspedes Del Pozo W, Saavedra-Arbildo RP, Beraun-Cruz Y, Carranza-Cruz MS and Gutarra Castillo BA (2018) Avances en el estudio de las bases genéticas y organolépticas del cacao fino o de aroma en el Perú. Proceedings of the International Symposium on Cocoa Research (ISCR), Lima, Peru, 13–17 November 2017 https://www.icco.org/wp-content/uploads/T1.230.AVANCES-EN-EL-ESTUDIO-DE-LAS-BASES-GENETICAS-Y-ORGANOLEPTICAS-DEL-CACAO-FINO-O-DE-AROMA-EN-EL-PERU.pdf

Chocolate Codex (2021) Countries of origin. Where cacao grows. http://chocolatecodex.com/portfolio/countries-of-origin/

Chong T-C and Phua P-K (1993) Cocoa germplasm conservation and utilization at Cocoa Research Station, Quoin Hill - Department of Agriculture, Sabah, Malaysia. In Conservation, characterization and utilization of cocoa genetic resources in the 21st century. CRU, UWI (Trinidad), 13–17 September 1992. CRU, Trinidad (pp. 379–38). Port-of-Spain, Trinidad: The Cocoa Research Unit, University of the West Indies.

Ciferri R and Ciferri F (1957) The evolution of cultivated cacao. Evolution 9: 381–397.

Cilas C, Bastide P (2020) Challenges to Cocoa Production in the Face of Climate Change and the Spread of Pests and Diseases. Agronomy 2020, 10 (9), 1232. https://doi.org/10.3390/agronomy10091232

Claire L, Fouet O, Legavre T, Lopes U, Sounigo O, Eyango MC, Mermaz B, Da Silva MR, Loor Solorzano RG, Argout X, Gyapay G, Ebaiarrey HE, Colonges K, Sanier C, Rivallan R, Mastin G, Cryer N, Boccara M, Verdeil J-L, Mousseni IBE, Gramacho KP and Clément D (2017) Deciphering the Theobroma cacao self-incompatibility system: from genomics to diagnostic markers for self-compatibility. Journal of Experimental Botany 68(17): 4775–4790. doi: 10.1093/jxb/erx293

Clarke T (n.d.) Pacific Islands Cocoa Book https://tadep-png.com/wp-content/uploads/2021/02/Pacific-Islands-Cocoa-Book.pdf
Clarence-Smith WG (2000) Cocoa and Chocolate, 1765-1794. London and New York: Routledge

Clement CR, De Cristo-Ara′ujo M, Coppens D'Eeckenbrugge G, Alves Pereira A, Picanço-Rodrigues D (2010) Origin and domestication of native Amazonian crops. Diver 2(1):72–106.

CLIP (Solomon Islands Cocoa Livelihoods Improvement Project) (2010) Solomon Islands cocoa book. Solomon Islands Cocoa Livelihoods Improvement Project. Australian Government Aid Program. https://pacificfarmers.com/wp-content/uploads/2014/07/CLIP-cocoa-book.pdf. Accessed 13 June 2021.

CocoaNect (2018) Makira Gold, Solomon Islands. Sourcing Report No. 11. http://www.cocoanect.com/wp-content/uploads/2018/02/Sourcing-Report-11-Makira-Gold.pdf

Coe SD and Coe MD (1996) The True History of Chocolate. London: Thames and Hudson.

Coe SD and Coe MD (2007) The True History of Chocolate. 2nd ed. New York: Thames and Hudson.

Coe SD and Coe MD (2013) The True History of Chocolate 3rd ed. (Thames and Hudson, London.

CoEx (2010) International Cocoa Awards 2010. Bioversity International. http://www.cocoaofexcellence.org/s/50selected2010f.xls

CoEx (2011) International Cocoa Awards 2011. Bioversity International. https://www.cocoaofexcellence.org/fileadmin/Websites/CocoaOfExcellence/Media/50selected_2011.pdf

CoEx (2013) 2013 Edition of the Cocoa of Excellence and the results of the International Cocoa Awards. Bioversity International. https://www.cocoaofexcellence.org/fileadmin/Websites/CocoaOfExcellence/Media/ICA2013-ALL-50-CHOCOLATES.pdf

CoEx (2015) Cocoa of Excellence Programme and the International Cocoa Awards. Rewarding Excellence in Producing High-quality Cocoa Origins. Results of the 2015 Edition. Bioversity International. https://www.cocoaofexcellence.org/fileadmin/Websites/CocoaOfExcellence/Media/CoEx-ICA-2015-ALL-50-CHOCOLATES.pdf

CoEx (2017) Cocoa of Excellence Programme & 2017 Edition of the International Cocoa Awards. Results of the 2017 Edition. Bioversity International. https://www.cocoaofexcellence.org/fileadmin/Websites/CocoaOfExcellence/Media/CoEx-ICA-2017-ALL-50-CHOCOLATES-with-ICA-FINAL.pdf

CoEx (2019) The 2019 International Cocoa Award Winners and Producers of the Best 50 Samples. http://www.cocoaofexcellence.org/s/CoEx-2019-ICA-Best50.pdf

CoEx (2021) 2021 Cocoa of Excellence Awards. Producers' information. Bioversity International. http://www.cocoaofexcellence.org/s/CoEx-2021-Awards-Producers-Info-21Dec21.pdf

Coke T [1810] (1971) A history of the West Indies containing the natural, civil and ecclesiastical history of each island with an account of the missions, vol. 2. Reprint, London: Cass.

Colonges K, Jimenez J-C, Saltos A, Seguine E, Solorzano RGL, Fouet O, Argout X, Assemat S, Davrieux F, Cros E, Lanaud C and Boulanger R (2022) Integration of GWAS, metabolomics, and sensorial analyses to reveal novel metabolic pathways involved in cocoa fruity aroma GWAS of fruity aroma in *Theobroma cacao*. Plant Physiology and Biochemistry 171: 213-225. Doi: 10.1016/j.plaphy.2021.11.006.

Colonges K, Jimenez J-C, Saltos A, Seguine E, Loor Solorzano RG, Fouet O, Argout X, Assemat S, Davrieux F, Cros E, Boulanger R and Lanaud C (2021) Two main biosynthesis pathways involved in the synthesis of the floral aroma of the Nacional cocoa variety. Front. Plant Sci. 12:681979. doi: 10.3389/fpls.2021.681979

Cook LR (1982) Chocolate production and use. New York, USA: Harcourt Brace Jovanovich, Inc.

Cope FW (1958) Incompatibility in Theobroma cacao. Nature 181: 279.

Cope FW (1962) The mechanism of pollen incompatibility in Theobroma cacao L. Heredity 17:157-182.

Cortés Peña AL (1997) Algunos ejemplos del control gubernamental sobre los jesuitas tras la expulsión. In: Mestre Sanchís A and Giménez Lopez E (eds) Disidencias y exilios en la España Moderna. Actas de la IV Reunión Científica de la Asociación Española de Historia Moderna, 27-30 May 1996, Alicante. 2: 691–701. Caja de ahorros del Mediterráneo, Universidad de Alicante https://digital.csic.es/bitstream/10261/89598/1/R.C.AEHM_Alicante_1996_2_p.691-701_Cort%c3%a9s_Pe%c3%b1a.pdf

Cosme S, Cuevas HE, Zhang D, Oleksyk TK and Irish BM (2016) Genetic diversity of naturalized cacao (*Theobroma cacao* L.) in Puerto Rico. Tree Genetics and Genomes 12(5): 1-13. https://doi.org/10.1007/s11295-016-1045-4

Covich AP and Nickerson NH (1966) Studies of Cultivated Plants in Choco Dwelling Clearings, Darien, Panama. Economic Botany 20(3): 285-301. https://www.jstor.org/stable/4252756

Crown PL and Hurst WJ (2009) Evidence of cacao use in the Prehispanic American Southwest. Proc. Natl Acad. Sci. USA 106, 2110–2113.

Cruickshank AM (1970) Cocoa in Grenada. Cocoa Growers' Bulletin 15: 4–11.

CTAHR (2011) College of Tropical Agriculture and Human Resources, University of Hawai'i at Mānoa. Cacao presentation. https://www.ctahr.hawaii.edu/defrankj/Streaming%20Media/Windows_Media/hcb_BEVERAGE_CLASS_F2011/text_f2011/pdf_slideshows_f2011/08_Cacao10_252011.pdf. Accessed 7 November 2021.

Cuatrecasas J (1964) Cacao and its Allies: A Taxonomic Revision of the Genus Theobroma. Contributions from the United States National Herbarium, 35(6), 379–614. Retrieved from http://www.jstor.org/stable/23493192

Cubero E, Enríquez G, Hernández A, Rodríquez T (1992) Calidad del cacao en cuatro zonas cacaoteras de Costa Rica. Turrialba 42(3): 287–293.

Dame Cacao (2021a) Cambodian Cacao & Chocolate Culture. https://damecacao.com/cambodian-cacao-chocolate-culture/ updated November 7, 2019.

Dame Cacao (2021b) Hawaiian Chocolate & Cacao Culture. https://damecacao.com/hawaiian-chocolate-cacao-culture-hawaii/

Daniels S, Läderach P and Paschall M (2012) Reaching high-value markets: fine flavor cocoa in Ghana. International Institute for Environment and Development. https://pubs.iied.org/sites/default/files/pdfs/migrate/16036IIED.pdf. Accessed 31 August 2021

Davrieux F, Rakotomalala JJ, Assemat S, Raherinandrasana NL, Staub I and Descroix F (2018) Adaptation du processus de fermentation aux contraintes locales. Application au cacao du Sambirano de Madagascar. https://www.icco.org/wp-content/uploads/T5.22.ADAPTATION-DU-PROCESSUS-DE-FERMENTATION-AUX-CONTRAINTES-LOCALES.-APPLICATION-AU-CACAO-DU-SAMBIRANO-DE-MADAGASCAR.pdf

de la Cruz M, Whitkus R, Gómez-Pompa A and Mota-Bravo L (1995) Origins of cacao cultivation. Nature 375: 542-543. https://doi.org/10.1038/375542a0

De Merva S (1618) Letter dated 31st January 1618. In The Trinidad Historical Society, publication no. 190, a letter from Dr. Salcedo de Merva to the King of Spain. Mss. 36320. [In Spanish]. British Museum.

de Planhol X (1947) Le cacao en Côte d'Ivoire: étude de géographie régionale. In: L'Information Géographique 11(2): 50-57. doi : https://doi.org/10.3406/ingeo.1947.5249

de Schawe CC, Durka W, Tscharntke T, Hensen I and Kessler M (2013) Gene flow and genetic diversity in cultivated and wild cacao (*Theobroma cacao*) in Bolivia. American Journal of Botany 100(11): 2271–2279. doi:10.3732/ajb.1300025

de Smet M (2018) Cocoa production in the "Oriente" region of Cuba (Baracoa): Assessment, understanding and potential. Master en bioingénieur : sciences agronomiques. Liège Université, Belgium.

de Walque B (2018). Biophysical Control on Cocoa Quality in Santander, Colombia. MSc thesis Ghent University. Retrieved from https://lib.ugent.be/fulltxt/RUG01/002/509/472/RUG01-002509472_2018_0001_AC.pdf

Deheuvels O, Decazy B, Perez R, Roche G, Amores F (2004) The first Ecuadorean "Nacional" cocoa collection based on organoleptic characteristics. Trop Sci 44:23–27

Department of Export Agriculture (2021) Cocoa. http://www.dea.gov.lk/cocoa/

Deuss J (1981) La vulgarisation cacaoyère au Togo. Café Cacao Thé 25 (1): 37–44.

Deutsch J-G (1990) Educating the middlemen: a political and economic history of statutory cocoa marketing in Nigeria, 1936–1947. PhD thesis, University of London.

Devy L, Anita-Sari I, Imam Saputra T, Wahyu Susilo A, Wachjar A and Sobir (2018) Identification of molecular marker based on MYB transcription factor for the selection of Indonesian fine cacao (*Theobroma cacao* L.). Pelita Perkebunan (a Coffee and Cocoa Research Journal), 34(2), 59–68. https://doi.org/10.22302/iccri.jur.pelitaperkebunan.v34i2.314

Díaz-Valderrama JR, Leiva-Espinoza ST, Aime MC (2020) The history of cacao and its diseases in the Americas. Phytopathology, 110 (10): 1604–1619
https://doi.org/10.1094/PHYTO-05-20-0178-RVW

Diczbalis Y (2013) Commercialising cocoa growing in North Queensland. RIRDC Publication No. 13/114. Rural Industries Research and Development Corporation, Barton, Australia.

Diczbalis Y, Lemin C, Richards N, and Wicks C (2010) Producing Cocoa in Northern Australia. RIRDC Publication No 09/092. Rural Industries Research and Development Corporation, Barton, Australia.

Dillon N, Diczbalis Y, Oakeshott J, and Nagalevu P (2020) Aligning Pacific cocoa genetics to productivity and quality for the craft speciality chocolate market. Proceedings 2019, 36: 105. doi:10.3390/proceedings2019036105

Dinarti D, Susilo AW, Meinhardt LW, Ji K, Motilal LA, Mischke S and Zhang D (2015) Genetic diversity and parentage in farmer selections of cacao from Southern Sulawesi, Indonesia revealed by microsatellite markers. Breeding Science 65: 438–446 doi:10.1270/jsbbs.65.438

Division of Agriculture: Government of the Commonwealth of Dominica. 2019. Cocoa and coffee project. Available from
http://divisionofagriculture.gov.dm/programmes/cocoa-and-coffee-project [accessed 20 July 2019].

Dole N (2012) Sri Lanka – a chocoholic's paradise. Sunday Observer, 2 September 2012.
www.archives.sundayobserver.lk/2012//09/02/fea14.asp

Donovan J, Soto G, Stoian D and Astorga C (2008) Towards a sustainable cocoa sector in Belize. An action plan based on analysis of production systems, rural livelihoods, and market environment. Report in partial fulfillment of RUTA/UNOPS Special Services Contract SE-005-18.
https://www.researchgate.net/publication/257307523_Towards_a_sustainable_cocoa_sector_in_Belize

Dos Santos Dias LA, Pontes Barriga J, Yoshio Kageyama P and Cordeiro de Almeida CMV (2003) Variation and its distribution in wild cacao populations from the Brazilian Amazon. Brazilian Archives of Biology and Technology 46(4): 507–514.
https://doi.org/10.1590/s1516-89132003000400003

Dos Santos IC, De Almeida A-AF, Anhert D, Da Conceição AS, Pirovani CP, Pires JL, Valle RR and Baligar V (2014) Molecular, physiological and biochemical responses of theobroma cacao L. genotypes to soil water deficit. PLoS ONE, 9(12), e115746.
https://doi.org/10.1371/journal.pone.0115746

Duchaufour H., R.T., Rakotoarisoa J., Ramamonjisoa B. et Rakotondravao (Editeurs Scientifiques) (2016) Recherche interdisciplinaire pour le développement durable et la

biodiversité des espaces ruraux malgaches. Application à différentes thématiques de territoire. Actes du projet FSP PARRUR « PArtenariat et Recherche dans le secteur RURal ». Antananarivo SCAC/PARRUR.
http://www.apdra.org/images/Apdra/Pdf/Articles%20scientifiques/Collectif_Parrur_web.pdf

Durán E and Dubón A (2016) Tipos genéticos de cacao y distribución geográfica en Honduras. Centro de Comunicación Agrícola de la FHIA La Lima, Cortés, Honduras, C.A.

Duthie DW (1938) Observations on the biochemistry of cacao kernel. I. Tannin and catechin. Seventh Annual Report on Cacao Research 1937. Government Printing Office, Port of Spain, Trinidad.

Edwards DT (1961) An Economic View of Agricultural Research in Jamaica. Social and Economic Studies 10(3): 306–339. http://www.jstor.org/stable/27853635. Accessed 4 October 2021.

Edwards V (2014) Vanuatu cocoa growers target the fine chocolate market. The Australian. 21 November 2014.
https://www.theaustralian.com.au/travel/vanuatu-cocoa-growers-target-the-fine-chocolate-market/news-story/30fcb1bbcb90396245072ad0c8165ec0. Accessed 27 Spetember 2021.

Edwin J and Masters WA (2005) Genetic improvement and cocoa yields in Ghana. Experimental Agriculture 41: 491–503. doi:10.1017/S0014479705002887

Effiom RA (n.d.) The development of cocoa economy in the Central Cross River Basin of eastern Nigeria since 1874. 30 p.

Efombagn IBM, Motamayor JC, Sounigo O, Eskes AB, Nyassé S, Cilas C, Schnell R, Manzanares-Dauleux MR and Kolesnikova-Allen M (2008) Genetic diversity and structure of farm and GenBank accessions of cacao (*Theobroma cacao* L.) in Cameroon revealed by microsatellite markers. Tree Genetics and Genomes, 4(4): 821–831. doi:10.1007/s11295-008-0155-z

Efombagn MIB, Sounigo O, Nyassé S, Manzanares-Dauleux M, Cilas C, Eskes MAB and Kolesnikova-Allen (2006) Genetic diversity in cocoa germplasm of southern Cameroon revealed by simple sequences repeat (SSRS) markers. African Journal of Biotechnology, 5(16): 1441–1449. https://doi.org/10.4314/ajb.v5i16.43136

Efombagn MIB, Sounigo O, Nyassé S, Manzanares-Dauleux M and Eskes AB (2009) Phenotypic variation of cacao (*Theobroma cacao* L.) on farms and in the gene bank in Cameroon. Journal of Plant Breeding and Crop Science 1(6): 258–264.
https://academicjournals.org/journal/JPBCS/article-full-text-pdf/FD2B1BD1445

Efron Y (1996) Cocoa breeding in Papua New Guinea. INGENIC Newsletter 2: 9–10.

Emenius C (2012) Livelihood and transition to certified cacao production in the Peruvian Amazonas - gendered responsibilities in Irazola. Master's thesis, Swedish University of Agricultural Science, Uppsala, Sweden.

English A (2018) Determinants of Liberian Farmgate Cocoa Prices. MSc Thesis, University of Tennessee, https://trace.tennessee.edu/utk_gradthes/3642

Erazo XAR (2014) Diversidad genética de cacao *Theobroma cacao* L. con marcadores moleculares microsatélites. MSc thesis, Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Palmira, Colombia.

Erickson-Davis M (2016) Huge cacao plantation in Peru illegally developed on forest-zoned land. Mongabay Series: Global Forest Reporting Network, Global Forests

Eskes AB, Rodriguez CAC, Ahnert D, Condori D, Parizel A, De Paula Durão C. F, Matsigenkas and Chuncho growers in Peru (2018) Advances on genetical and naturally induced variations for fine flavors and aromas in Theobroma cacao. Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru.
https://www.icco.org/wp-content/uploads/T5.17.ADVANCES-ON-GENETICAL-AND-NATURALLY-INDUCED-VARIATIONS-FOR-FINE-FLAVORS-AND-AROMAS-IN-THEOBROMA-CACAO.pdf

Espino RRC, Tonogbanua KA, Espino MRM and Ramos JV (2018) DNA profiling of cacao (*Theobroma cacao* L.) Varieties in the Philippines using microsatellite markers. International Symposium of Cocoa Research (ISCR), Lima, Peru, 13–17 November 2017
https://www.icco.org/icco-documentation/international-cocoa-symposium-2017/international-cocoa-symposium-2017-proceedings/#toggle-id-1

Everaert H, De Wever J, Tang TKH, Vu TLA, Maebe K, Rottiers H, Lefever S, Smagghe G, Dewettinck K and Messens K (2020) Genetic classification of Vietnamese cacao cultivars assessed by SNP and SSR markers. Tree Genetics and Genomes 16: 43.
https://doi.org/10.1007/s11295-020-01439-x

Everaert H, Rottiers H, Pham PHD, Ha LTV, Nguyen TPD, Tran PD, de Wever J, Maebe K, Smagghe G, Dewettinck K and Messens K (2017) Molecular characterization of Vietnamese cocoa genotypes (*Theobroma cacao* L.) using microsatellite markers. Tree Genetics and Genomes 13(5): 1–11. doi:10.1007/s11295-017-1180-6

Fagan HJ (1984) An Assessment of Pathological Research on Cocoa in Jamaica from 1950 to 1980 and Current Research Priorities. Tropical Pest Management 30(4): 430–439.

Fagan HJ and Topper BF (1988) Agronomic research on cocoa in Jamaica 1950–1980 and current research trends. Tropical Agriculture (Trinidad) 65(4): 290–294.

Fallon J and Herr M (2011) Agricultural Livelihoods Program. AidWorks Initiative Number INJ090; INJ711; INJ622. Independent Completion Report.
https://www.dfat.gov.au/sites/default/files/alp-icr.pdf. Accessed 13 June 2021.

Fang W, Meinhardt LW, Mischke S, Bellato CM, Motilal L and Zhang D (2014) Accurate determination of genetic identity for a single cacao bean, using molecular markers with a nanofluidic system, ensures cocoa authentication. Journal of Agricultural and Food Chemistry 62(2): 481–487. https://doi.org/10.1021/jf404402v

FAO (2010) Agriculture for Growth: learning from experience in the Pacific Summary results of five country studies in Fiji, Samoa, Solomon Islands, Tonga and Vanuatu. http://www.fao.org/docrep/013/am011e/am011e00.pdf. Accessed 8 February 2021.

Fibrianto K, Azhar LOMF, Widyotomo S and Harijono H (2021) Effect of cocoa bean origin and conching time on the physicochemical and microstructural properties of Indonesian dark chocolate. Brazilian Journal of Food Technology 24: e2019249. doi:10.1590/1981-6723.24919

Figueira A, Lambert S, Carpenter D, Pires JL, Cascardo JCM and Romanczyk L (1998) The similarity of cocoa flavour of fermented seeds from fingerprinted genotypes of *Theobroma cacao* L. from Brazil and Malaysia. Tropical Agriculture (Trinidad) 74(2): 132–139.

Fister AS, Leandro-Muñoz ME, Zhang D, Marden JH, Tiffin P, DePamphilis C, Maximova S and Guiltinan MJ (2020) Widely distributed variation in tolerance to *Phytophthora palmivora* in four genetic groups of cacao. Tree Genetics and Genomes 16: 1. https://doi.org/10.1007/s11295-019-1396-8

Fowler WR (1985) Ethnohistoric Sources on the Pipil-Nicarao of Central America: A Critical Analysis. Ethnohistory 32(1): 37–62. doi:10.2307/482092

Frasch T (2014) The Coming of Cacao and Chocolate to Ceylon. Food and History, 12(1), 137–152. doi:10.1484/j.food.5.105146

Frederick HH (2015) Reviving the Cocoa Industry in Samoa 2016. https://www.academia.edu/31472204/Reviving_the_Cocoa_Industry_in_Samoa_2016 Accessed 29 August 2021

Garibay SV and Ugas R (2010) Organic farming in Latin America and the Caribbean. In The World of Organic Agriculture - Statistics and Emerging Trends 2010. Eds H. Willer and L. Kilcher, IFOAM, Bonn, and FiBL, Frick. http://orgprints.org/17931/

Geo L and Saediman H (2019) Analysis of Factors Affecting Cocoa Development in Southeast Sulawesi. Pakistan Journal of Nutrition, 18(5), 479–490. https://doi.org/10.3923/pjn.2019.479.490

Ghana Cocoa Board (2021a) The first-ever fine flavour cocoa fermentation centre opens at Offinso. COCOBOD News April 2021 p. 14. https://cocobod.gh/resource_files/cocobod-news-april-2021.pdf. Accessed 31 August 2021.

Ghana Cocoa Board (2021b) The green Ghana dream: COCOBOD planting more than 1.6 million trees in the 2020/2021 crop year. https://cocobod.gh/news/the-green-ghana-dream-cocobod-planting-more-than-16-million-trees-in-the-20202021-crop-year. Accessed 31 August 2021.

Gill N (2019) Mapping the Flavors of Cacao Chuncho. https://www.newworlder.com/mapping-the-flavors-of-chuncho-cacao/

Gnongbo TY (2003) Mise en valeur agricole et évolution du milieu naturel dans la zone forestière du Litimé (Togo). Les Cahiers d'Outre-Mer 224: 443-460. Doi: 10.4000/com.752
Gockowski J, Afari-Sefa V, Sarpong DB, Osei-Asare YB, and Dziwornu AK (2011) Increasing Income of Ghanaian Cocoa Farmers: Is Introduction of Fine Flavour Cocoa a Viable Alternative. Quarterly Journal of International Agriculture 50 (2): 175–200

Godfred T (2017) Cocoa farming and management. Doi: 10.13140/RG.2.2.31553.58727. https://www.researchgate.net/publication/343431937_COCOA_FARMING_AND_MANAGEMENT_PREPARED_FOR_MANAGEMENT. Accessed 29 August 2021.

Golikova P (2016) It's official — the Fijian cacao industry is alive again. https://medium.com/conscious-cacao-stories/its-official-the-fijian-cacao-industry-is-alive-again-4411133a976bf

Gómez-Pompa A, Flores JS and Fernandez MA (1990) The sacred cacao groves of the Maya. Latin American Antiquity, 1, 247–257. doi:10.2307/972163. Available at http://www.jstor.org/stable/972163?seq=1#page_scan_tab_contents.

González-Orozco CE, Galán AAS, Ramos PE and Yockteng R (2020) Exploring the diversity and distribution of crop wild relatives of cacao (*Theobroma cacao* L.) in Colombia. Genetic Resources and Crop Evolution, 67(8), 2071–2085. https://doi.org/10.1007/s10722-020-00960-1

Gopaulchan D, Motilal LA, Bekele FL, Clause S, Ariko JO, Ejang HP and Umaharan P (2019) Morphological and genetic diversity of cacao (*Theobroma cacao* L.) in Uganda. Physiology and Molecular Biology of Plants 25(2): 361–375. https://doi.org/10.1007/s12298-018-0632-2

Gopaulchan D, Motilal LA, Kalloo RK, Mahabir A, Moses M, Joseph F and Umaharan P (2020) Genetic diversity and ancestry of cacao (*Theobroma cacao* L.) in Dominica revealed by single nucleotide polymorphism markers. Genome, 63(12), 583–595. https://doi.org/10.1139/gen-2019-0214

Green RH and Hymer S (1966) The Introduction of Cocoa in the Gold Coast: A Study in the Relations Between African Farmers and Colonial Agricultural Experts" (1966). Discussion Papers. 9. https://elischolar.library.yale.edu/egcenter-discussion-paper-series/9

Grivetti LH and Shapiro H-Y (eds) (2009) Chocolate, History, Culture, and Heritage John Wiley & Sons, Hoboken.

Gu F, Tan L, Wu H, Fang Y, Xu F, Chu Z, Wang Q. 2013. Comparison of Cocoa Beans from China, Indonesia and Papua New Guinea. Foods. 2(2):183-197. doi: 10.3390/foods2020183.

Gunathilake HAJ (n.d.) Cacao as a mixed crop with coconut plantation. Journal of the National Institute of Plantation Management 4(2): 95–112.

Gutiérrez-López N, Ovando-Medina I, Salvador-Figueroa M, Molina-Freaner F, Avendaño-Arrazate CH and Vázquez-Ovando A (2016) Unique haplotypes of cacao trees as revealed by trnH-psbA chloroplast DNA. PeerJ, 2016(4). https://doi.org/10.7717/peerj.1855

Ha DT and Shively G (2005) Coffee vs. cacao: A case study from the Vietnamese central highlands. Journal of natural resources and life sciences education 34 (1): 107–111.

Hancock L and McCarthy S (2021) An Area Roughly the Size of California—166,000 Square Miles—Lost to Deforestation Worldwide Between 2004 and 2017. https://www.worldwildlife.org/press-releases/an-area-roughly-the-size-of-california-166-000-square-miles-lost-to-deforestation-worldwide-between-2004-and-2017

Handley LR (2016) The effects of climate change on the reproductive development of *Theobroma cacao* L.

Harris J (2014) Making chocolate in New Caledonia. https://newcaledoniatoday.wordpress.com/2014/08/31/making-chocolate-in-new-caledonia/

Harrison LC (1935) Dominica: a wet tropical human habitat. Economic Geography, 11: 62–76. doi:10.2307/140650.

Harrison S, Karim S, Alauddin M and Harrison R (2016) The contribution of agroforestry to economic development in Fiji and Vanuatu. In Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu ACIAR Monograph MN191, eds. Steve Harrison and Md Saiful Karim, Australian Centre for International Agricultural Research (ACIAR). https://core.ac.uk/download/pdf/78104878.pdf Accessed 14 June 2021.

Hart JH (1900) Cacao. A treatise of cultivation and curing of cacao. Trinidad: Mirror

Hartley [sic] BGD and Chalmers WS (1970) Germplasm collection. In Annual Report on Cacao Research 1970. University of the West Indies, Trinidad. 7pp.

Hayford K (2021) China's Hainan cocoa makes international cocoa awards shortlist. July 24, 2021. https://thecocoapost.com/chinas-hainan-cocoa-makes-international-cocoa-awards-shortlist/

Hebbar P, Bittenbender HC and O`Doherty D (2011) Farm and Forestry Production and Marketing Profile for Cacao (*Theobroma cacao*). In: Elevitch, CR (ed.). Specialty Crops for Pacific Island Agroforestry. Permanent Agriculture Resources (PAR), Holualoa, Hawai'i. http://agroforestry.net/scps

Hegmann E, Phillips W, Lieberei R and Ploeger A (2018) New resistant cocoa selections from Costa Rica have Fine Aroma potential. Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru. https://www.icco.org/wp-content/uploads/T5.256.-NEW-RESISTANT-COCOA-SELECTIONS-FROM-COSTA-RICA-HAVE-FINE-AROMA-POTENTIAL.pdf

Henderson JS, Joyce RA, Hall GR, Hurst WJ and McGovern PE (2007) Chemical and archaeological evidence for the earliest cacao beverages. Proc. Natl Acad. Sci. USA 104: 18937–18940.

Hermann L, Felbinger C, Haase I, Rudolph B, Biermann B and Fischer M (2015) Food fingerprinting: characterization of the Ecuadorean type CCN-51of *Theobroma cacao* L. using microsatellite markers. J. Agric. Food Chem. 63: 4539–4544. DOI: 10.1021/acs.jafc.5b01462

Hernández J (1978) Fitotecnia del cacao. La Habana, Cuba: Editorial Pueblo y Educación.

Hill T (2019) How Hawaii's Cacao is Making the World Sweeter https://www.hawaiimagazine.com/how-hawaiis-cacao-is-making-the-world-sweeter/. Accessed 7 November 2019.

Hivu DO (2013) The impact of smallholder cocoa production on rural livelihoods: A case study in the Solomon Islands. M.Agriscience thesis, Massey University, New Zealand. https://mro.massey.ac.nz/bitstream/handle/10179/5981/02_whole.pdf?sequence=2&isAllowed=y

Hockings KJ, Yamakoshi G and Matsuzawa T (2017) Dispersal of a Human-Cultivated Crop by Wild Chimpanzees (Pan troglodytes verus) in a Forest–Farm Matrix. International Journal of Primatology 38: 172–193. https://doi.org/10.1007/s10764-016-9924-y

Horta Téllez HB, Sandoval-Aldana AP, Garcia-Muñoz MC and Cerón-Salazar IX (2019) Evaluation of the fermentation process and final quality of five cacao clones from the department of Huila, Colombia. DYNA 86(210): 233–239. doi:10.15446/dyna.v86n210.75814

Houston H and Wyer T (2012) Why Sustainable Cocoa Farming Matters for Rural Development. Center for Strategic & International Studies. Retrieved from https://www.csis.org/analysis/why-sustainable-cocoa-farmingmatters-rural-development

Howes FN (1946) The early introduction of cocoa to West Africa. African Affairs 45(180): 152–153. https://doi.org/10.1093/oxfordjournals.afraf.a093508

Hufstader C (2021) New data shows deforestation in Peruvian Amazon responsible for sizable carbon emissions. Oxfam. March 17 2021. https://www.oxfamamerica.org/explore/stories/new-data-shows-deforestation-in-peruvian-amazon-responsible-for-sizable-carbon-emissions/

Hunter J (2015) Cocoa Industry Returning to Path of Growth. Jamaica Information Service. https://jis.gov.jm/cocoa-industry-returning-path-growth/. Accessed 1 October 2021.

Hunter JR (1990) The status of cacao (*Theobroma cacao*, Sterculiaceae) in the western hemisphere. Economic Botany, 44(4), 425–439. https://doi.org/10.1007/BF02859775

Hurst WJ, Tarka SM Jr, Powis TG, Valdez F Jr and Hester TR (2002) Cacao usage by the earliest Maya civilization. Nature 418: 289–290.

Hvistendahl M (2008) Amazonian harvest. Can prehistoric farming methods lead us to a sustainable future? Archaeology 61(4): 20–25. https://www.jstor.org/stable/41780382

Hyland HL (1968) Plant inventory no. 171. USDA, Washington, DC. Retrieved from https://play.google.com/books/reader?id=EIkWAAAAYAAJ&hl=en&pg=GBS.PA173
Instituto Brasileiro de Geografia e Estatística (IBGE) (2013) Coordenação de Agropecuária, Produção agrícola municipal: culturas temporárias e permanentes, 2012. Rio de Janeiro: IBGE. Available: http://biblioteca.ibge.gov.br/visualizacao/periodicos/66/pam_2012_v39_br.pdf

ICCO (2016-2020a) Growing Cocoa. https://www.icco.org/growing-cocoa/

ICCO (2016-2020b) Fine or Flavour Cocoa. https://www.icco.org/fine-or-flavor-cocoa/. Accessed 1 October 2021.

ICCO (2016-2020c) ICCO Panel recognizes 23 countries as fine and flavour cocoa exporters. https://www.icco.org/icco-panel-recognizes-23-countries-as-fine-and-flavour-cocoa-exporters/. Accessed 1 Dec 2021.

IICA (2020) El cacao, un cultivo clave que mantiene la República Dominicana como uno de los países líderes en la exportación de productos orgánicos en el mundo. https://www.iica.int/en/node/18000. Accessed 2 October 2021

.

Imperial Department of Agriculture for the West Indies. 1903. Notes on economic plants. In Reports on the botanic station, agricultural school and cacao experiment plots, Dominica 1902–1903. Barbados: Imperial Commissioner of Agriculture for the West Indies. pp. 4–9.

Imperial Department of Agriculture for the West Indies. 1920. Cacao. In Report on the Agricultural Department, Dominica, 1919–1920. Barbados: Imperial Commissioner of Agriculture for the West Indies. pp. 11–12.

INDaily (2017) Helping Vanuatu Cocoa Growers get most value from their crop. The LEAD, 26 June 2017. https://theleadsouthaustralia.com.au/industries/manufacturing/helping-vanuatu-cocoa-growers-get-most-value-from-their-crop/. Accessed 27 September 2021.

Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (2019) Entregan 12 mil plantas de nuevas variedades de cacao a productores en Tabasco. https://www.gob.mx/inifap/prensa/entregan-12-mil-plantas-de-nuevas-variedades-de-cacao-a-productores-en-tabasco-215999?idiom=es

Inter-American Institute for Cooperation on Agriculture (IICA). 1997. Agriculture in Dominica. 1991–1995 and Beyond. Working Document #3 of 13. Trinidad and Tobago, West Indies: IICA.

IPCC (2018) Global Warming of 1.5 °C; An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty; Masson-Delmotte, V.P., Zhai, H.-O., Pörtner, D., Roberts, J., Skea, P.R., Shukla, A., Pirani, W., Moufouma-Okia, C., Péan, R., Pidcock, S., et al., Eds.; IPCC: Paris, France, 2018; Available online: https://www.ipcc.ch/sr15/download/

Irfan, Sulaiman I, Ikhsan CN and Faizun N (2018) Quality and market chain of Aceh Cocoa Beans. The 7th AIC-ICMR on Sciences and Engineering 2017. IOP Conf. Series: Materials Science and Engineering 352 (2018) 012003 doi:10.1088/1757-899X/352/1/012003

Jagoret P, Michel-Dounias I and Malézieux E (2011) Long-term dynamics of cocoa agroforests: a case study in central Cameroon. Agroforestry Systems 81:267–278. doi: 10.1007/s10457-010-9368-x

Jagoret P, Michel-Dounias I, Snoeck D, Ngnogué HT and Malézieux E (2012) Afforestation of savannah with cocoa agroforestry systems: a small-farmer innovation in central Cameroon. Agroforestry Systems 86:493–504. doi: 10.1007/s10457-012-9513-9

Jean-Marie E, Bereau D, Poucheret P, Guzman C, Boudard F and Robinson JC (2021) Antioxidative and immunomodulatory potential of the endemic French Guiana wild cocoa "guiana." Foods, 10(3). https://doi.org/10.3390/foods10030522

Jelliffe DB, Jelliffe EFP, Garcia L and de Barrios G (1961) The children of the San Blas Indians of Panama. An ecologic field study of health and nutrition. Tropical Pediatrics 59(2): 271–285.

Ji K, Zhang D, Motilal LA, Boccara M, Lachenaud P and Meinhardt LW (2013) Genetic diversity and parentage in farmer varieties of cacao (*Theobroma cacao* L.) from Honduras and Nicaragua as revealed by single nucleotide polymorphism (SNP) markers. Genetic Resources and Crop Evolution 60(2): 441–453.
https://doi.org/https://link.springer.com/article/10.1007/s10722-012-9847-1

Johns ND (1999) Conservation in Brazil's chocolate forest: The unlikely persistence of the traditional cocoa agroecosystem. Environmental Management 23(1): 31–47.

Johnsiul L and Awang A (2019) Evaluation of clonal uniformity in Class One Malaysian Commercial Cocoa Clones based on SSR markers. International Journal of Agriculture, Forestry and Plantation 8: 12–17.

Johnsiul L and Yazik NM (2019) Evaluation of the genetic diversity and relationship of Class II Malaysian Commercial Cocoa Clones using microsatellite markers. Malaysian Cocoa Journal 11: 116–126.

Johnson ES, Bekele F, Brown S, Song Q, Zhang D, Meinhardt LW and Schnell RJ (2009) Population structure and genetic diversity of the Trinitario cacao (Theobroma cacao L.) from Trinidad and Tobago. Crop Science 49(2): 564–572. https://doi.org/10.2135/cropsci2008.03.0128

Johnson ES, Bekele F and Schnell R (2004) Field Guide to the ICS Clones of Trinidad. Serie Tecnica Manual Tecnico/CATIE, (January 2004), 1–32.

Joseph EL [1838] (1970) History of Trinidad. Cass Library of West Indian Studies no.13. Reprint, London: Frank Cass & Co.

Julian Witjaksono A (2016) Cocoa farming system in Indonesia and its sustainability under climate change. Agriculture, Forestry and Fisheries 5(5): 170–180. doi: 10.11648/j.aff.20160505.15.

July Martínez W (2007) Caracterización morfológica y molecular del Cacao Nacional Boliviano y de selecciones élites del Alto Beni, Bolivia. MSc thesis CATIE, Turrialba, Costa Rica.

KamKav Farm (2021) What is the Future of Asia Cacao? October 10, 2020. https://kamkavfarm.com/blogs/news/what-is-the-future-of-asia-cacao

Karmo H (2020) Liberia cocoa sector brainstorms on way forward- Post COVID-19. Front Page Africa. Last updated 29 June 2020. https://frontpageafricaonline.com/agric-matters/liberia-cocoa-sector-brainstorms-on-way-forward-post-covid-19/. Accessed 15 August 2021.

Karthikkumar RB and Jansirani P (2014) Seasonal performance of cocoa for pod and bean characters in Tamil Nadu. Trends in Biosciences 7(2): 261–263.

Kaufman T and Justeson J (2007) The history of the word for cacao in ancient Mesoamerica. Ancient Mesoamerica 18: 193–237. doi: 10.1017/S0956536107000211.

Kaur A (1995) The origins of cocoa cultivation in Malaysia. Journal of the Malaysian Branch of the Royal Asiatic Society 68 (1): 67–80.

Keane P, Moxon J, Saul-Maora J, Clarke T, Tade E, Vinning G and Loh D (2017) History of cocoa research and improvement in Papua New Guinea. In: Papua New Guinea Cocoa Extension Manual, Compiled by Philip Keane, edited by E. Tade, A. Nongkas, J. Saul-Maora, P. Gende, D. Yinil and J. Marfu. PNG Cocoa and Coconut Institute, Tavilo, East New Britain Province, Papua New Guinea, pp. 216–231.

Khazanah Research Institute (2016) A Monograph of a Malaysian Cocoa Smallholder: Working Paper. Kuala Lumpur: Khazanah Research Institute. License: Creative Commons Attribution CC BY 3.0.

Khoury CK, Achicanoy HA, Bjorkman AD, 11 others and Struik PC (n.d.) Estimation of countries' interdependence in plant genetic resources provisioning national food supplies and production systems. International Treaty on Plant Genetic Resources for Food and Agriculture Research Study 8. http://www.fao.org/3/bq533e/bq533e.pdf

Kiesow S (2017) Cocoa culture on São Tomé and Príncipe: The rise and fall of cocoa on the islands in the nineteenth and twentieth centuries. Agricultural History 91(1): 55–77. https://www.jstor.org/stable/10.3098/ah.2017.091.1.55

Klooster W (2014) Curaçao as a Transit Center to the Spanish Main and the French West Indies. In Dutch Atlantic Connections, 1680-1800. Linking Empires, Bridging Borders. Eds, G.

Oostindie and JV Roitman. Brill. https://www.jstor.org/stable/10.1163/j.ctt1w8h3c9.7. Chapter doi 10.1163/9789004271319_003

Knapp AW (1920) Cocoa and chocolate. Their history from plantation to customer. London: Chapman and Hall, Ltd.

Koinyeneh GC (2021) Cocoa farmers to benefit from improved seedlings in Liberia. Front Page Africa. Last updated 13 April 2021. https://frontpageafricaonline.com/agric-matters/cocoa-farmers-to-benefit-from-improved-seedlings-in-liberia/. Accessed 15 August 2021.

Kolvalii S and Vigneri M (2017) Cocoa Coast. The board-managed cocoa sector in Ghana. International Food Policy Research Institute, Washington, DC. doi:10.2499/9780896292680

Krug CA, Quartey-Papafio E (1964) World cocoa survey, vol 63. Food and Agriculture Organisation of the United Nations, Rome

Lachenaud P (1993) Recent Cocoa Germplasm Conservation Initiatives of IRCC in French Guiana. In International Workshop on Conservation, Characterization and Utilization of Cocoa Genetic Resources in the 21st Century, pp. 253–255. Port-of-Spain, Trinidad: The Cocoa Research Unit, University of the West Indies.

Lachenaud P (2007) Ortet Selection in Cacao Progenies from the Kérindioutou River in French Guiana. Ingenic Newsletter, (11), 5–7.

Lachenaud P, Mooleedhar V and Couturier C (1997) Brief report on collection of wild cacao from the Euleupousing and Yaloupi rivers in French Guiana. INGENIC Newsletter, 3, 20–21.

Lachenaud P and Motamayor JC (2004) Red pods in progenies from the Euleupousing river in French Guiana. Ingenic Newsletter (9): 12–15. Retrieved from http://agritrop.cirad.fr/522481/

Lachenaud P and Motamayor JC (2017) The Criollo cacao tree (*Theobroma cacao* L.): a review. Genetic Resources and Crop Evolution 64(8): 1807–1820. DOI 10.1007/s10722-017-0563-8

Lachenaud P and Oliver G (2005) Variability and selection for morphological bean traits in wild cocoa trees (*Theobroma cacao* L.) from French Guiana. Genetic Resources and Crop Evolution 52: 225–231

Lachenaud P, Paulin D, Ducamp M and Thevenin JM (2007) Twenty years of agronomic evaluation of wild cocoa trees (*Theobroma cacao* L.) from French Guiana. Scientia Horticulturae 113(4): 313–321. https://doi.org/10.1016/j.scienta.2007.05.016

Lachenaud P, Rossi V, Thevenin JM and Doaré F (2015) The "Guiana" genetic group: A new source of resistance to cacao (*Theobroma cacao* L.) black pod rot caused by Phytophthora capsici. Crop Protection 67: 91–95. https://doi.org/10.1016/j.cropro.2014.09.015

Lachenaud Ph. and Sallée B (1993) Les cacaoyers spontanés de Guyane. Localisation, écologie et morphologie. Café Cacao Thé 37 (2): 101–114.

Lachenaud P, Sounigo O and Sallee B (2005) Wild cocoa trees in French Guiana: state of research. Acta Botanica Gallica 152 (3): 325–346.
https://www.researchgate.net/publication/297533344_Wild_cocoa_trees_in_French_Guiana_state_of_research

Lachenaud P and Zhang D (2008) Genetic diversity and population structure in wild stands of cacao trees (*Theobroma cacao* L.) in French Guiana. Ann For Sci 65:310–316

Lahive F, Hadley P and Daymond AJ (2019) The physiological responses of cacao to the environment and the implications for climate change resilience. A review. Agron. Sustain. Dev. 39, 22.

Lass RA and Wood GAR (1971) Cocoa in India. Cocoa Growers' Bulletin 17: 20–26.

Legg JT (1972) Measures to control spread of cocoa swollen shoot disease in Ghana. PANS Pest Articles & News Summaries 18(1): 57–60. DOI: 10.1080/09670877209413460

Lehmann S and Springer-Heinze A (2014) Value chain development for cocoa smallholders in Ecuador. In René A. Hernández, Jorge Mario Martínez and Nanno Mulder, "Global value chains and world trade: Prospects and challenges for Latin America", ECLAC Books, No. 127 (LC/G.2617-P), Santiago, Chile, Economic Commission for Latin America and the Caribbean (ECLAC), 2014.

Lerceteau E, Quiroz J, Soria J, Flipo S, Pétiard V and Crouzilat D (1997) Genetic differentiation among Ecuadorian *Theobroma cacao* L. accessions using DNA and morphological analyses. Euphytica 95: 77–87, 1997

Lewis J (2014) Demarquete African Queen, Catongo & Grandiflorum Chocolates. Mostly About Chocolate Blog 25 Nov 2014.
http://mostlyaboutchocolate.com/demarquete-africal-queen-catongo-grandiflorum-chocolates/

Li F, Qin X, Hao Ch, Yan L, Wu B and Lai J (2016) Genetic Diversity and Association Analysis of Cacao Germplasm Using SSR Markers[J]. Chinese Journal of Tropical Crops 37(2): 226–233. (In Chinese with English abstract)

Li F, Wu B, Wu G, Zhu Z, Qin X and Lai J (2021) Comparison experiment of six different cacao (*Theobroma cacao* L.) strains /varieties. Chinese Journal of Tropical Crops 42(6): 1625–1631. Doi:10.3969/j.issn.1000-2561.2021.06.017

Li F, Wu B, Qin X, Yan L and Lai J (2019) Preliminary evaluation on cold resistance of cacao germplasm resources and physiological response under low temperature stress. Chinese Journal of Tropical Crops 40(11): 2135–2141. (In Chinese with English abstract)

Lindell C (2020) “Global Cocoa and Chocolate Market Projected to Reach $67.22 Billion by the End of 2025.” Candy Industry. 2020. https://www.candyindustry.com/articles/89286-global-cocoa-and-chocolate-market-projected-to-reach-6722-billion-by-the-end-of-2025.

Lindo AA, Robinson DE, Tennant PF, Meinhardt LW and Zhang D (2018) Molecular characterization of cacao (*Theobroma cacao*) germplasm from Jamaica using single nucleotide polymorphism (SNP) markers. Tropical Plant Biology 11(3–4): 93–106. https://doi.org/10.1007/s12042-018-9203-5

Liogier A (1992) Las plantas introducidas en las Antillas después del descubrimiento y su impacto en la ecología. La Habana, Cuba: Jardín Botánico Nacional and Universidad Pinar del Río.

Liyanage M de S, Tejwani KG and Nair PKR (1984) Intercropping under coconuts in Sri Lanka. Agroforestry Systems 2: 215–228. Contribution No. 7 of the series on Agroforestry System Descriptions under ICRAF's AF Systems Inventory Project, funded partially by the United States Agency for International Development (USAID) (see Agroforestry Systems I(S), 269–272, 1983 for project details https://pdf.usaid.gov/pdf_docs/PNAAZ318.pdf

Lloyd J (2014) Champions for chocolate - smallholder cocoa farmers linked to high-end chocolate makers. PARDI Communications ACIAR, http://aciarblog.blogspot.com/2014/03/champions-for-chocolate-smallholder.html. Accessed 27 September 2021.

Lockwood G and End M (1993) History, technique and needs for future cacao collection. In: International workshop of conservation, characterization and utilization of cocoa genetic resources in the 21st century. Port-of-Spain, Trinidad, 13th –17th September 1992. pp. 1–14.

Lockwood G and Gyamfi MMO (1979) The CRIG Cocoa Germplasm Collection with notes on codes used in the breeding programme at Tafo and elsewhere. Technical Bulletin, No. 10, Cocoa Research Institute of Ghana.

Loh YJ (2021) Cacao is changing in southeast Asia. Whetstone Magazine, 9 June 2021, https://www.whetstonemagazine.com/journal/cacao-is-changing-in-southeast-asia

Loor RG, Risterucci AM, Courtois B, Fouet O, Jeanneau M, Rosenquist E, Amores F, Vasco A, Medina M and Lanaud C (2009) Tracing the native ancestors of the modern Theobroma cacao L. population in Ecuador. Tree Genetics and Genomes 5(3): 421–433. Doi: 10.1007/s11295-008-0196-3

Loor Solorzano RG, Fouet O, Lemainque A, Pavek S, Boccara M, Argout X, Amores F, Courtois B, Risterucci AM and Lanaud C (2012) Insight into the wild origin, migration and domestication history of the fine flavour Nacional *Theobroma cacao* L. variety from Ecuador. PLoS ONE 7(11): e48438. Doi: 10.1371/journal.pone.0048438

Loor Solorzano RG, Lachenaud P, Fouet O, Argout X, Pena G, Castro Macias J, Amores FM, Lanaud C, Valdez F and Hurtado J (2015) Rescue of cacao genetic resources related to the nacional variety: Surveys in the Ecuadorian Amazon (2010-2013). Revista ESPAMCiencia, 6(E): 7–15. https://hal.ird.fr/ird-01347309/file/ARTICLE%20cacao%20ESPAMCiencia.pdf

López M, Gori M, Bini L, Ordoñez E, Durán E, Gutierrez O, Masoni A, Giordani E, Biricolti S and Palchetti E (2021) Genetic purity of cacao Criollo from Honduras is revealed by SSR molecular markers. Agronomy 11(2): 225. https://doi.org/10.3390/agronomy11020225

Louis AA (2011) Les libres de couleur en Martinique des origines à 1815. L'entre-deux d'un groupe social dans la tourmente coloniale. PhD thesis, Université des Antilles et de la Guyane.

Lovett L (2017) Frenchman Setting the Bar for Myanmar Chocolate. The Irrawaddy, 7 July 2017. https://www.irrawaddy.com/specials/frenchman-setting-bar-myanmar-chocolate.html

Lukman, Zhang D, Susilo AW, Dinarti D, Bailey B, Mischke S and Meinhardt LW (2014) Genetic identity, ancestry and parentage in farmer selections of cacao from Aceh, Indonesia revealed by single nucleotide polymorphism (SNP) markers. Tropical Plant Biology 7(3–4): 133–143. https://doi.org/10.1007/s12042-014-9144-6

Luna F, Crouzillat D, Cirou L; Bucheli P (2002) Chemical composition and flavor of Ecuadorian cocoa liquor. Journal of Agricultural and Food Chemistry 50(12): 3527–3532. doi:10.1021/jf0116597

M & O Consulting S.A.C. (2008) Estudio de caracterización del potencial genético del cacao en el Peru. Informe Final "Proyecto de cooperación ue-Perú en materia de asistencia técnica relativa al comercio - apoyo al programa estratégico nacional exportaciones (penx 2003-2013)" Consultoría: 24/2007/pnrc/lote 2. Lima, Peru. https://www.midagri.gob.pe/portal/download/pdf/direccionesyoficinas/dgca/estudio_caracterizacion.pdf

Maciso FP (2019) Caracterización agronómica y morfológica de fruto y semilla de cuatro clones promisorios de cacao (Theobroma cacao L.), Kimbiri, Cusco. Ingeniero Agroforestal thesis, Universidad Nacional de San Cristóbal de Huamanga, Ayacucho – Perú

Maharaj K, Bekele FL, Ramnath D, Sankar RS, Bekele I, Bidaisee GG, Maharaj P and Jennings K (2019) Selection of putative relic cacao (*Theobroma cacao* L.) genotypes in farmers' fields in Trinidad and Tobago. Tropical Agriculture (Trinidad) 96(1): 1–14. https://doi.org/10.37234/ta96012019/00000960101

Maharaj K, Maharaj P, Bekele FL, Ramnath D, Bidaisee GG, Bekele I, Persad C, Jennings K and Sankar R (2011) Trinidad selected hybrids: An investigation of the phenotypic and agro-economic traits of 20 selected cacao cultivars. Tropical Agriculture (Trinidad) 88(4): 175–185.

Malhotra SK and Apshara SE (2017) Genetic resources of cocoa (*Theobroma cacao* L.) and their utilization - An Appraisal. Indian J. Genet., 77(2): 199–213. DOI: 10.5958/0975-6906.2017.00027.X

Malua MB (2003) SIDS and multilateral trade liberalisation in agriculture: The Pacific Islands. UNCTAD https://unctad.org/system/files/official-document/ditctncd20031p5_en.pdf

Marcano M, Pugh T, Cros E, Morales S, Portillo Páez EA, Courtois B, Glaszmann JC, Engels JMM, Phillips W, Astorga C, Risterucci AM, Fouet O, González V, Rosenberg K, Vallat I Dagert M and Lanaud C (2007) Adding value to cocoa (*Theobroma cacao* L.) germplasm information with domestication history and admixture mapping. Theor Appl Genet 114: 877–884. doi:10.1007/s00122-006-0486-9

Marcano de Segovia MJ (2007) Cartografía genética de factores del rendimiento y de caracteres morfológicos, en una población cultivada de cacao criollo "moderno" (*Theobroma cacao* L.), mediante un análisis de asociación. PhD thesis, Universidad de los Andes Postgrado en Ciencias Médicas Fundamentales.

Marita JM, Rodriguez JM and Nienhuis J (2000) Development of an algorithm identifying maximally diverse core collections. Genetic Resources and Crop Evolution 47(5): 515–526. https://doi.org/10.1023/A:1008784610962

Marfu J, Butubu J, Efron Y and Epaina P (2017a) Cocoa planting material: Clones, hybrid seedlings, budwood gardens and nursery management. In: Papua New Guinea Cocoa Extension Manual, Compiled by Philip Keane, edited by E. Tade, A. Nongkas, J. Saul-Maora, P. Gende, D. Yinil and J. Marfu. PNG Cocoa and Coconut Institute, Tavilo, East New Britain Province, Papua New Guinea, pp. 24–45.

Marfu J, Butubu J, Efron Y and Epaina P (2017b) New generation cocoa varieties in Papua New Guinea. In: Papua New Guinea Cocoa Extension Manual, Compiled by Philip Keane, edited by E. Tade, A. Nongkas, J. Saul-Maora, P. Gende, D. Yinil and J. Marfu. PNG Cocoa and Coconut Institute, Tavilo, East New Britain Province, Papua New Guinea, pp. 232–250.

Martin MPLD (1987) Cocoa in Fiji. Cocoa Growers Bulletin 38: 23–27.

Mata-Quirós A, Arciniegas-Leal A, Phillips-Mora W, Meinhardt LW, Motilal L, Mischke S, and Zhang D (2018) Assessing hidden parentage and genetic integrity of the "United Fruit Clones" of cacao (*Theobroma cacao*) from Costa Rica using SNP markers. Breeding Science 68(5): 545–553. https://doi.org/10.1270/jsbbs.18057

Mawardi S, Winarno H, and Suhendy D (1995) The present status of cacao breeding at ICCRI: results and future programmes. In: Proceedings of the International Workshop on Cocoa Breeding Strategies, Kuala Lampur, 1994. INGENIC, Reading, UK, pp. 81–87.

McCormick E (2018) Hopes for a Cambodia cocoa province. Khmer Times. June 22, 2018. https://www.khmertimeskh.com/503421/hopes-for-a-cambodia-cocoa-province/

McGregor A (2006) Solomon Islands smallholder agriculture study, vol 3 Markets and Marketing Issues. Canberra, Australia: AusAid, Commonwealth of Australia. https://www.dfat.gov.au/sites/default/files/solomon_study_vol3.pdf. Accessed 8 February 2021

McGregor A, Watas PC, and Tora L (2009) The Vanuatu Organic Cocoa Growers Association (VOCGA): A Case Study of Agricultural Growth in the Pacific. http://www.fao.org/3/am013e/am013e00.pdf. Accessed 8 February 2021.

McMahon PJ, Susilo AW, Parawansa AK, Bryceson SR, Nurlaila, Mulia S, Saftar A, Purwantara A, bin Purung H, Lambert S, Guest DI and Keane PJ (2018) Testing local cacao selections in Sulawesi for resistance to vascular streak dieback. Crop Protection 109: 24–32. https://doi.org/10.1016/j.cropro.2018.02.026

McNeil CL (2009) Chocolate in Mesoamerica: A Cultural History of Cacao Univ. Press of Florida, Gainesville.

Mejia A, Meza G, Espichan F, Mogrovejo J and Rojas R (2020) Chemical and sensory profiles of Peruvian native cocoas and chocolates from the Bagua and Quillabamba regions. Food Sci. Technol. 41: 576–582. doi: 10.1590/fst.08020

Mejíaa RA, Ruizb C, Portalesb R and Rojasa R (2018) Quality profile of Peruvian dark chocolate: A preliminary approach. Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru. https://www.icco.org/wp-content/uploads/T5.111.-QUALITY-PROFILE-OF-PERUVIAN-DARK-CHOCOLATE-A-PRELIMINARY-APPROACH.pdf

Menezes AGT, Batista NN, Ramos CL, Silva ARA, Efraim P, Pinheiro ACM and Schwan RF (2016) Investigation of chocolate produced from four different Brazilian varieties of cocoa (Theobroma cacao L.) inoculated with Saccharomyces cerevisiae. Food Research International, 81: 83–90. doi:10.1016/j.foodres.2015.12.036

Mfeck Eyenga LB, Kamdem CB, Temple L and Mathe S (2017) Rendements et mécanismes d'adoption du matériel végétal amélioré: le cacao au centre-Cameroun. Tropicultura, 35(2): 110–120.

Michel I, Carrière S-M, Manga Essouma F, Bihina MA, Blanchet A, Moisy C, Ngono F and Levang P (2019) Les cacaoyères agroforestières au Centre et au Sud du Cameroun: diversité et dynamique. In Agroforesterie et services écosystémiques en zone tropicale : Recherche de compromis entre services d'approvisionnement et autres services écosystémiques. Josiane Seghieri and Jean-Michel Harmand (eds.), First edition, Versailles : Éditions Quæ, pp. 85-98. Online http://books.openedition.org/quae/38580 Accessed 1st September 2021.

Ministry of Agriculture (2012) National Cocoa Development Strategy: The Case for Optimizing Farmer Income from Cocoa Production In Liberia. Ministry of Agriculture, Monrovia, Liberia. https://ekmsliberia.info/wp-content/uploads/2019/11/NCDS_Final_2012.doc

Monteiro WR, Lopes UV and Clement D (2009) Genetic improvement in cocoa. In Breeding Plantation Tree Crops: Tropical Species (pp. 589–626). Springer New York. https://doi.org/10.1007/978-0-387-71201-7_16

Mooleedhar V (1997) A study of the morphological variation in a relic Criollo cacao population from Belize. Report for 1997. pp 5-13. Cocoa Research Centre, The University of the West Indies, St. Augustine, Trinidad and Tobago.

Mooleedhar V (1999) The Criollo germplasm of Belize – a significant addition to the conserved cocoa germplasm. In Proc. 12th Intl Cocoa Res. Conf., 17–23 November 1996, Salvador, Bahia, Brésil. Malaysia: COPAL. pp 459–462.

Mooleedhar V, Maharaj W and O'Brien H (1995) The collection of Criollo cocoa germplasm in Belize. Cocoa Growers' Bulletin 49: 26–40.

Moreira IMV (2017) Analytical study of cocoa beans and characterization of chocolates of different cocoa hybrids during the spontaneous and inoculated fermentation processes. PhD thesis, Universidade Federal de Lavras. http://repositorio.ufla.br/bitstream/1/28260/2/TESE_Analytical%20study%20of%20cocoa%20beans%20and%20characterization%20of%20chocolates%20of%20different%20cocoa%20hybrids%20during%20the%20spontaneous%20and%20inoculated%20fermentation%20processes.pdf

Moriarty K, Elchinger M, Hill G, Katz J, and Barnett J (2014) Cacao intensification in Sulawesi: A Green Prosperity Model project. Work for Others Report NREL/TP-5400-62434, September 2014. https://www.nrel.gov/docs/fy14osti/62434.pdf

Morillo C. Y, Morillo C. AC, Muñoz F. JE, Ballesteros P. W and González A (2014) Caracterización molecular con microsatélites amplificados al azar (RAMs) de 93 genotipos de cacao (*Theobroma cacao* L.). Agronomía Colombiana, 32(3), 315–325. https://doi.org/10.15446/agron.colomb.v32n3.46879

Motamayor JC and Lanaud C (2003) Molecular analysis of the origin and domestication of *Theobroma cacao* L. Crop Science 43(2): 749–50. https://doi.org/10.2135/cropsci2003.749a.

Motamayor JC, Lachenaud P, da Silva e Mota, J, Loor R, Kuhn DN, Brown JS and Schnell RJ (2008) Geographic and genetic population differentiation of the Amazonian chocolate tree (Theobroma cacao L). PLoS ONE 3(10): 1–8. https://doi.org/10.1371/journal.pone.0003311

Motamayor JC, Risterucci AM, Heath M and Lanaud C (2003) Cacao domestication II: Progenitor germplasm of the Trinitario cacao cultivar. Heredity 91(3): 322–330. https://doi.org/10.1038/sj.hdy.6800298

Motamayor JC, Risterucci AM, Lopez PA, Ortiz CF, Moreno A and Lanaud C (2002) Cacao domestication I: The origin of the cacao cultivated by the Mayas. Heredity 89(5): 380–386. https://doi.org/10.1038/sj.hdy.6800156

Motilal LA (2018) The role of gene banks in preserving the genetic diversity of cacao. In Achieving sustainable cultivation of cocoa – Volume 1 Genetics, Breeding, Cultivation and Quality, ed. Prof. P Umaharan, Chapter 3, pp. 47–99, Cambridge, UK: Burleigh Dodds Science Publishing Limited. doi:10.19103/AS.2018.0021.03

Motilal LA and Sreenivasan TN (2012) Revisiting 1727: Crop Failure Leads to the Birth of Trinitario Cacao. Journal of Crop Improvement, 26(5), 599–626. https://doi.org/10.1080/15427528.2012.663734

Motilal LA, Zhang D, Umaharan P, Mischke S, Mooleedhar V and Meinhardt LW (2010) The relic Criollo cacao in Belize - Genetic diversity and relationship with Trinitario and other cacao clones held in the International Cocoa Genebank, Trinidad. Plant Genetic Resources: Characterisation and Utilisation 8(2): 106–115. https://doi.org/10.1017/S1479262109990232

Motilal LA, Zhang D, Umaharan P, Boccara M, Mischke S, Sankar A and Meinhardt LW (2012) Elucidation of genetic identity and population structure of cacao germplasm within an international cacao genebank. Plant Genetic Resources: Characterization and Utilization 10(3): 232–241. doi:10.1017/S1479262112000305.

Muhs DR, Kautz RR and MacKinnon JJ (1985) Soils and the location of cacao orchards at a Maya site in western Belize. J. Archaeol. Sci. 12: 121–137.

Myers JG (1930) Notes on wild cacao in Surinam and British Guiana. Bulletin of Miscellaneous Information 1, Royal Botanic Gardens, Kew, pp. 1–10. doi:10.2307/4107595

Nagai C (2019) Cacao varieties in Hawaii. HARC Fine Cacao Field Day September 21, 2019; Maunawili Breeding Station, Oahu. http://www.harc-hspa.com/uploads/2/6/1/7/26170270/harc_cacao_field_day_2019.pdf. Accessed 7 November 2021.

Nagai C, Heinig R, Olano CT, Motamayor JC and Schnell RJ (2009) Fingerprinting of cacao germplasm in Hawaii. Hawaii Agriculture Research Center. Cacao Report No. 1. September 2009, 14pp.

National Organization Committee, Trinidad and Tobago (2019) Inaugural National Cocoa Awards Ceremony 2019. https://exportt.co.tt/wp-content/uploads/2019/02/National-Cocoa-Awards-BookletFAW-002.pdf

N'Goran JAK, Lachenaud PH, Bastide PH, and Paulin D (1993) Cocoa germplasm conservation initiatives in Côte d'Ivoire. In Proceedings International Workshop on Conservation, Characterization, and Utilization of Cocoa Genetic Resources in the 21st Century, 13–17 September 1992, Port of Spain, Trinidad. pp. 221-227.

Newson LA (1976) Aboriginal and Spanish Colonial Trinidad: A study in culture contact. London: Academic Press.

Nieburg O (2017, July 20) Cocoa in the Congo: emerging origin for organic chocolate maker. Confectionary news. Retrieved June 10, 2021, from https://www.confectionerynews.com/Article/2017/07/20/Cocoa-in-the-Congo-Emerging-origin-for-organic-chocolate-makers

Nielson J (2007) Global markets, farmers and the state: Sustaining profits in the Indonesian cocoa sector. Bulletin of Indonesian Economic Studies 43(2): 227–250. DOI: 10.1080/00074910701408073

Nieves-Orduña HE, Müller M, Krutovsky KV, Gailing O (2021) Geographic patterns of genetic variation among cacao (*Theobroma cacao* L.) populations based on chloroplast markers. Diversity 13: 249, 17pp. https://doi.org/10.3390/d13060249

Northern Territory Government of Australia (2021) Cocoa. https://nt.gov.au/environment/home-gardens/growing-vegetables-at-home/cocoa. Last updated 26 February 2016

Nosti Nava J (1970) Café y cacao. La Habana, Cuba: Edición Revolucionaria

Nottelmann S, Bisping B, Kadow D, Krabbe Ch., Krähmer A, Rohn S, Rudolph B, Tietz F, Zug K, Sobotta F, Wallbrunn Cv and Riehn K (2018) Sensory and GC-O analyses of cocoa and chocolate along the cocoa production chain. Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru. https://www.icco.org/wp-content/uploads/T5.197.SENSORY-AND-GC-O-ANALYSES-OF-COCOA-AND-CHOCOLATE-ALONG-THE-COCOA-PRODUCTION-CHAIN.pdf

Nuala Lara AL (2016) Caracterización morfológica en la adaptabilidad de tres clones de cacao (Theobroma cacao L.), en el CIPCA provincia de Napo, Ecuador. Escuela de Ingeniería Agropecuaria, Universidad Estatal Amazonica, Pastaza - Ecuador.

Núñez González N (2010) El cacao y el chocolate en Cuba. La Habana, Cuba: Instituto Cubano de Antropología. Fundación Fernando Ortiz.

Nya Ngatchou J (1981). Etat d'avancement des travaux de génétique et d'amélioration du cacaoyer au Cameroun. Proc. 7th International Cocoa Research Conference, 5-12 November 1979, Douala, Cameroon. pp. 507–511.

Olatoye ST and Esan EB (1993) Recent Innovation in cacao genetic resources conservation in Nigeria. In Proceedings International Workshop on Conservation, Characterization, and Utilization of Cacao Genetic Resources in the 21st Century, 13–17th September, 1992, Port of Spain, Trinidad. pp. 281–291.

Oliva M and Maicelo Quintana JL (2020) Identification and selection of ecotypes of fine native cocoa aroma from the north-eastern zone of Peru. Rev. Investig. Agroproducción Sustentable 4: 31–39. doi: 10.25127/aps.20202.556

Oliva Cruz SM (2020) Caracterización socioeconómica de la diversidad biológica de cacao Criollo fino de aroma en comunidades rurales de la región Amazonas. PhD thesis, Universidad Nacional Toribio Rodríguez De Mendoza De Amazonas, Chachapoyas-Perú. http://repositorio.untrm.edu.pe/handle/UNTRM/2211

Ofori A, Padi FK, Ameyaw GA, Dadzie AM and Lowor ST (2015) Genetic variation among cacao (*Theobroma cacao* L.) progenies for resistance to cacao swollen shoot virus disease in relation to total phenolic content. Plant Breeding 134: 477–484. https://doi.org/10.1111/pbr.12282

Ofori A, Padi FK and Amoako-Attah I (2020) Field evaluation of cacao progenies derived from Guiana clones for yield and black pod disease resistance. Crop Science 60(1): 249–261. https://doi.org/10.1002/csc2.20101

Ogata N (2002) Studies of Mesoamerican tropical trees: Trees of the Maya region and a case study on the ethnobotany and phylogeography of cacao (*Theobroma cacao* L.). ProQuest Dissertations and Theses. University of California, Riverside. Retrieved from http://search.proquest.com/docview/276317540?accountid=47173%5Cnhttp://uf2mu7dg8q.search.serialssolutions.com/?ctx_ver=Z39.88-2004&ctx_enc=info:ofi/enc:UTF-8&rfr_id=info:sid/ProQuest+Dissertations+%26+Theses+Global&rft_val_fmt=info:ofi/fmt:kev:mtx:dissert

Olasupo FO, Aikpokpodion PO (2019) Cacao genetic resources conservation and utilization for sustainable production in Nigeria. doi: http://dx.doi.org/10.5772/intechopen.82703

Olasupo FO, Adewale DB, Aikpokpodion PO, Muyiwa AA, Bhattacharjee R, Gutierrez OA, Motamayor JC, Schnell RJ, Ebai S and Zhang D (2018) Genetic identity and diversity of Nigerian cacao genebank collections verified by single nucleotide polymorphisms (SNPs): a guide to field genebank management and utilization. Tree Genetics and Genomes 14(2): 16p. https://doi.org/10.1007/s11295-018-1244-2.

Onumah JA, Onumah EE, Al-Hassan RM, and Brümmer B (2013) Meta-frontier analysis of organic and conventional cocoa production in Ghana. Agric. Econ. Czech 59(6): 271–280.

Opeke LK (1972a) Cacao breeding in Nigeria during the 1960-69 decade. In Proc. 4th Intl. Cocoa Res. Conf., 8–18 January 1972, St. Augustine, Trinidad, Government of Trinidad and Tobago, West Indies. pp. 25–31.

Opeke LK (1972b) The Trinidad-Nigeria cacao introduction programme 1962-70. In Proc. 4th Intl. Cocoa Res. Conf., 8–18 January 1972, St. Augustine, Trinidad, Government of Trinidad and Tobago, West Indies. pp. 32–37.

Opoku SY, Bhattacharjee R, Kolesnikova-Allen M, Motamayor JC, Schnell R, Ingelbrecht I, Enu-Kwesi L and Adu-Ampomah Y (2007) Genetic diversity in cocoa (*Theobroma cacao* L.) germplasm collection from Ghana. Journal of Crop Improvement 20(1–2): 73–87. https://doi.org/10.1300/J411v20n01_04

Ortiz JAC, Dominiguez MA and Valerio RR (1981) Situacion del cultivo del cacao de la Republica Dominicana. In Proc. 7th Intl. Cocoa Res. Conf., 5–12 November 1979, Douala, Cameroun. pp. 685-689.

Osorio-Guarín JA, Berdugo-Cely J, Coronado RA, Zapata YP, Quintero C, Gallego-Sánchez G and Yockteng R (2017) Colombia a source of cacao genetic diversity as revealed by the population structure analysis of germplasm bank of *Theobroma cacao* L. Frontiers in Plant Science, 8(November). https://doi.org/10.3389/fpls.2017.01994

Ottley CR (1955) An account of life in Spanish Trinidad (from 1498–1797) with a chronological table of events (from 1498–1955) and sundry appendices. Port of Prince, Trinidad: College Press.

Ozturk G and Young GM (2017) Food Evolution: The Impact of Society and Science on the Fermentation of Cocoa Beans. Comprehensive Reviews in Food Science and Food Safety 16: 431–455

Paulin D, Ducamp M and Lachenaud P (2008) New sources of resistance to *Phytophthora megakarya* identified in wild cocoa tree populations of French Guiana. Crop Protection 27(7): 1143–1147. doi:10.1016/j.cropro.2008.01.004

Pellegrin F and Nandris D (1991) Compte rendu de mission: Fidji, Vanuatu, Papouasie Nouvelle Guinée, Salomon (du 4 au 28 septembre 1991). Rapports de Missions Sciences de la Vie, Phytopathologie, No 1, 1991. ORSTOM.

Peter PK and Chandramohanan R (2011) Occurrence and distribution of cocoa (Theobroma cocoa L.) diseases in India. J.Res. Ang Rau 39(4): 44–50, 2011

Petithuguenin P (2000) The situation of cocoa production in Uganda. First consultancy progress report for the ADC/IDEA project. CIRAD, France

Petithuguenin P and Roche G (1995) Equateur: la fili`ere cacao, bilan et perspectives. Plantations, Recherche, Développement 2 (4): 15–21.

Petitjean Roget J and Bruneau-Latouche E (1983) Personnes et familles a la Martinique au XVII° siècle. D'après recensements et terrier nominatifs. Tome 1. Documents. Societe d'Histoire de la Martinique. Fort de France.

PHAMA (Pacific Horticultural & Agricultural Market Access Program) (n.d.) Pacific Cocoa Export Industry Overview. https://phamaplus.com.au/wp-content/uploads/2016/05/Cocoa_FS_Overview6.pdf. Accessed 12 June 2021.

Phillips T (2020a) Amazon deforestation surges to 12-year high under Bolsonaro. The Guardian Mon 30 November 2020 https://www.theguardian.com/environment/2020/dec/01/amazon-deforestation-surges-to-12-year-high-under-bolsonaro

Phillips T (2020b) Cacao not gold: 'chocolate trees' offer future to Amazon tribes. The Guardian Sat 25 January 2020 https://www.theguardian.com/environment/2020/jan/25/cacao-not-gold-chocolate-trees-offer-future-to-amazon-tribes-aoe

Piankarn C, Liamkaew R, Chaisu K and Chiu C-H (2021) Fermentation profile of Thai cocoa beans. The 4th PIM International Conference March 3, 2021. https://conference.pim.ac.th/zh/wp-content/uploads/2021/03/A-Agriculture.pdf

Pontie G (1992) Une operation de developpement café-cacao au Togo: essai d'évaluation. In: Robineau Claude (ed.), Penouil M. (pref.). Les terrains du développement : approche pluridisciplinaire des économies du Sud. Paris : ORSTOM, p. 197–220. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/divers07/37489.pdf

Posnette AF (1943) Cacao selection on the Gold Coast. Trop Agric Trin 20: 149:155.

Posnette AF (1948) New Introductions. Quarterly Report of the West African Cocoa Research Institute, October–December, 12.

Posnette AF & Todd JMcA (1951) Virus diseases of cacao in West Africa. VIII. The search for virus-resistant cacao. Annals Applied Biology 38: 785-800.

Pound FJ (1933) Criteria and methods of selection in cacao. In Second Annual Report on Cacao Research 1932, pp, 27–29. Port-of-Spain, Trinidad: Government Printing Office.

Pound FJ (1935) The progress of selection 1934. In Fourth Annual Report on Cacao Research 1934, pp. 7–11. Port-of-Spain, Trinidad: Government Printing Office.

Pound FJ (1936) The completion of selection 1935. In Fifth Annual Report on Cacao Research 1935, pp. 7–16. Port-of-Spain, Trinidad: Government Printing Office.

Pound FJ (1938) Cacao and witches' broom disease (*Marasmius perniciosus*) of South America with notes on other species of *Theobroma*: report on a visit to Ecuador, the Amazon valley and Colombia April 1937–April 1938. Yuille's Printery, Port of Spain, Trinidad and Tobago.

Pound FJ (1943) Cacao and witches' broom disease (*Marasmius perniciosa*). Report on a recent visit to the Amazon territory of Peru, September 1942–February 1943. Yuille's Printery, Port of Spain, Trinidad and Tobago

Powis TG, Cyphers A, Gaikwad NW, Grivetti L and Cheong K (2011) Cacao use and the San Lorenzo Olmec. Proc. Natl. Acad. Sci. USA 108: 8595–8600.

Powis TG, Valdez F, Hester TR, Hurst WJ and Tarka SM (2002) Spouted vessels and cacao use among the Preclassic Maya. Lat. Am. Antiq. 13: 85–106.
Powis TG, Hurst WJ, del Carmen Rodríguez M, Ortíz Ceballos P, Blake M, Cheetham D, Coe MD and Hodgson JG (2007) Oldest chocolate in the New World. Antiquity [online]. 81 (314), pp. http://www.antiquity.ac.uk/ProjGall/powis/index.ht. Available from: http://www.antiquity.ac.uk/ProjGall/powis/index.html.

Powis TG, Hurst J, Rodríguez MC, Ponciano OC, Blake M, Cheetha D, Coe MD and Hodsgson JG (2008) The origins of cacao use in Mesoamerica. Mexicon 30: 35–38. Available from http://www.jstor.org/stable/23759545

Presilla ME (2009) The new taste of chocolate. A cultural and natural history of cacao with recipes. USA: Ten Speed Press.

Preuss P (1901) Expedition nach central und Sudamerika 1899/900. Verlag des Kolonial-Wirtschaftlichen Komitees, Berlin. Accessed 18 August 2021, https://ia801205.us.archive.org/6/items/b24870547/b24870547.pdf

Prothero GW (1920) ed. New Hebrides. Handbooks prepared under the direction of the Historical Section of the Foreign Office – No. 147. London: HM Stationery Office. https://dl.wdl.org/11943/service/11943.pdf. Accessed 14 June 2021.

Purseglove JW (1968) Tropical crops: Dicotyledons. London: Longman Group.

Qin X, Hao C, Wu G, Li F and Lai J (2014) Advances on Germplasm Research and Utilization of *Theobroma cacao* L.[J]. Chinese Journal of Tropical Crops 35(1): 188–194. (In Chinese with English abstract)

Quesnel VC (1967) A short history of cacao and chocolate. 1. Historical. J. Agric. Soc. Trinidad and Tobago 67(1): 19–24.

Quintero R, ML and García L, LN (2010) La producción de cacao en Venezuela: Hacia una nueva ruralidad Actualidad Contable FACES Año 13 Nº 20, Enero – Junio 2010. Mérida. Venezuela (114–123)

Radio New Zealand (2016) French chocolatier buys Vanuatu cocoa plantation. 29 Dec 2016. https://www.rnz.co.nz/international/pacific-news/321418/french-chocolatier-buys-vanuatu-cocoa-plantation

Rahman AAA (1990) The cocoa industry in Malaysia, Kiel Working Papers, No. 449. https://www.econstor.eu/bitstream/10419/46857/1/256316090.pdf
Accessed 29 August 2021

Rahmat M, Fisal A and Noor Faridzah D (2018) Sensory and flavor profile of Malaysian and Ghanian fermented cocoa beans. Malaysian Cocoa Journal 10: 100–106.

Ramírez C de, Ramis C and Gómez C (2011) Descripción morfológica de frutos y semillas del cacao Criollo Porcelana (*Theobroma cacao* L.) en el Sur del Lago de Maracaibo. Rev. Fac. Agron. (LUZ). 2011, 28 Supl. 1: 1-13

Ramírez Méndez LA (2015) El cultivo del cacao venezolano a partir de Maruma. Historia Caribe 10(27): 69–101. DOI: http://dx.doi.org/10.15648/hc.27.2015.3

Ramírez Sulvarán JA, Sigarroa Rieche AK and Del Valle Vargas RA (2014) Characterization of Cocoa (*Theobroma cacao* L.) Farming systems in the Norte de Santander Department and assessment of their sustainability. Rev. Fac. Nal. Agr. Medellín 67(1):7177–7187.

Ramos G, González N, Zambrano A and Gómez A (2013) Olores y sabores de cacaos (*Theobroma cacao* L.) venezolanos obtenidos usando un panel de catación entrenado. Revista Científica UDO Agrícola 13(1): 114–127.

Ramos Ospino A, Gómez Alvaréz M, Machado-Sierra E and Aranguren Y (2020) Caracterización fenotípica y genotípica de cultivares de cacao (*Theobroma cacao* L.) de Dibulla, La Guajira, Colombia [Phenotypic and genotypic characterization of cacao cultivars (*Theobroma cacao* L.) from Dibulla, La Guajira, Colombia. Ciencia & Tecnología Agropecuaria 21(3): 1–17. Retrieved from http://revistacta.agrosavia.co/index.php/revista/article/view/1557

Restrepo JPG, Leiva-Rojas EI and Ramírez Pisco R (2017) Phenology of cocoa tree in a tropical moist forest. Científica 45(3): 240–252. http://dx.doi.org/10.15361/1984-5529.2017v45n3p240-252

Reyes H (1993) Criollo cacao germplasm in Venezuela. In Proceedings International Workshop on Conservation, Characterization, and Utilization of Cacao Genetic Resources in the 21st Century, 13–17 September, 1992, Port of Spain, Trinidad. pp 244–252.

Richard A and Ræbild A (2016) Tree diversity and canopy cover in cocoa systems in Ghana. New Forests 47: 287–302. doi: 10.1007/s11056-015-9515-3

Richardson JE, Whitlock BA, Meerow AW, and Madriñán S (2015) The age of chocolate: a diversification history of *Theobroma* and Malvaceae. Front. Ecol. Evol., 3 doi:10.3389/fevo.2015.00120

Rodríguez J (1924) El Cacao, manual del agricultor en Fernando Poo. Barcelona, España: Artes Gráficas S. A.

Rodriguez-Medina C, Arana AC, Sounigo O, Argout X, Alvarado GA and Yockteng R (2019) Cacao breeding in Colombia, past, present and future. Breeding Science 69(3): 373–382. https://doi.org/10.1270/jsbbs.19011

Rolim SG and Chiarello AG (2004) Slow death of Atlantic forest trees in cocoa agroforestry in southeastern Brazil. Biodiversity and Conservation 13: 2679–2694.

Romina Villegas P and Carlos Astorga D (2005) Caracterización morfológica del cacao Nacional Boliviano, Alto Beni, Bolivia. Agroforestería en las Américas 43–44:81–85. https://digital.csic.es/handle/10261/89598

Rondon Carvajal JG (1993) International Workshop on Conservation, Characterization and Utilization of Cocoa Genetic Resources in the 21 Century. In Cocoa Genetic Resources in Colombia (pp. 269–278). Port-of-Spain, Trinidad: The Cocoa Research Unit, University of the West Indies.

Rottiers H, Everaert H, Boeckx P, Limba G, Baert G, De Wever J. Maebe K, Smagghe G, Dewettnick K and Messens K (2018) Unraveling the genetic background of the Yangambi Research Center cacao germplasm collection, DR Congo. Tree Genetics and Genomes 14: 68. https://doi.org/10.1007/s11295-018-1285-6

Rottiers H, Tzompa Sosa DA, Lemarcq V, De Winne A, De Wever J, Everaert H, Jaime JAB, Dewettinck K and Messens K (2019) A multipronged flavor comparison of Ecuadorian CCN51 and Nacional cocoa cultivars. European Food Research and Technology 245(11): 2459–2478. Doi: 10.1007/s00217-019-03364-3

Roussel M (1967) Bilan des travaux de selection et d'melioration du cacaoyer a Madagascar. In Proc. 2nd Intl. Cocoa Res. Conf., 19–26 November 1967, Salvador et Itabuna, Bahia, Brésil. Bahia, Brasil: CEPLAC, pp. 81-84.

Rubiyo, Izzah NK, Sulistiyorini I, and Tresniawati C (2015) Evaluation Of Genetic Diversity In Cacao Collected From Kolaka, Southeast Sulawesi, Using SSR Markers. [Evaluasi Keragaman Genetik Koleksi Kakao dari Kolaka, Sulawesi Tenggara, dengan Menggunakan Marka SSR]. Indonesian Journal Agricultural Science 16(2): 71–78.

Ruf F (1991) Les crises cacaoyères. La malédiction des âges d'or? In: Cahiers d'études Africaines 31(121–122) La Malédiction. pp. 83–134. doi : https://doi.org/10.3406/cea.1991.2110

Ruf F, Ehret P and Yoddang (1996) Smallholder Cocoa in Indonesia: Why a Cocoa Boom in Sulawesi? In Cocoa Pioneer Fronts since 1800: the role of smallholders, planters, and merchants, W. G. Clarence-Smith (ed.), Palgrave Macmillan UK. pp. 212–231.

Ruiz Abreu CE (2016) El cacao de Tabasco en la Nueva España: producción, comercio y mercados. In Cacao: producción, consumo y comercio. del período prehispánico a la actualidad en América Latina, LC Barrera (ed.), Frankfurt a. M., Madrid: Vervuert Verlagsgesellschaft. https://doi.org/10.31819/9783954878505-006

Ruiz JC, Roa Gamboa O and Marin Arguello I (2011) Molecular ecology of genetic diversity of cacao cultivated in the south-east region of Nicaragua. International Research Journal of Agricultural Science 1(1): 6–13.

Saatchi S, Agosti D, Alger K, Delabie J and Musinsky J (2001) Examining fragmentation and loss of primary forest in the Southern Bahian Atlantic Forest of Brazil with radar imagery. Conservation Biology 15(4): 867–875.

Saavedra-Arbildo RP, Cárdenas-Salazar H, Márquez-Dávila KJ, Beraun-Cruz Y, Carranza-Cruz MS, Hurtado-Gonzales OP and Chia-Wong JA (2018) Colecta y estudio de las caracteristicas morfologicas y organolepticas en fruta fresca y licor de arboles de cacao (*Theobroma cacao* L.) con atributos de poseer caracteristicas de fino y de aroma. Proceedings of the International Symposium on Cocoa Research (ISCR), Lima, Peru, 13-17 November 2017. https://www.icco.org/wp-content/uploads/T5.232.-COLECTA-Y-ESTUDIO-DE-LAS-CARACTERISTICAS-MORFOLOGICAS-Y-ORGANOLEPTICAS-EN-FRUTA-FRESCA-Y-LICOR-DE-ARBOLES-DE-CACAO-THEOBROMA-CACAO.pdf

Sabatier D and Prévost M-F (1987) Une forêt à cacaoyer sauvages sur le Haut-Campoi, en Guyane Française. Centre ORSTOM de Cayenne. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_5/b_fdi_01/010004354.pdf. Accessed 13 October 2021.

Sagra y Peris R de la (1842) Historia fisica, politica y natural de la isla de Cuba. Primera parte. Historia fisica y politica. Tomo I. Introduccion, geografia, clima, poblacion y agricultura. Paris: En la Libreria de Arthus Bertrand, librero de la Sociedad de Geografia https://bibdigital.rjb.csic.es/idurl/1/9824 https://bibdigital.rjb.csic.es/medias/d9/2d/80/64/d92d8064-c1ce-4fc3-bde4-63779d564d4f/files/385.pdf. Accessed 13 October 2021.

Sagra y Peris R de la (1845) Historia fisica, politica y natural de la isla de Cuba. Segunda parte. Historia natural. Tomo X. Botanica. Paris: En la Libreria de Arthus Bertrand, librero de la Sociedad de Geografia. https://bibdigital.rjb.csic.es/idurl/1/9833 https://bibdigital.rjb.csic.es/medias/9b/6e/35/f5/9b6e35f5-0da0-401f-9a6b-9066f27c0d8c/files/SAG_Hist_10.pdf. Accessed 13 October 2021.

Sainovski S (n.d.) The sweet taste of success in Vanuatu. https://www.worldvision.org.nz/the-sweet-taste-of-success-in-vanuatu/. Accessed 27 September 2021

Sainovski S (2017) Cocoa beans produced in Vanuatu by World Vision-trained farmer among top 50 in the world. Sunday August 27, 2017. https://www.wvi.org/pressrelease/cocoa-beans-produced-vanuatu-world-vision-trained-farmer-among-top-50-world. Accessed 27 September 2021.

Sánchez I, Zárate LA, Gallego G and Tohme J (2007) Análisis de la diversidad genética de accesiones de *Theobroma cacao* L. del banco de conservación a cargo de Corpoica. Revista Corpoica – Ciencia y Tecnología Agropecuaria 8(2): 26–31.

Sánchez P, Jaffé K and Muller MC (1989) El género Theobroma en el Territorio Federal Amazonas (Venezuela). I. Notas etnobotánicas y consideraciones agronómicas. Turrialba 39(4): 440–446.

Sánchez PA and Jaffé K (1989) El género Theobroma en el Territorio Federal Amazonas (Venezuela). II. Distribución Geográfica. Turrialba 39(4): 446–454.

Sankar AA, Motilal LA, Zhang D and Umaharan P (2018) genetic diversity and genetic structure of wild cacao collected in the Oriente using single nucleotide polymorphisms. Proceedings of the International Symposium on Cocoa Research. November 13–17, 2017, Cusco, Peru. https://www.icco.org/?media_dl=3799

Santos ESL, Cerqueira-Silva CBM, Mori GM, Ahnert D, Mello DLN, Pires JL, Corrêa RX and de Souza AP (2015) Genetic structure and molecular diversity of cacao plants established as local varieties for more than two centuries: the genetic history of cacao plantations in Bahia, Brazil. PLoS ONE 10(12): e0145276. https://doi.org/10.1371/journal.pone.0145276

Schnell RJ, Olano CT, Brown JS, Meerow AW, Cervantes-Martinez C, Nagai C and Motamayor JC (2005) Retrospective determination of the parental population of superior cacao (*Theobroma cacao* L.) seedlings and association of microsatellite alleles with productivity. J. Amer. Soc. Hort. Sci. 130(2): 181–190.

Schroth G, Läderach P, Martinez-Valle AI, Christian Bunn C and Jassogne L (2016) Vulnerability to climate change of cocoa inWest Africa: Patterns, opportunities and limits to adaptation. Sci. Total Environ. 556: 231–241. https://doi.org/10.1016/j.scitotenv.2016.03.024

Sereno ML, Albuquerque PSB, Vencovsky R and Figueira A (2006) Genetic diversity and natural population structure of cacao (*Theobroma cacao* L.) from the Brazilian Amazon evaluated by microsatellite markers. Conservation Genetics 7:13–24. DOI 10.1007/s10592-005-7568-0

Servicio de Información Agroalimentaria y Pesquera (2019) Cacao, orgullo mexicano. https://www.gob.mx/siap/articulos/cacao-orgullo-mexicano

Shephard CY (1932) The cacao industry of Trinidad. Some economic aspects. Part III: History of the industry up to 1870. Port of Spain, Trinidad: Government Printing Office.

Shimabukuro B (2005) Chocolate dreams. Star Bulletin Wednesday, June 22, 2005. http://archives.starbulletin.com/2005/06/22/features/index.html. Accessed 7 November 2021.

Silva S and Figueira A (2005) Phylogenetic analysis of *Theobroma* (Sterculiaceae) based on Kunitz-like trypsin inhibitor sequences. Plant Syst. Evol. 250, 93–104. doi: 10.1007/s00606-004-0223-2

Silva CRS, Venturieri GA and Figueira A (2004) Description of Amazonian *Theobroma* L. collections, species identification, and characterization of interspecific hybrids. Acta Bot. Bras. 18(2): 333–341.

Skoog GE (2016) Cocoa in post-conflict Liberia. The role of institutions for the development of inclusive agricultural markets. The Nordic Africa Institute, Uppsala, Sweden.

Somarriba E and Beer J (2011) Productivity of *Theobroma cacao* agroforestry systems with timber or legume service shade trees. Agroforestry Systems 81:109–121 DOI 10.1007/s10457-010-9364-1

Somarriba E and Lachenaud P (2013) Successional cocoa agroforests of the Amazon-Orinoco-Guiana shield. Forests Trees and Livelihoods 22(1): 51–59. https://doi.org/10.1080/14728028.2013.770316

Somarriba E and Trujillo L (2005) El Proyecto. Modernización de la cacaocultura orgánica del Alto Beni, Bolivia. Agroforestería en las Américas 43–44: 6–14

Soria V (1970) Principal varieties of cocoa cultivated in tropical America. Cocoa Growers' Bulletin 15: 13–21.

Soto D (2017) Cadena productiva del cacao. Propuesta de un modelo de negocio para el sector cacaotero que fomente la innovación y la productividad dentro de la cadena de valor en Venezuela 2017. República Bolivariana de Venezuela, Facultad de Ciencias Económicas y Sociales, Escuela de Economía, Universidad Católica Andrés Bello, Caracas, Venezuela.

Sotomayor Cantos IA, Tarqui Freire OM, Loor Solorzano RG, Amores Puyutaxi FM and Motamayor JC (2017). Variación fenotípica y selección de genotipos de cacao de alto rendimiento en Ecuador. Revista ESPAMCIENCIA 8(2): 23–33.
http://190.15.136.171/index.php/Revista_ESPAMCIENCIA/article/view/140

Spring J (2021) Destruction of Brazil's Amazon rainforest speeds up for 2nd straight month. Reuters. Environment. May 7 2021.
https://www.reuters.com/business/environment/deforestation-brazils-amazon-rainforest-rises-second-straight-month-2021-05-07/

Stevens P (2021) Thai cocoa – breaking the mold.
https://anarchychocolate.com/thai-cocoa-breaking-the-mold/

Steijn C (2018) Demystifying the cocoa sector in Côte d'Ivoire and Ghana. Desk research. The Royal Tropical Institute (KIT).
https://www.kit.nl/wp-content/uploads/2018/11/Cocoa-desk-research-Cedric-Steijn-1.pdf

Struik S (2021) The Thai cacao struggle. Bar Talks, 5 March 2021.
https://bartalks.net/the-thai-cacao-struggle/

Stuart A (2017) Chiang Mai Coco: Northern Thailand's hidden chocolate farms. Citylife Fri 1 Dec 2017.
https://www.chiangmaicitylife.com/clg/business/agriculture/chiang-mai-coco-northern-thailands-hidden-chocolate-farms/

Stuart D (2009) in Chocolate in Mesoamerica: A Cultural History of Cacao (ed. McNeil, C. L.) 184–201. Univ. Press of Florida, Gainesville.

Susilo AW, Zhang D, Motilal LA, Mischke S and Meinhardt LW (2011) assessing genetic diversity in Java fine-flavor cocoa (*Theobroma cacao* L.) germplasm by using simple sequence repeat (SSR) markers. Tropical Agriculture and Development, 55(2), 84–92. https://doi.org/10.11248/jsta.55.84

Susilo AW, Zhang D and Motilal L (2013) Assessing genetic diversity cocoa (*Theobroma cacao* L.) collection resistant to cocoa pod borer using simple sequence repeat markers. Pelita Perkebunan 29(1): 1–9

Sukha DA and Ali NA (2018) Analysing sensory and processing quality of cocoa. In Achieving sustainable cultivation of cocoa. Vol. 1. Genetics, breeding, cultivation and quality. Edited by P. Umaharan. Burleigh Dodds Science Publishing Limited, Cambridge, U.K. pp. 395–442. doi:10.19103/AS.2017.0021.27.

Sukha DA and Butler DR (2005) The CFC/ICCO/INIAP cocoa flavor project: Investigating the spectrum of fine flavour within genotypes and between origins. INGENIC Newsletter 10: 22–25.

Sukha DA, Butler DR, Umaharan P and Boult E (2008) The use of an optimised organoleptic assessment protocol to describe and quantify different flavour attributes of cocoa liquors made from Ghana and Trinitario beans. Eur Food Res Technol 226: 405–413
DOI 10.1007/s00217-006-0551-2

Sukha DA, Umaharan P and Butler DR (2018) Evidence for applying the concept of "Terroir" in cocoa (*Theobroma cacao* L.) flavour and quality attributes. In Proceedings of the International Symposium on Cocoa Research. November 13-17, 2017, Cusco, Peru.
https://www.icco.org/wp-content/uploads/T5.44.EVIDENCE-FOR-APPLYING-THE-CONCEPT-OF-TERROIR-IN-COCOA-THEOBROMA-CACAO-L.-FLAVOUR-AND-QUALITY-ATTRIBUTES.pdf

Takrama J, Kun J, Meinhardt L, Mischke S, Opoku SY, Padi FK, and Zhang D (2014) Verification of genetic identity of introduced germplasm in Ghana using single nucleotide polymorphism (SNP) markers. African Journal of Biotechnology 13(21): 2127–2136. Doi: 10.5897/AJB2013.1331

Tankou CM (2016) The Cameroon Cocoa Story. Department of Crop Science, University of Dschang, Cameroon.
http://www.supplychainge.org/fileadmin/reporters/at_files/Cameroon_cocoa_story.pdf

Tay EB, Lee MT and Lamin K (1993) Ccooa germplasm conservation initiatives in Malaysia. In International Workshop on Conservation, Characterization and Utilization of Cocoa Genetic Resources in the 21st Century. 13th–17th September 1992, The Cocoa Research Unit, The University of the West Indies, Trinidad. pp. 231–238.

Tezara W, Urich R, Jaimez R, Coronel I, Araque O, Azócar C and Chacón I (2016) Does Criollo cocoa have the same ecophysiological charactersitics as Forastero? Botanical Sciences 94(3): 563-574. DOI: 10.17129/botsci.552

Thomas Evan, Zonneveld M, Loo J, Hodgkin T, Galluzzi G and van Etten J (2012) Present spatial diversity patterns of Theobroma cacao L. in the neotropics reflect genetic differentiation in Pleistocene refugia followed by human-influenced dispersal. PLoS ONE 7: e47676.doi: 10.1371/journal.pone.0047676

Thondaiman V, Rajamani K, Senthil L, Shoba N, and Joel AJ (2013) Genetic diversity in cocoa (*Theobroma cacao* L.) plus trees in Tamil Nadu by simple sequence repeat (SSR) markers. African Journal of Biotechnology 12(30): 4747–4753. doi: 10.5897/AJB2013.12423

Thong JKC, Ng SK, Ooi HSH and Leng KY. 1992. Cocoa in Peninsular Malaysia. I: The early history. Cocoa Growers' Bulletin 45: 7–25

Thorold CA (1955) Observations on *Theobroma cacao* in Fernando Po. Journal of Ecology 43(1): 219–225. https://www.jstor.org/stable/2257131

Topik S (2003) The Global Coffee Economy in Africa, Asia, and Latin America, 1500–1989. Cambridge: University Press.

Topper B (1993) Conservation initiatives in Jamaica. In International Workshop on Conservation, Characterization and Utilization of Cocoa Genetic Resources in the 21st Century, pp. 228–230. Port-of-Spain, Trinidad: The Cocoa Research Unit, University of the West Indies.

Toramo E, Desai N, Amosa F, Diczbalis Y and Dillon N (2019) Assessing morphological characteristics of elite Cocoa accessions (*Theobroma cacao* L.) in Makira Island, Solomon Islands. Journal of South Pacific Agriculture 22: 30-41. http://repository.usp.ac.fj/12368/1/59-303-1-PB.pdf

Toxopeus H (1968) Establishment of cacao clones in Nigeria. Euphytica 17: 38–45.

Toxopeus H (1971) De geschiedenis van de Nigeriaanse cacaocultuur en de sociaal-economische revolutie van de 19e eeuw [History of the Nigerian cocoa crop in the light of the socioeconomic revolution of the 19th century in West Africa]. Landbouwkundig Tijdschrift 83(12): 485–490. https://resolver.kb.n/resolve?urn=MMUBWA04:016005013:pdf Accessed 8 September 2021

Toxopeus H (1985a) Botany, types and populations. In GAR Wood & RA Lass (Eds.), Cocoa (4th ed., pp. 11–37). Oxford: Blackwell Science.

Toxopeus H (1985b) Planting material. In GAR Wood & RA Lass (Eds.), Cocoa (4th ed., pp. 80–92). Oxford: Blackwell Science.

Trognitz B, Cros E, Assemat S, Davrieux F, Forestier-Chiron N, Ayestas E, Kuant A, Scheldeman X and Hermann M (2013) Diversity of cacao trees in Waslala, Nicaragua: associations between genotype spectra, product quality and yield potential. PloS One, 8(1), e54079. https://doi.org/10.1371/journal.pone.0054079

Trognitz B, Scheldeman X, Hansel-Hohl K, Kuant A, Grebe H, and Hermann M (2011) Genetic population structure of cacao plantings within a young production area in Nicaragua. PLoS ONE 6(1): e16056. doi:10.1371/journal.pone.0016056

Tsutsumi CC (2008) Hawaii's Back Yard. Star Bulletin Vol. 13, Issue 195, Sunday, July 13, 2008 http://archives.starbulletin.com/2008/07/13/travel/tsutsumi.html. Accessed 7 November 2021.

Urquhart DH (1958) Prospects for cocoa-growing in Uganda and Zanzibar. Cadbury Brothers Ltd., Bournville

Utro F, Cornejo OE, Livingstone D, Motamayor JC and Parida L (2012) ARG-Based Genome-Wide Analysis of Cacao Cultivars. BMC Bioinformatics 13 (SUPPL.19): S17. https://doi.org/10.1186/1471-2105-13-S19-S17

Vail G (2009) Cacao use in Yucatan among the Pre-hispanic Maya. In: Chocolate: history, culture, and heritage, LE Grivetti and HY Shapiro HY, eds. New Jersey: John Wiley & Sons Inc. p 3–15.

Van Hall CJJ (1914) Cocoa. London: MacMillan and Co., Limited.

Van Hall CJJ (1932) Cacao (2nd ed.). London: Macmillan and Co., Limited.

Vargas V and Vásquez M (2018) Cacao fino y de aroma: una alternativa para la agroexportacion. Proceedings of the International Symposium on Cocoa Research. November 13-17, 2017, Cusco, Peru.
https://www.icco.org/wp-content/uploads/T5.E4.-CACAO-FINO-Y-DE-AROMA-UNA-ALTERNATIVA-PARA-LA-AGROEXPORTACION.pdf

Vázquez-Ovando A, Chacón-Martínez L, Betancur-Ancona D, Escalona-Buendía H and Salvador-Figueroa M (2015a) Sensory descriptors of cocoa beans from cultivated trees of Soconusco, Chiapas, Mexico. Food Science and Technology (Campinas) 35(2): 285–290. doi:10.1590/1678-457x.6552

Vázquez-Ovando A, Molina-Freaner F, Nuñez-Farfán J, Betancur-Ancona D and Salvador-Figueroa M (2015b). Classification of cacao beans (*Theobroma cacao* L.) of southern Mexico based on chemometric analysis with multivariate approach. European Food Research and Technology 240(6): 1117–1128. https://doi.org/10.1007/s00217-015-2415-0

Vázquez-Ovando JA, Molina-Freaner F, Nuñez-Farfán J, Ovando-Medina I and Salvador-Figueroa M (2014) Genetic identification of theobroma cacao L. Trees with high Criollo ancestry in Soconusco, Chiapas, Mexico. Genetics and Molecular Research 13(4): 10404–10414. https://doi.org/10.4238/2014.December.12.2

Velásquez S, R, Santana G, Medina A and Betancourt C (2015) *In vitro* morphogenesis of Venezuelan cocoa (*Theobroma cacao* L.) genotypes. Chilean J. Agric. Anim. Sci., ex Agro-Ciencia 31(3): 171–176.

Vello F and Garcia JR (1971) Características das principais variedades de cacau cultivadas na Bahia. Theobroma 1: 3–10.

Vello F, Garcia JR and Magalhães WS (1972) Production and selection of cacao hybrids in Bahia. In: Proc. 4th Intl Cocoa Res. Conf., 8–18 January 1972, St. Augustine, Trinidad. Government of Trinidad and Tobago, West Indies, pp.38–56.

Vello F, Mariano AH, Garcia JR, Nascimento TF and Magalhães WS (1969) O programa de melhoramento genético do cacau na Bahia. In: Memórias da 2a Conferência Internacional de Pesquisas em Cacau. 1967. Bahia, Brasil. pp. 43–55.

Vernon SJ and Sundaram S (1972) Current cocoa research in Fiji. In Proc. 4th Intl. Cocoa Res. Conf., 8–18 Jan 1972, St. Augustine, Trinidad. Government of Trinidad and Tobago, West Indies, pp. 689–693.

Vernooy R (2015) Effective implementation of crop diversification strategies for Cambodia, Laos PDR and Vietnam: Insights from past experiences and ideas for new research. Bioversity International, Rome, Italy.

Vinning GS (2017) Cocoa in the Pacific: the first 50 years.

Vinning G, Keane P and Loh D (2017) History and importance of cocoa growing in

Papua New Guinea. In: Papua New Guinea Cocoa Extension Manual, Compiled by Philip Keane,edited by E. Tade, A. Nongkas, J. Saul-Maora, P. Gende, D. Yinil and J. Marfu. PNG Cocoa and Coconut Institute, Tavilo, East New Britain Province, Papua New Guinea, pp. 188–199.

Wang B, Motilal LA, Meinhardt LW, Yin J and Zhang D (2020) Molecular characterization of a cacao germplasm collection maintained in Yunnan, China using single nucleotide polymorphism (SNP) markers. Tropical Plant Biology 13(4): 359–370. https://doi.org/10.1007/s12042-020-09267-y

Webster JB (1963) The Bible and the plough. Journal of the Historical Society of Nigeria 2(4): 418–434. https://www.jstor.org/stable/41856670.

Whitkus R, De La Cruz M, Mota-Bravo L and Gómez-Pompa A (1998) Genetic diversity and relationships of cacao (*Theobroma cacao* L.) in southern Mexico. Theoretical and Applied Genetics 96(5): 621–627. https://doi.org/10.1007/s001220050780

Whitlock BA and Baum DA (1999) Phylogenetic relationships of *Theobroma* and *Herrania* (Sterculiaceae) based on sequences of the nuclear gene vicilin. Syst. Bot. 24, 128–138. doi: 10.2307/2419544

Whitlock BA, Bayer C and Baum DA (2001) Phylogenetic relationships and floral evolution of the Byttnerioideae (Sterculiaceae or Malvaceae s.l.) based on sequences of the chloroplast gene ndhF. Syst. Bot. 26, 420–437. doi: 10.1043/0363-6445-26.2.420

Wilcox MD (2007) Tree crop sub-sector. Comprehensive assessment of the agriculture sector in Liberia (CAAS-Lib). Volume 2.1 - Sub-Sector Reports. Part II. Ministry of Agriculture, Liberia.
https://openknowledge.worldbank.org/bitstream/handle/10986/7674/431760SR0v20Wh110CAAS1LIB12111Feb08.pdf

Wiredu AN, Mensah-Bonsu A, Andah EK and Fosu KY (2011) Hybrid Cocoa and Land Productivity of Cocoa Farmers in Ashanti Region of Ghana. World Journal of Agricultural Sciences 7(2): 172–178. https://www.idosi.org/wjas/wjas7(2)/11.pdf Accessed 29 August 2021.

Woda S, Martínez A, González V, López O and Tejada RA (2016) Genética y calidad Componentes esenciales de la estrategia nacional de cacao. Centro de Comunicación Agrícola de la Fundación Hondureña de Investigación Agrícola (FHIA), La Lima, Cortés, Honduras, C.A.

Wolters B (1999) Dispersion and ethnobotany of the cacao tree and other Amerindian crop plants. Journal of Applied Botany 73: 128–137.

Wood GAR (1991) A history of early cocoa introductions. Cocoa Growers' Bulletin 44: 7–11.

Wood GAR and Lass RA (1985) Cocoa (4th Ed.). London: Longman.

World Population Review. Cocoa Producing Countries 2022. (https://worldpopulationreview.com/country-rankings/cocoa-producing-countries

Yahaya H (2021) Ways Nigeria Can Improve Cocoa Production - Boss, Cocoa Institute. Daily Trust, 26th August 2021, https://dailytrust.com/ways-nigeria-can-improve-cocoa-production-boss-cocoa-institute. Accessed 9 September 2021.

Yamada MM, Faleiro FG, Lopes UV, Bahia RC, Pires JL, Gomes LMC and Melo GRP (2001) Genetic variability in cultivated cacao populations in Bahia, Brazil, detected by isozymes and RAPD markers. Crop Breeding and Applied Biotechnology 1(4): 377–384.

Yang JY, Scascitelli M, Motilal LA, Sveinsson S, Engels JMM, Kane NC, Dempewolf H, Zhang D, Maharaj K and Cronk QCB (2013) Complex origin of Trinitario-type *Theobroma cacao* (Malvaceae) from Trinidad and Tobago revealed using plastid genomics. Tree Genetics and Genomes, 9(3), 829–840. https://doi.org/10.1007/s11295-013-0601-4

Yao CYA, Kpangui KB, Vroh BTA, and Ouattara D (2016) Pratiques culturales, valeurs d'usage et perception des paysans des espèces compagnes du cacaoyer dans des agroforêts traditionnelles au centre de la Côte d'Ivoire. Revue d'Ethnoécologie 9: 19pp doi : 10.4000/ethnoecologie.2474

Yazik NM, Ramba H, Japar A and Jamil ZM (2019) Evaluation and assessment of commercial cocoa clones at Cocoa Research and Development Center Bagan Datuk, Perak. Malaysian Cocoa Journal 11: 42–46.

Yinil D, Tade E, Bapiwai P and Fidelis C (2017) Where can cocoa be grown successfully in Papua New Guinea? In: Papua New Guinea Cocoa Extension Manual, Compiled by Philip Keane, edited by E. Tade, A. Nongkas, J. Saul-Maora, P. Gende, D. Yinil and J. Marfu. PNG Cocoa and Coconut Institute, Tavilo, East New Britain Province, Papua New Guinea, pp. 14–23.

Youbi PH, Kaho F, Ngoufo R, Mbolo M, and Edoa D (2018) Evaluation du rendement de deux variétés de cacaoyers dans la Région du Centre du Cameroun. In Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo 10: 59–66. doi:10.5281/zenodo.1215939

Young AM (2007) The chocolate tree. A natural history of cacao. USA: University Press of Florida.

Zárate DA, Andresen E, Estrada and Serio-Silva JC (2014) Black Howler Monkey (Alouatta pigra) Activity, Foraging and Seed Dispersal Patterns in Shaded Cocoa Plantations Versus Rainforest in Southern Mexico. American Journal of Primatology DOI: 10.1002/ajp.22276

Zarrillo S, Gaikwad N, Lanaud C, Powis T, Viot C, Lesur I, Fouet O, Argout X, Guichoux E, Salin F, Loor Solorzano R, Bouchez O, Vignes H, Severts P, Hurtado J, Yepez A, Grivetti L, Blake M and Valdez F (2018) The use and domestication of *Theobroma cacao* during the mid-Holocene in the upper Amazon. Nat. Ecol. Evol. 2: 1879–1888. https://doi.org/10.1038/s41559-018-0697-x

Zhang D, Arevalo-Gardini E, Mischke S, Zúñiga-Cernades L, Barreto-Chavez A and del Aguila JA (2006) Genetic diversity and structure of managed and semi-natural populations of cocoa (*Theobroma cacao*) in the Huallaga and Ucayali valleys of Peru. Annals of Botany 98(3): 647–655. doi:10.1093/aob/mcl146

Zhang D, Boccara M, Motilal L, Butler DR, Umaharan P, Mischke S and Meinhardt L (2008) Microsatellite variation and population structure in the "Refractario" cacao of Ecuador. Conservation Genetics 9(2): 327–337. https://doi.org/10.1007/s10592-007-9345-8

Zhang D, Mischke S, Johnson ES, Phillips-Mora W and Meindhart L (2009a) Molecular characterization of an international cacao collection using microsatellite markers. Tree Genetics & Genomes (2009) 5:1–10 DOI 10.1007/s11295-008-0163-z

Zhang D, Boccara M, Motilal L, Mischke S, Johnson ES, Butler DR, Bailey B and Meinhardt L (2009b) Molecular characterization of an earliest cacao (*Theobroma cacao* L.) collection from Upper Amazon using microsatellite DNA markers. Tree Genetics and Genomes 5(4): 595–607. DOI 10.1007/s11295-009-0212-2

Zhang D, Figueria A, Motilal L, Lachenaud P and Meinhardt L (2011). Theobroma. In K. Chittaranjan (Ed.), Wild Crop Relatives: Genomic and Breeding Resources. Springer. https://doi.org/10.1007/978-3-642-21250-5

Zhang D, Arevalo Gardini E, Motilal LA, Baligar V, Bailey B, Zuñiga-Cernades L, Arevalo-Arevalo CE and Meinhardt L (2011b). Dissecting genetic structure in farmer selections of *Theobroma cacao* in the Peruvian amazon: implications for on farm conservation and rehabilitation. Tropical Plant Biology 4(2): 106–116. DOI 10.1007/s12042-010-9064-z

Zhang D, Martínez WJ, Johnson ES, Somarriba E, Phillips-Mora W, Astorga C, Mischke S and Meinhardt LW (2012) Genetic diversity and spatial structure in a new distinct *Theobroma cacao* L. population in Bolivia. Genetic Resources and Crop Evolution 59(2): 239–252. DOI 10.1007/s10722-011-9680-y

Zhang D and Motilal L (2016) Origin, dispersal, and current global distribution of cacao genetic diversity. In Cacao Diseases: A History of Old Enemies and New Encounters (pp. 3–31). Springer International Publishing. https://doi.org/10.1007/978-3-319-24789-2_1