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REVEIW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY, BREEDING, CULTIVATION AND PROCESSING OF COCOA (*Theobroma cacao* L.)

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ABSTRACT

Cocoa belongs to the Family Sterculiaceae (Malvaceae/ mallow family), Genus *Theobroma* and species *Theobroma cacao* L. Cocoa is one of 26 species belonging to the genus *Theobroma*. In 2008, researchers proposed a new classification based upon morphological, geographic, and genomic criteria: 10 groups have been named according to their geographic origin or the traditional cultivar name. These groups are: Amelonado, Criollo, Nacional, Contamana, Curaray, Cacao guiana, Iquitos, Marañon, Nanay, and Purús. The genome of *T. cacao* is diploid, its size is 430 Mbp, and it comprises 10 chromosome pairs (2n=2x=20). The cocoa bean (technically cocoa seed) or simply cocoa, also called cacao is the dried and fully fermented seeds of cocoa, from which cocoa solids (a mixture of nonfat substances) and cocoa butter (the fat) can be extracted. Cocoa beans are the basis of chocolate, and Mesoamerican foods including tejate, an indigenous Mexican drink. Cocoa is the source of all the different types of chocolate found on the market today. It is made from the fruit of the cocoa tree. The tree has been cultivated for centuries by the Maya, and over time, has spread to tropical regions in the Americas, Africa, Asia and Oceania. The word *cocoa* comes from the Spanish word *cacao*, which is derived from the Nahuatl word *cacauatl*. The Nahuatl word, in turn, ultimately derives from the reconstructed Proto-Mixe–Zoquean word *kakawa* . The Amazon basin is an area that harbors genetic diversity and variability of cocoa; scattered populations of wild cocoa, cultivated cacao and related species of this genus can be found there. Cocoa beans may be cultivated under shade, as done in agroforestry. Agroforestry can reduce the pressure on existing protected forests for resources, such as firewood, and conserve biodiversity. Integrating shade trees with cocoa plants reduces risk of soil erosion and evaporation, and protects young cocoa plants from extreme heat. Agroforests act as buffers to formally protected forests and biodiversity island refuges in an open, human-dominated landscape. People around the world enjoy cocoa in many different forms, consuming more than 3 million tons of cocoa beans yearly. Once the cocoa beans have been harvested, fermented, dried and transported they are processed in several components. Processor grindings serve as the main metric for market analysis. Processing is the last phase in which consumption of the cocoa bean can be equitably compared to supply. After this step all the different components are sold across industries to many manufacturers of different types of products. Cocoa, being a highly cross pollinated and self- incompatible crop shows greater diversity. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Cultivation, Processing, Uses, and Health Benefits of cocoa are discussed.

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INTRODUCTION

Cocoa belongs to the Family Sterculiaceae (Malvaceae/ mallow family), Genus *Theobroma* and species *Theobroma cacao* L. (Wikipedia, 2023a). The genus Theobroma comprises more than 22 species, including other cocoa-like fruits, also native to the Amazon basin. These include copoazú (*Theobroma grandiflorum*) and mocambo (*Theobroma bicolor*) (Quintero, 2023). Cacao (*Theobroma cacao*) is one of 26 species belonging to the genus *Theobroma* classified under the subfamily Byttnerioideae of the mallow family Malvaceae. In 2008, researchers proposed a new classification based upon morphological, geographic, and genomic criteria: 10 groups have been named according to their geographic origin or the traditional cultivar name. These groups are: Amelonado, Criollo, Nacional, Contamana, Curaray, Cacao guiana, Iquitos, Marañon, Nanay, and Purús (Wikipedia, 2023a).

Theobroma is the name given by Linnaeus meaning "Food of the Gods" (Greek name Theos = Gods, Broma = Food) to the chocolate tree cocoa. *Theobroma bicolor* and *grandiflorum* are other better known species. *T. bicolor* is typical with the inflorescence appearing in the axils of new leaves and the branches bent down as the pods reach maturity. Seeds of *Theobroma bicolor* are used as adulterant. *Theobroma cacao* is a diploid with 2n = 20. *Theobroma cacao* ssp.*cacao* includes Criolla populations of Central and South America and *Theobroma cacao* ssp. *sphaerocarpum* which includes other populations like Forastero and Trinitario (Auxcilia and Shab, 2017). The genome of *T. cacao* is diploid, its size is 430 Mbp, and it comprises 10 chromosome pairs (2n=2x=20) (Wikipedia, 2023a). Cocoa, being a highly cross pollinated and self-incompatible crop shows greater diversity (Kunikullaya *et al*., 2018).

The word *cocoa* comes from the Spanish word *cacao*, which is derived from the Nahuatl word *cacauatl*. The Nahuatl word, in turn, ultimately derives from the reconstructed Proto-Mixe–Zoquean word *kakawa* (Wikipedia, 2023). The generic name Theobroma is derived from the Greek for "food of the gods"; from *theos*, meaning 'god' or 'divine', and *broma*, meaning 'food'. The specific name *cacao* is the Hispanization of the name given to the plant in indigenous Mesoamerican languages such as *kakaw* in Tzeltal, K'iche' and Classic Maya; *kagaw* in Sayula Popoluca; and *cacahuatl* in Nahuatl meaning "bean of the cocoa-tree" (Wikipedia, 2023a). The common names are cocoa (English), cacaoyer (French), cacaoeiro/cacau (Portuguese/Brazil), kakao (Swedish), árbol del cacao/cacaotero/calabacillo/forester (Spanish) and echter Kakaobaum (German). There is archaeological evidence that the Mayans cultivated cacao 2000–4000 years before the Spanish arrived in South America (Powis *et al.,* 2011). Cacao is one of the economically important tree crops in West and Central Africa and is native to the tropical forests of South America. The botanical name of cacao is *Theobroma cacao*, first defined by Carolus Linnaeus, the father of modern-day taxonomic plant classification, and was published in his classic book, *Systema Naturae* in the mid-1700s. *Theobroma* is a Greek word that can be translated as 'Food of Gods': 'theos' meaning 'god' and 'broma' meaning 'food'. The word 'cacao' is derived from the Olmec and the subsequent Mayan languages (Kakaw), and the word 'chocolate' is derived from the Nahuatl (the Aztec language) term '*cacahuatl'*, which is in turn derived from Olmec/Mayan etymology (Dillinger *et al*., 2000). Common names (Growables, 2023) in different languages are *viz*., English: cacao, cocoa; Spanish: árbol del cacao, cacaotero, calabacillo, forastero; French: cacaoyer, cacaotier; German: Kakao, Kakaopflanze; Portuguese: cacau, cacaoeiro; and Swedish: kakao.

Domesticated cacao trees grow to about 8-12 m tall and can grow for up to 50 years. Cacao fruit or "pods" develop from fertilised flowers and are about the size and shape of an American football. They can grow between 15-40 cm long and can take on various colours. Cacao trees produce about 20-30 pods each year and each pod contain roughly 20-60 beans (Selenohealth, 2023). Worldwide, three genetic types of cocoa are recognized: the Criollo that has a white cotyledon and is poorly cultivated because it is very susceptible to diseases; the Forastero, from the Amazon region; and the Trinitario, a hybrid of the Forastero and the Criollo. The genetic group Forastero presents cotyledon of purple color due to anthocyanins, it is also the most resistant to diseases and the most cultivated worldwide (Avendaño-Arrazate *et al.,* 2018). The Olmecs in Mexico cultivated the cacao tree for its beans as long ago as 400 BCE. The cacao tree is unusual because it produces flowers directly on its trunk and branches, rather than on new shoots. This flowering method is called cauliflory. The Latin name *Theobroma* means 'food of the gods' (Kew, 2023). The cocoa beans are the major ingredient for the cocoa industry, for the manufacturing of chocolate and derivatives, cosmetics and medicines (Monteiro et al., 2009). Cacao, *Theobroma cacao* L., Malvaceae *sensu lato* is a perennial crop, on which the thriving global chocolate industry is based. It is an important agricultural commodity in many developing countries in West Africa, South-East Asia, Latin America and the Caribbean (Becker, 1999). Cocoa is the source of all the different types of chocolate found on the market today. It is made from the fruit of the cocoa tree (*Theobroma cacao*). The tree has been cultivated for centuries by the Maya, and over time, has spread to tropical regions in the Americas, Africa, Asia and Oceania (Chocolate, 2020). The cocoa bean (technically cocoa seed) or simply cocoa, also called cacao is the dried and fully fermented seed of *Theobroma cacao*, from which cocoa solids (a mixture of nonfat substances) and cocoa butter (the fat) can be extracted. Cocoa beans are the basis of chocolate, and Mesoamerican foods including tejate, an indigenous Mexican drink (Wikipedia, 2023). Cocoa, highly concentrated powder made from chocolate liquor—a paste prepared from cocoa beans, the fruit of the cacao—and used in beverages and as a flavouring ingredient. Cocoa is the key ingredient in chocolate and chocolate confections. The cocoa bean is the seed of the cacao tree (*Theobroma cacao*), a tropical plant indigenous to the equatorial regions of the Americas. From the processed cocoa bean comes the fluid paste, or liquor, from which cocoa powder and chocolate are made. Chocolate is sold directly to the consumer as solid bars of eating chocolate, as packaged cocoa, and as baking chocolate. It is also used by confectioners as coating for candy bars and boxed or bulk chocolates, by bakery product manufacturers and bakers as coating for many types of cookies and cakes, and by ice-cream companies as coating for frozen novelties. Cocoa powders, chocolate liquor, and blends of the two are used in bulk to flavour various food products and to provide the flavours in such "chocolate" products as syrups, toppings, chocolate milk, prepared cake mixes, and pharmaceuticals (Russell Cook et al., 2023). More than 80% of the world's chocolate comes from low quality bulk beans of the Forastero variety. Craft chocolate makers use mostly fine, and sometimes rare bean varieties to make some of the amazing chocolate we feature in our boxes (BCV, 2023). Scientists at the International Center for Agricultural Research and Development (CIRAD) believe that the world's original *Theobroma* could be millions of years old, and the particular species we now regard as the cacao tree could be about 10 to 15 thousand years old. The cacao plant first appeared in the Amazon basin, and was likely domesticated by the Olmecs civilization, predating the Mayans (BCV, 2023). For the next 3 to 5,000 years, the Mesoamerican civilizations including the Olmecs, Mayans and Aztecs cultivated and domesticated the T. Cacao plant extensively. The fermented and dried cacao beans were regarded as " food of the gods," and also used as a form of currency (BCV, 2023).

Theobroma cacao – The Food of the Gods, provides the raw material for the multi-billion dollar chocolate industry, and is also the main source of income for about 6 million smallholders around the world. Additionally, cocoa beans have a number of other non-food uses in the pharmaceutical and cosmetic industries. Specifically, the potential health benefits of cocoa have received increasingattention as it is rich in polyphenols, particularly flavonoids (Wickramasuriya and Dunwell, 2017). At present, the demand for cocoa and cocoa-based products in Asia is growing particularly rapidly and chocolate manufacturers are increasing investment in this region. However, in many Asian countries, cocoa production is hampered due to many reasons including technological, political and socio-economic issues (Wickramasuriya and Dunwell, 2017). There is a great demand for high quality cocoa beans. Thus, to ensure long term sustainability of cocoa production, future research should focus on the development of improved cacao varieties that can both tolerate changing climates, but also meet the stringent quality criteria demanded by the chocolate industry (Wickramasuriya and Dunwell, 2017). The diploid tropical fruit crop species (2n = 2x = 20), *Theobroma cacao* (cacao) is an economically important agricultural commodity for millions of people worldwide. It is grown by about 6 million farmers globally, and livelihoods of more than 40 million people depend on cocoa. The majority of world cocoa production (approximately 80-90%) comes from smallholder farmers. This croporiginated from the Amazonian basin and today it is cultivated in many regions of the humid tropics (Wickramasuriya and Dunwell, 2017).

To make chocolate, cacao fruits are harvested when they are ripe and opened to remove the beans inside. The beans are fermented, dried, roasted, husked, and then ground up to make a thick paste called chocolate liquor which is the basis of all chocolate products**.** Different types of chocolate are made by mixing ingredients like sugar and milk with chocolate liquor (Kew, 2023). Cacao (*Theobroma cacao*) is an evergreen tree whose fully fermented seeds, known as " cacao beans," are the main ingredient in cacao nibs, cacao paste, cacao butter, as well as the very popular confection, chocolate. Cacao beans are grown inside pods that can take on a variety of colours and are surrounded by a white fruit. The cacao plant and cacao beans have a long history of use by the indigenous cultures of latin America where they have been cultivated for thousands of years (Oliva-Cruz *et al.,* 2022). Cacao beans were regarded as a sacred and valuable commodity and used for trades and tribute to Aztecs kings. They were typically made into a drink to be consumed by nobility or as part of shamanic or religious cacao ceremonies. Ceremonial cacao is a powerhouse of uplifting, blissful and health enhancing molecules (Selenohealth, 2023).

Chocolate is derived from the cocoa bean, which is obtained from the fruit of the cocoa tree, *Theobroma cacao* (Linnaeus). Cocoa continues to be an important source of export earnings for many producing countries, particularly in Africa, Latin America and South-East Asia (Afoakwa, 2016). In 2020, global cocoa bean production reached 5.8 million tonnes, with Ivory Coast leading at 38% of the total, followed by Ghana and Indonesia. Cocoa beans, cocoa butter, and cocoa powder are traded on futures markets, with London focusing on West African cocoa and New York on Southeast Asian cocoa. Various international and national initiatives aim to support sustainable cocoa production, including the Swiss Platform for Sustainable Cocoa (SWISSCO), the German Initiative on Sustainable Cocoa (GISCO), and Beyond Chocolate, Belgium. At least 29% of global cocoa production was compliant with voluntary sustainability standards in 2016. Deforestation due to cocoa production remains a concern, especially in West Africa. Sustainable agricultural practices, such as agroforestry, can support cocoa production while conserving biodiversity. Cocoa contributes significantly to economies like Nigeria, and demand for cocoa products continues to grow steadily at over 3% annually since 2008 (Wikipedia, 2023). The most common product made with cocoa is chocolate (from Nahuatl *xocoltotl*), made from a mixture of sugar, cocoa mass and cocoa butter, to which are added other ingredients to suit the confectioner (milk, nuts, etc.), since its preparation is traditionally sweet. Chocolate is currently consumed in a huge variety of presentations: in bars, in powder, as drinks, etc. Its preparation is culturally regarded as its own in various parts of Europe, where it arrived after the colonization of America and where it took advantage of the culinary tradition (Conceptdaily, 2023). The native peoples of Mesoamerica prepared hot and cold beverages by mixing cocoa with corn, achiote, chili or anise (Quintero, 2023). One of the world's most popular products, chocolate, comes from the cacao tree. It is made from cacao beans: The seeds stored in the yellow fruit of the cacao tree. Cacao beans have been eaten by humans for thousands of years. The Mayans and Aztecs mixed ground cacao beans with chilli to make a bitter and spicy drink. Cacao beans were so highly valued by the Aztecs that they were used as currency (Kew, 2023).

The cocoa beans are the primary source of raw material for the multi-billion dollar industry that produces chocolate and associated confectionery products, with Switzerland being the country with the highest consumption, though much of this is due to purchases by tourists to that country. The economic significance of the chocolate industry has been recently reviewed with the global market for chocolate rising 13% from 2010 to reach US$101 billion in 2015 (Wickramasuriya and Dunwell, 2017). Cocoa is the dried and fully fermented fatty seed of the cacao tree from which chocolate is made. "Cocoa" can often also refer to the drink commonly known as hot chocolate; cocoa powder, the dry powder made by grinding cocoa seeds and removing the cocoa butter from the dark, bitter cocoa solids; or it may refer to the combination of both cocoa powder and cocoa butter together (Vikaspedia, 2020). Major cocoa bean processors include Hershey's, Nestlé and Mars, all of which purchase cocoa beans via various sources. Chocolate can be made from *T. cacao* through a process of steps that involve harvesting, fermenting of *T. cacao* pulp, drying, harvesting, and then extraction. Roasting *T. cacao* by using superheated steam was found to be better than conventional roasting (use of ovens) because it resulted in same quality of cocoa beans in a shorter amount of time (Wikipedia, 2023a). People around the world enjoy cocoa in many different forms, consuming more than 3 million tons of cocoa beans yearly. Once the cocoa beans have been harvested, fermented, dried and transported they are processed in several components. Processor grindings serve as the main metric for market analysis. Processing is the last phase in which consumption of the cocoa bean can be equitably compared to supply. After this step all the different components are sold across industries to many manufacturers of different types of products (Wikipedia, 2023).

Cocoa (*Theobroma cacao L.*) belonging to the family of *Sterculiaceae*. Therefore, the Amazon basin is an area that harbors genetic diversity and variability of *Theobroma cacao*; scattered populations of wild cacao, cultivated cacao and related species of this genus can be found there (Quintero, 2023). Health Cacao beans are rich in antioxidants which help protect cells from damage. They are also known to increase endorphins, a hormone which boosts happiness (Kew, 2023). Cocoa plant is a small (4 to 8 m height) evergreen tree. In India, it is mainly cultivated in Karnataka, Kerala and Tamil Nadu mainly as intercrop with Arecanut and Coconut. Slowly the area under cultivation is being promoted by many chocolate producing companies as contract farming. In 2008, India produced approximately 8500 metric tonnes of cocoa (Vikaspedia, 2020). Cocoa beans may be cultivated under shade, as done in agroforestry. Agroforestry can reduce the pressure on existing protected forests for resources, such as firewood, and conserve biodiversity. Integrating shade trees with cocoa plants reduces risk of soil erosion and evaporation, and protects young cocoa plants from extreme heat. Agroforests act as buffers to formally protected forests and biodiversity island refuges in an open, human-dominated landscape. Research of their shade-grown coffee counterparts has shown that greater canopy cover in plots is significantly associated with greater mammal species diversity. The amount of diversity in tree species is fairly comparable between shade-grown cocoa plots and primary forests (Wikipedia, 2023).

Cocoa was evolved as an under-storey crop in the Amazonian forests. Thus commercial cultivation of cocoa can be taken up in plantations where 50 per cent of light is ideally available. In India, coconut and arecanut gardens are suited best for cultivating Cocoa. Under arecanut 30-50% of sunlight penetrates through their canopy which can be intercepted by cocoa (Vikaspedia, 2020). Propagation is by seed, airlayering, cuttings or grafting. Seeds germinate in 5-10 days, but lose viability quickly if they dry out. Seedlings should be grown under 50% shade. Cacao may be cleft or patch grafted. Propagation may be by cuttings, buddings or graftings, but seeding is cheaper. Seeds germinate at maturity, and are viable only a short time. They may be stored 10–13 weeks if moisture content is kept at 50% (Growables, 2023). Newly planted trees should be allowed to grow to 0.3–0.6 m. If no branching occurs, then the top should be cut back to initiate branching. Three to 4 main branches should be allowed to develop. Remove all others. Plant height should be limited to 1.8–2.4 m to facilitate care and make protection from winds, excessive light, and cold temperatures easier. Periodically, selected branches should be removed to allow an increase in light and air movement inside the plant canopy. This will enhance pod production and reduce fungal disease problems. Damaged or diseased branches should also be removed regularly. Pruning should be done at the end of the summer to prepare the tree for the following crop (Growables, 2023).

Cacao beans constituted both a ritual beverage and a major currency system in pre-Columbian Mesoamerican civilizations. At one point, the Aztec empire received a yearly tribute of 980 loads (Classical Nahuatl: *xiquipilli*) of cacao, in addition to other goods. Each load represented exactly 8,000 beans. The buying power of quality beans was such that 80–100 beans could buy a new cloth mantle. The use of cacao beans as currency is also known to have spawned counterfeiters during the Aztec empire (Wikipedia, 2023a). Cocoa is cultivated commercially in South and Central Americas, Caribbean, Africa, Asia and in some Pacific Islands. But most of the cocoa currently produced in the world (around 70%)

comes from West African countries, especially Ivory Coast, Ghana and Nigeria (Monteiro *et al*., 2009). In India, cocoa is an introduced crop and widely grown as an intercrop in coconut and arecanut gardens of South India *viz*., Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Andhra Pradesh leads in production (7700 MT) and productivity (800 kg/ha). Tamil Nadu ranks first in area covering about 29,205 hectares with a production and productivity of 1650 MT and 320 kg/ha respectively. The national productivity of cocoa is 580 kg/ha (Kunikullaya *et al.,* 2018). More than 15 million people in African, Caribbean and Pacific countries are now directly involved in cacao cultivation, and there are approximately 5 million cocoa farmers in over 50 countries. The World Cocoa Foundation reported that 40-50 million people worldwide depend on cocoa for their livelihood. The annual global consumption of cocoa beans is approximately 3 million tonnes (ICCO, 2006), and is valued at USD 5.1 billion. The future outlook for the industry is bright and has been further enhanced in recent years by report of the medical benefits of dark chocolate (rich in anti- oxidants), which are now well-documented and publicized (ICCO, 2006).

The Maya believed the *kakaw* (cacao) was discovered by the gods in a mountain that also contained other delectable foods to be used by them. According to Maya mythology, the Plumed Serpent gave cacao to the Maya after humans were created from maize by divine grandmother goddess Xmucane. The Maya celebrated an annual festival in April to honor their cacao god, Ek Chuah, an event that included the sacrifice of a dog with cacao-colored markings, additional animal sacrifices, offerings of cacao, feathers and incense, and an exchange of gifts. In a similar creation story, the Mexica (Aztec) god Quetzalcoatl discovered cacao (*cacahuatl*: "bitter water"), in a mountain filled with other plant foods. Cacao was offered regularly to a pantheon of Mexica deities and the Madrid Codex depicts priests lancing their ear lobes (autosacrifice) and covering the cacao with blood as a suitable sacrifice to the gods. The cacao beverage was used as a ritual only by men, as it was believed to be an intoxicating food unsuitable for women and children (Wikipedia, 2023a). Cacao (*Theobroma cacao*) trees grow in tropical environments with most growth concentrated in a region called the "Cacao belt," which is anywhere within 20 degrees north or south of the Equator. These trees require shade, usually provided by the foliage of shade trees, such as palms, banana plants, and *Gliricidia sepium* or madre de cacao ("mother of the cacao") (Fig. 1) (Selenohealth, 2023).

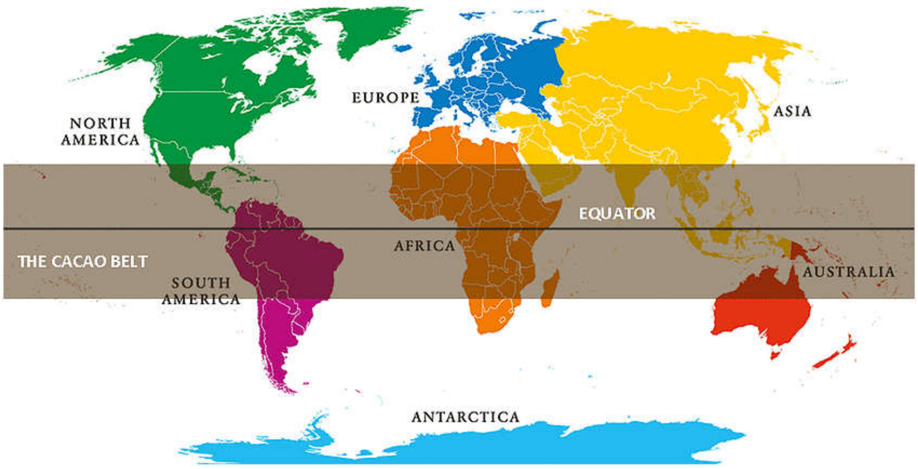


Fig. 1. "Cacao belt,"- within 20 degrees north or south of the Equator

At the end of the 19th century, in 1890, only 5% of the world's cocoa production was grown in Africa, mainly on the islands of Equatorial Guinea. At the beginning of the 20th century, cocoa production in the Americas accounted for 78% of world production. Subsequently, in the 1920s and 1930s, Africa achieved a better position in the world market for this commodity, accounting for 47% and 64%, respectively. More recently, in 2017 the Americas contributed about 15% to global production of this item, while Africa approximately 70%. Therefore, we can confirm the pre-eminence of the African continent as a world producer at present, albeit of Forastero or ordinary cocoa of lower quality (Quintero, 2023). Some cocoa varieties should be able to self-pollinate – they have both male and female components – but due to genetic limitations, the male and female cells can fail to fuse and produce a fruit. Early agroforestry cocoa systems were respectful of biodiversity. Cocoa plants grew in the shade of the rainforest canopy surrounded by naturally growing trees such as banana, Inga (a fruit that was part of the indigenous diet) and others. Recently, this old-fashioned system has been overtaken by more aggressive agricultural practices, such as cultivation in full sun, that involve massive loss of tree cover. But economics is driving the changing practices, which puts both the land and small farmers in danger. Planting seeds that could be incompatible from a genetic point of view has generated trees with little productivity, in the range of 350 kg/ha. This is a very modest yield for smallholders, which makes a farmer's total net income of USD480 per hectare, well below the survival standards. On the contrary, companies' open-sun fields produce an average of 2-3 tons per hectare, observed Guharay (TWAS, 2019). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Cultivation, Processing, Uses, and Health Benefits of Cocoa are discussed.

ORIGIN AND DOMESTICATION

Cheesman (1944) believed the Upper Amazon near the Colombian–Ecuadorian border, on the eastern flanks of the Andes, to be its centre of origin. He argued that although cacao cultivation has been practised in Mexico and Central America for over 2000 years, there was no evidence of its wild populations in the region. Later, Schultes (1984) hypothesised that cacao dispersed along two routes from the Amazon Valley, one leading to the north and the other the west. In this way, the domestication of cacao was thought to have occurred in South America and then spread to Central America and Southern Mexico, carried by migrating Indians. It is also estimated that the Mayas and Aztecs domesticated and consumed cocoa, while the Mayas, Olmecs, Toltecs and Aztecs used cocoa beans as the bitter drink, *chocolatl*, as well as a currency for trading, at least 1400 years ago. Several expeditions and studies have shown that cocoa was first cultivated in Mexico by the Aztecs before it spread to the Caribbean islands. Later, Hernán Cortés, a Spaniard, carried cocoa to Spain in 1520s and used it as a beverage as well as a crop for cultivation. It was the Spaniards who also introduced the crop into Equatorial Guinea in the seventeenth century. Whitlock *et al*. (2001) suggested the region extending from the forests of the Amazon to the Orinoco and Tabasco in Southern Mexico to be the centre of origin of cacao.

Cocoa occurs naturally in the South of Mexico to Bolivia and also in the Brazilian Amazon Forest. Due to the large genetic diversity of species observed, it was suggested that the cocoa tree originated in the Upper Amazon, in the zones of the confluence of the rivers Solimões, Putumayo and Caquetá. In spontaneous distribution, the cocoa tree is found in the lower stratum of the forests, in glades and on the banks of the great rivers, where high temperature and high humidity prevail (Monteiro *et al*., 2009). Cacao (Theobroma cacao L.) was domesticated in Mesoamerica and is native to the South American rainforest. Belizean Criollo is a group of relic landraces that are thought to be similar to those used by the Olmecs and Mayans during early domestication (Motilal *et al*., 2010). The crop is a native of South America, and Upper Amazon basin is considered as the centre of origin with greatest morphological diversity (Kunikullaya *et al*., 2018). Cocoa (*Theobroma cacao*) is native to the Amazon Basin (South America) but its domestication took place in Central America – in the so-called Mesoamerican Biological Corridor – a small area if compared to bigger fields in West Africa. With time, however, Central America has turned into a valuable source of the highest-grade cocoa (Bekele and Phillips-Mora, 2019). Chocolate is derived from the seeds of the cacao tree, *Theobroma cacao L.*, which literally means " food of the gods." The plant originated in the Western Amazon region of South America and has been cultivated for more than 3,000 years in many parts of Central and South America. Today it's grown in equatorial regions around the world, including western Africa and several tropical regions in Asia (Shoemaker, 2021).

Theobroma cacao belongs to the Malvaceae family and originated in the humid tropical regions of the north of South America, and mainly from the Amazonian basin. *T. cacao* is a tree of great agronomic and economic interest (Colonges *et al.,* 2022). Cocoa is native of Brazil North, Colombia, Costa Rica, Ecuador, French Guiana, Guyana, Peru, Suriname, Venezuela. It was introduced to Andaman Islands, Belize, Bolivia, Brazil Northeast, Cameroon, Cayman Islands, Central American Pacific Islands, China South-Central, Cook Islands, Cuba, Dominican Republic, El Salvador, Fiji, Ghana, Guatemala, Guinea, Gulf of Guinea Islands, Hainan, Haiti, Honduras, Ivory Coast, Jamaica, Laos, Leeward Islands, Mexico Southeast, Mexico Southwest, Nicobar Islands, Nigeria, Puerto Rico, Seychelles, Sri Lanka, Togo, Trinidad-Tobago, Vietnam, Windward Islands, Zaïre (Kew, 2023). Cacao trees originated in the Amazon basin of South America and were spread throughout Central America by various Mesoamerican civilisations, including the Olmecs, Mayans and the Aztecs (Selenohealth, 2023). The cacao tree, native to the Amazon rainforest, was first domesticated 5,300 years ago in South America before being introduced to Central America by the Olmecs. Cacao was consumed by pre-Hispanic cultures in spiritual ceremonies and its beans were a common currency in Mesoamerica. The cacao tree grows in a limited geographical zone, and today, West Africa produces nearly 70% of the world's crop (Wikipedia, 2023). Cocoa is native to America and occurs commonly in the territories of Colombia, Venezuela, Brazil, Ecuador, Peru, Bolivia and Trinidad and Tobago, but also in the hot zones of Mexico and on the African continent, in Ivory Coast, Cameroon , Nigeria, Togo, Republic of Congo and Ghana, as well as in the Asian rainforest of Malaysia and Indonesia (Conceptdaily, 2023). Cocoa is of jungle origin, probably Amazonian. It is thought that the ancient Mesoamerican settlers, 5000 years ago, would have found it and transported it to the current Mexican territory, since evidence of its ritual use by the Olmec culture was found, 3500 years ago. In fact, many theories about its origin are derived from its name, which could come from the Mayan *cacaoatl*, derived from the classic Maya kakaw. In fact, there is abundant documentation on the taste for cocoa-based beverages of the Mayan cultures, especially the elite. In fact cacao infusions were left in the tombs of the Mayan kings. It is also known that the Aztec Empire valued cacao and in some pre-Columbian cultures it was used as currency. Europeans learned about cocoa after the conquest and colonization of America, and for the first time they included sugar in cocoa drinks to adapt them to their palate, unaccustomed to the bitterness of the fruit (Conceptdaily, 2023). There are two distinct types of cocoa, Criollo types (*Cacao dulce*) that developed north of the Panama isthmus, and Forastero (*Cacao amargo*) which originated in the Amazon basin. Criollo types were cultivated by the indigenous people of Central and South America and were the type Europeans were first exposed to. Commercial production commenced in Brazil using the Forastero types, mainly a uniform type called Amelonado. Both types were distributed throughout the Caribbean, where they hybridized in Trinidad, creating a distinct hybrid called Trinitario. Spanish explorers took cocoa to the Philippines, where it spread throughout southeast Asia, India, and Ceylon. Amelonado cocoa was taken to West Africa (Growables, 2023).

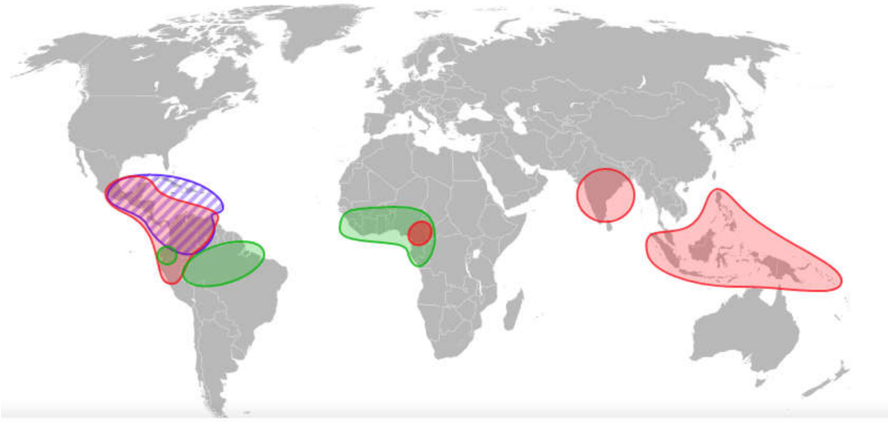
Cacao *(Theobroma cacao*) is a tropical fruit native to the Amazon, domesticated in Central America by the indigenous people of the region long before the arrival of the conquistadors (Quintero, 2023). Origin of this tropical understory tree in the family of the Sterculiaceae are the Amazon Headwaters from where it moved to Central America. Cocoa cultivation began by Mayan tribes in Central America, ca. 1500 BC (Growables, 2023). The precise identification of the origin of cocoa in tropical America is controversial, due to the discussion about the genesis and dispersion of this crop. According to Cartay, the primary center of origin is often confused with the center of domestication; the former refers to the geographical area where the largest number of wild species of the item is concentrated, while the latter refers to the place where it began to be used in its various uses (culinary, medicinal or even as a means of exchange) (Quintero, 2023).

Thesis #1 Origin in Central America: On the one hand, the north-south dispersion thesis postulates that cocoa originated in Central America and was brought to South America with the pre-Columbian indigenous migrations. It was stated that there are several archaeological evidences of migrations from Alaska to South America; they also point out that *Theobroma cacao L.* was spread by the colonizers during the conquest and colonization processes in America.

Thesis #2 Amazonian origin: On the other hand, the thesis of south-north dispersion argues that the origin of cocoa is the Amazon**.** The species was first domesticated in the Orinoco region, including the Orinoco region, and from there it spread northward through dissemination by man, animals or the wind, and was later domesticated by ancient civilizations in Central America. The precise origin of cocoa is further complicated by the fact that of the twenty-two known species, nineteen are found in South America; thirteen of them are represented in the Orinoco-Amazon region, of which ten are exclusive to this area. Cocoa was first cultivated exclusively in the Americas. The major production centers during the colonial period were Soconusco (in the coastal region between Mexico and Guatemala), Guayaquil in Ecuador and the coastal regions of northern Venezuela (Fig. 2) (Quintero, 2023).

Domestication

The evidence of cocoa as a domesticated crop comes from archaeological findings in Costa Rica indicating that cocoa was already used as a drink by the Mayans as early as 400 BC. In the 14th century, the Aztecs regarded the cocoa as the food of the Gods, placing much emphasis on the sanctity of cocoa. The spread of cocoa around the world began during the Spanish colonialism. Christopher Columbus was the first European to come in contact with cocoa, who reached Nicaragua in 1502, searching for a sea route to India. At that period, cocoa was already an important tree to the indigenous people. Cocoa beans were used as currency in some parts of Central America. It was Hernan Cortés, leader of an expedition in 1519 to the Aztec empire, who returned to Spain in 1528 bearing the Aztec recipe for xocoatl (chocolate drink) with him. The drink was initially received unenthusiastically and it was not until sugar was added that it became a popular drink in the Spanish courts. Its formula was kept as a secret to be enjoyed only by nobility.



Red: Theobroma cacao (Trinitarios)
Blue: Theobroma cacao (Criollos)
Green: Theobroma cacao (Forasteros)

Fig. 2. Global distribution of the main cocoa species

Eventually, the secret was revealed and the drinks fame spread to other lands. As the cocoa drink had become so appreciated, the European demand for the product also increased at that time, as so the interest in other new lands for expanding cocoa plantings. In 1560, the cocoa from Caracas, Venezuela, was introduced in the Island of Sulawesi, in Indonesia. In 1600, the Spanish also introduced cocoa in Philippines. In 1615, the French became aware of the use of cocoa, a century after the first discovery of the chocolate drink by the Spanish court. By the mid-1600s, the chocolate drink had gained widespread popularity in France. The Spanish princess Anna of Austria married French King Louis XIII who introduced, among other Spanish customs, the drinking of chocolate at the French court. There was increasing interest by the Europeans for new lands for the cultivation of cocoa. The French introduced cocoa in many locations, such as the islands of Martinique and St Lucia in 1660, Dominican Republic in 1665, Guyanas in 1684 and Grenada in 1714. The Caribbean Islands of Martinique became one of the major cocoa producers by 1680. The English took this crop to Jamaica by 1670; and, the Dutch took over plantations in the Curaçao islands in 1620 and introduced cocoa from Philippines to Indonesia and Malaysia in 1778. Cocoa was introduced to Bahia, in 1746, with seeds coming from Para, a northern State of Brazil. With the increase in demand for chocolate in Europe, more areas were required for expanding the cocoa plantings. Thus, the cocoa was taken to Africa in the beginning of the eighteenth century with the introduction of the Amelonado cocoa from Brazil to the islands of Príncipe (1822), São Tomé (1830) and Fernando Pó (1854). Later on, cocoa was introduced in the African continent, when it was taken from the Island of Fernando Pó to Nigeria (1874) and Ghana (1879) and, in 1905 cocoa arrived to the Ivory Coast, presently the Worlds largest cocoa producer. In Cameroon, cocoa was introduced during the colonial period of 1925-1939. There are also reports on two introductions of Trinitario cocoa from Trinidad to Sri Lanka in 1834 and 1880. And later, this variety was introduced to Singapore, Fiji, Samoa, Tanzania and Madagascar, from Sri Lanka. In Java, the failure of the coffee crop in 1880 encouraged the farmers to grow cocoa (Monteiro *et al.,* 2009). *T. cacao* is widely distributed from Southeastern Mexico to the Amazon basin. There were originally two hypotheses about its domestication; one said that there were two foci for domestication, one in the Lacandon Jungle area of Mexico and another in lowland South America. More recent studies of patterns of DNA diversity, however, suggest that this is not the case. One study sampled 1241 trees and classified them into 10 distinct genetic clusters. This study also identified areas, for example around Iquitos in modern Peru and Ecuador, where representatives of several genetic clusters originated more than 5000 years ago, leading to development of the variety, Nacional cocoa bean. This result suggests that this is where *T. cacao* was originally domesticated, probably for the pulp that surrounds the beans, which is eaten as a snack and fermented into a mildly alcoholic beverage. Using the DNA sequences and comparing them with data derived from climate models and the known conditions suitable for cacao, one study refined the view of domestication, linking the area of greatest cacao genetic diversity to a bean-shaped area that encompasses Ecuador, the border between Brazil and Peru and the southern part of the Colombian–Brazilian border. Climate models indicate that at the peak of the last ice age 21,000 years ago, when habitat suitable for cacao was at its most reduced, this area was still suitable, and so provided a refugium for the species. Cacao trees grow well as understory plants in humid forest ecosystems. This is equally true of abandoned cultivated trees, making it difficult to distinguish truly wild trees from those whose parents may originally have been cultivated **(**Wikipedia, 2023a**).** During the 16th century, following the arrival of the Spanish invaders, cargoes of cacao beans were exported to Europe. By the end of the 17th century, cacao had spread throughout Europe and further with more people enjoying cacao beverages, typically sweetened with sugar and used in milk based products (Selenohealth, 2023).

History of Cocoa: Cocoa and other chocolate products are enjoyed by billions of people around the globe, but surprisingly few people know the history of the confection. In fact, cocoa has appeared in different cultures worldwide for hundreds of years. Cocoa was first developed as a crop in many ancient South American cultures, with the Aztecs and Mayans being the most well-known of these indigenous populations. Researchers have found evidence of cocoa-based food dating back several thousand years. The modern word "chocolate" stems from two words in Nahuatl, the language spoken by many native groups: *chocolatl,* which translated literally means "hot water," and *cacahuatl*, which referred to a bitter beverage made with cocoa that was shared during religious ceremonies. The cacao bean was so significant to the local cultures that it was used as a currency in trade, given to warriors as a post-battle reward, and served at royal feasts. When the Spanish Conquistadors arrived in the New World and began the process of invading, colonizing, and ultimately destroying the native cultures, they also discovered the value of the local cacao crop. However, they brought their own innovation to the appropriated drink—the addition of sugar and spices to sweeten the bitter cocoa. After that point, chocolate became wildly popular amongst the Spanish, who kept the production method a secret from other Europeans for almost 100 years after their discovery. The Spanish could not hold onto their secret forever, and chocolate quickly spread across the rest of Western Europe. Chocolate—then still exclusively in the form of a drink—appeared in France, and then England, in royal courts and special "chocolate houses" that served the social elite. Hot chocolate was hailed by the upper classes as both delicious and healthy, and cocoa ultimately gained the reputation of being an aphrodisiac. The exclusivity of chocolate was ultimately diminished by the onset of the Industrial Revolution, when steam-powered machines made the production of cocoa powder significantly quicker and more affordable. Solid chocolate hit the market and found wild success by 1850, due to the discovery by Joseph Fry that adding cacao butter to the cocoa powder formed a solid mass. Sixty years later, the art of creating chocolate confections with flavored filling—referred to as *pralines* by their Belgian inventor, Jean Neuhaus II—went public. From there, the chocolate and cocoa industry exploded in popularity and quickly spread around the world. Throughout its centuries-long evolution, one factor has remained consistent and cocoa has attracted devotees worldwide. Today, over 4.5 million tons of cocoa beans are consumed annually around the globe, in everything from drinks to candy bars. It is safe to say that the ancient Mesoamericans who pioneered the crop could never have imagined the popularity cocoa would someday experience. To secure the future of chocolate and ensure that it's available for generations to come, it's essential that sustainable farming practices and ethical means of production are implemented in the cocoa supply chain. WCF has teamed up with over 100 companies around the world to make the cocoa supply chain more sustainable (WCF, 2018)

Cocoa consumption in Mesoamerica dates back to the pre-Hispanic period, and after the arrival of the Spaniards to the American continent, it was definitively consolidated in the 18th century as one of the most demanded products. Initially, this "Indian drink" composed of cocoa and corn, with some other ingredients such as achiote, chili and anise, was prepared in cold or hot water, having a very different flavor from the one we know today (Quiroz, 2014). Later, in 1528 Hernán Cortés took cocoa to Spain and gave it as a gift to King Carlos V, highlighting its invigorating properties. Christopher Columbus had already had contact with chocolate in 1502 during his fourth voyage to America, bringing both cocoa beans and the Aztec version of chocolate to the court, but it was not successful because of its bitter and pungent taste. Later, sugar was added to chocolate, once sugarcane began to be brought from the Canary Islands and cultivated in Mexico; then other ingredients such as cinnamon and vanilla were added. Thus, at the beginning of the 17th century, the court, the Spanish aristocracy and the high clergy became fond of the very particular flavor of chocolate (Quintero, 2023). Historians believe the Olmecs first discovered that the cocoa fruit was edible by observing rats eating it with gluttonous vigour. They soon realized the tree produced a fruit with a thousand flavours and nearly as many uses. The Olmecs (1500-400 BC) were almost certainly the first humans to consume chocolate, originally in the form of a drink. They crushed the cocoa beans, mixed them with water and added spices, chillies and herbs (Coe's Theory). They began cultivating cocoa in equatorial Mexico. Over time, the Mayans (600 BC) and Aztecs (400 AD) developed successful methods for cultivating cocoa as well. The cocoa bean was used as a monetary unit and as a measuring unit, 400 beans equalling a Zontli and 8000 equalling a Xiquipilli. During their wars with the Aztecs and the Mayans, the Chimimeken people's preferred method of levying taxes in conquered regions was in the form of cocoa beans. For these civilizations, cocoa was a symbol of abundance. It was used in religious rituals dedicated to Quetzalcoatl, the Aztec god responsible for bringing the cocoa tree to man, to Chak ek Chuah, the Mayan patron saint of cocoa and as an offering at the funerals of noblemen. Cocoa production advanced as people migrated throughout Meso-America but consumption of the drink remained a privilege for the upper classes and for soldiers during battle. By this time, the re-invigorating and fortifying virtues of cocoa were becoming widely recognized and embraced (WAC, 2023).

Discovery and Commercialization of Cocoa (16th century): In 1502, Columbus got his first glimpse of cocoa beans on a native canoe during a stop-over in Nicaragua, but he did not appreciate its awesome potential value. The true importance of this "brown gold" was not recognized until Hernando Cortez drank it with the Aztec emperor Montezuma, and brought it back to the Spanish court in 1528 along with the equipment necessary for brewing the drink. Even then, it is unlikely anyone envisaged its ultimate importance as a world commodity. Following a victorious war against the native tribes and the downfall of the Aztec civilization, Cortez intensified cultivation efforts in New Spain, with the intention of developing a lucrative trade with Europe. The Spanish court soon fell under the spell of this exotic elixir and adapted it to their taste, adding cane sugar, vanilla, cinnamon and pepper. Initially Spain reserved cocoa for its exclusive use, carefully guarding its existence from the rest of the world. They were so successful keeping cocoa secret that when a group of English pirates captured a Spanish galleon, not recognizing the value of the weighty cargo of beans, they burned them! In 1585, the first cargo of cocoa beans arrived on the Iberian Peninsula from New Spain, launching the trade in cocoa, and resulting in the establishment of the first chocolate shops, thus, ushering in a new era of rapidly growing demand for this mysterious nectar from the new world (WAC, 2023).

The expansion of cocoa in Europe (17th - 19th centuries): During the 17th century, cocoa began arriving in other ports throughout Europe, effortlessly conquering every region's palate. Chocolate beverages were first embraced by the French court following the royal marriage of King Louis XIII to the Spanish Princess Anne of Austria in 1615. In 1650 chocolate beverages first appeared in England coinciding with the arrival of tea from China and coffee from the Middle East. For many years it remained a treat reserved for the upper classes. In 1659 the first chocolate-confection maker opened in Paris. In 1720, Italian chocolate-makers received prizes in recognition of the quality of their products. Finally, in 1765, North America discovered the virtues of cocoa. In this way, chocolate developed across Europe and around the world, and slowly the presentation of chocolate changed. The first chocolate lozenge appeared in England in 1674; cocoa powder was originally produced by the Dutch in 1828; the chocolate bar originated in Great Brittan in 1830; and, the Swiss successfully entered the chocolate market with milk chocolate in 1830, followed shortly thereafter with chocolate imbued with hazelnuts. Thanks to this extended period of culinary and manufacturing innovation, chocolate consumption rapidly and continuously expanded. Pharmacological uses for cocoa and cocoa by-products were also widely explored, not too surprising given the properties its earliest consumers attributed to it (i.e. strengthening, restorative, aphrodisiac) (WAC, 2023).

Cocoa During the Industrial Era: The industrial era led to fundamental changes for chocolate and cocoa, impacting everyone from grower to end consumer. Spain, the first exporter of chocolate, opened the first chocolate factory in 1780 in Barcelona, followed shortly thereafter by Germany and Switzerland in the inexorable, relentless march towards full industrialization of cocoa. The origins of cocoa also gradually changed. Europeans began increasingly to colonise Africa, and they brought the cocoa tree with them. Cocoa was successfully planted in Sao Tome and Principe and then migrated as plantations spread throughout the African continent. The industrial epoch led to the slow decline of production in South America, despite its expansion from its original growing areas to the Amazon River and saw a new cocoa empire emerge on African soil. In effect, since the start of the 20th century, Africa has taken the lead and has become the biggest cocoa producer. Industrialization has had a marked democratizing effect on chocolate, transforming it from a rare delicacy reserved for royals, to a widely available and readily affordable treat for the masses. Not surprisingly, a plethora of new chocolate products began appearing as it became more popular, including chocolate with dried fruits, with liqueurs, fondu, praline, stuffed chocolates, powdered, spreads, frostings, pastes, hard candies, soft drinks and many, many others. Either hand-made or as a fast food, it is now an established part of the world's vocabulary and diet. Many improvements have been made since its ancient origins as a drink. Anthelme Brillat-Savarin poetically summed up our universal love affair with chocolate "What is health? It is chocolate!" (WAC, 2023).

Key dates

France, 1776 Doret invents a hydraulic process to grind cocoa beans into a paste, facilitating the first large-scale production of chocolate.

Holland, 1828 Chemist Coenraad van Houten invents a process for extracting cocoa butter, allowing for the extraction of cocoa powder. This makes chocolate more homogenous and less costly to produce.

England, 1847 Solid chocolate is offered to the general public for the first time, by the English company Fry and Sons (prior to this time, solid chocolate was available exclusively within royal courts).

Switzerland, 1830-1879 Chocolate flavored with hazelnuts is followed by milk chocolate, developed by Daniel Peter and Henri Nestlé respectively. During the same period, Rodolphe Lindt develops the chocolate fondant (fondu).

United States, 1893 Sweet maker Milton Hershey spots chocolate making equipment at the Worlds Fair in Chicago and begins production at a factory in Pennsylvania.

Chocolate followed the French and American infantry into the trenches of the First World War, and effectively all US chocolate production was requisitioned for the military during the Second World War. In France, chocolate sweets appeared between the wars, and French pralines (chocolates filled with almond and other nut based fillings) were considered the most fashionable. This inspired chocolate producers to experiment with new flavors, such as almond paste, cherries in aqua vitae, nougat, caramel (WAC, 2023).

History of cultivation: Cultivation, use, and cultural elaboration of cacao were early and extensive in Mesoamerica. Ceramic vessels with residues from the preparation of cacao beverages have been found at archaeological sites dating back to the Early Formative (1900–900 BC) period. For example, one such vessel found at an Olmec archaeological site on the Gulf Coast of Veracruz, Mexico dates cacao's preparation by pre-Olmec peoples as early as 1750 BC. On the Pacific coast of Chiapas, Mexico, a Mokaya archaeological site provides evidence of cacao beverages dating even earlier, to 1900 BC. The initial domestication was probably related to the making of a fermented, thus alcoholic, beverage. In 2018, researchers who analysed the genome of cultivated cacao trees concluded that the domesticated cacao trees all originated from a single domestication event that occurred about 3,600 years ago somewhere in Central America. Several mixtures of cacao are described in ancient texts, for ceremonial or medicinal, as well as culinary, purposes. Some mixtures included maize, chili, vanilla (*Vanilla planifolia*), and honey. Archaeological evidence for use of cacao, while relatively sparse, has come from the recovery of whole cacao beans at Uaxactun, Guatemala and from the preservation of wood fragments of the cacao tree at Belize sites including Cuello and Pulltrouser Swamp. In addition, analysis of residues from ceramic vessels has found traces of theobromine and caffeine in early formative vessels from Puerto Escondido, Honduras (1100–900 BC) and in middle formative vessels from Colha, Belize (600–400 BC) using similar techniques to those used to extract chocolate residues from four classic period (around 400 AD) vessels from a tomb at the Maya archaeological site of Rio Azul. As cacao is the only known commodity from Mesoamerica containing both of these alkaloid compounds, it seems likely these vessels were used as containers for cacao drinks. In addition, cacao is named in a hieroglyphic text on one of the Rio Azul vessels. Cacao is also believed to have been ground by the Aztecs and mixed with tobacco for smoking purposes. Cocoa was being domesticated by the Mayo Chinchipe of the upper Amazon around 3,000 BC (Wikipedia, 2023a).

Modern history: The first European knowledge about chocolate came in the form of a beverage which was first introduced to the Spanish at their meeting with Moctezuma in the Aztec capital of Tenochtitlan in 1519. Cortés and others noted the vast quantities of this beverage the Aztec emperor consumed, and how it was carefully whipped by his attendants beforehand. Examples of cacao beans, along with other agricultural products, were brought back to Spain at that time, but it seems the beverage made from cacao was introduced to the Spanish court in 1544 by Kekchi Maya nobles brought from the New World to Spain by Dominican friars to meet Prince Philip. Within a century, chocolate had spread to France, England and elsewhere in Western Europe. Demand for this beverage led the French to establish cacao plantations in the Caribbean, while Spain subsequently developed their cacao plantations in their Venezuelan and Philippine colonies. A painting by Dutch Golden Age artist Albert Eckhout shows a wild cacao tree in mid-seventeenth century Dutch Brazil. The Nahuatl-derived Spanish word *cacao* entered scientific nomenclature in 1753 after the Swedish naturalist Linnaeus published his taxonomic binomial system and coined the genus and species *Theobroma cacao*. Traditional pre-Hispanic beverages made with cacao are still consumed in Mesoamerica. These include the Oaxacan beverage known as *tejate* **(**Wikipedia, 2023a**).**

TAXONOMY

Cocoa belongs to the Family Sterculiaceae/Malvaceae (mallow family), Genus *Theobroma* and species *Theobroma cacao* L. **(**Growables, 2023; Wikipedia, 2023a**).** *Theobroma* is exclusively neotropical in origin and its natural dispersion is in the tropical lowland rainforests which extend from the Amazon basin through Southern Mexico (Cuatrecasas, 1964). Several studies on its morphological, anatomical, palynological and chemical characteristics as well as its DNA sequences have confirmed the inclusion ofthe family Sterculiaceae in a broadly defined Malvaceae *sensu latu* or Theobromeae (Takhtajan, 1997). There is minimal evidence on the practice of cacao cultivation by the various indigenous groups of the Amazonian rainforest. The wild relatives of cacao thus include two different groups of germplasm. The first is the large spectrum of wild populations which grow simultaneously in the Amazonian rainforest, ranging from French Guiana to Bolivia. There is no reproductive barrier between cultivated and wild cacao trees. Morphological characteristics of even the ancient cultigens, Criollo cacao from Mesoamerica, are similar to those of their wild counterparts. Wild cacao,therefore, may be used in breeding or commercial production, either as progenitors or asclones. The second category of wild cacao is that of the 22 related *Theobroma* species (Cuatrecasas, 1964), although these show crossing barrier with *T. cacao*. Three scholarly publications to date have recogniseda different number of species of *Theobroma* before Cuatrecasas (1964), which included 18species , 11 species and 13 species. Bernoulli (1869) described five categories based on floral morphology and fruit structure.These are:

***Cacao*:** Petal ligule stipitate; staminodes erect, subulate; stamens 2-antheriferous; calyx 5-parted, the laciniae equal. Ovate-oblong fruit included four species: *T. cacao* L.; *T. pentagona*, 'cacao lagarto' from Guatemala; *T. leiocarpa*, 'cumacaco' from Guatemala; and *T. saltzmanniana* from Bahia, Brazil.

Oreanthes: Petal appendix subsessile; staminodes erect, subulate; stamens 3-antheriferous; calyx 5-parted, the laciniae equal, included three species: *T. speciosa* Willd. Ex Spreng.; *T. quinquenervia* and *T. spruceana*, all from Brazil.

***Rhytidocarpus*:** Petal appendix subsessile; staminodes erect, claviform; stamens 2-antheriferous; calyx 5-parted, the laciniae equal; fruit woody, included two species:
T. bicolour Humb. & Bonpl. (synonym, *T. ovatifolia* DC.) and *T. glauca* Karst.

***Telmatocarpus*:** Petal appendix; staminodes erect, linear-subulate with broad base; stamens 3-antheriferous; calyx 5-parted, the laciniae equal; fruit ovate, lacunose, included only one species: *T. microcarpa* Mart.

***Glossopetalum*:** Petal ligule stipitate; staminodes reflexed, petaloid; stamens 3-antheriferous; calyx irregularly 3-5-fid, foliaceous; fruit sublignose. This is the largestsection, including eight species: *T. augustifolia* DC.; *T. subincana* Mart.; *T. sylvestris* Mart.; *T. macrantha* from Brazil; *T. ferruginea* from Peru; *T. obovata* from Brazil; *T. alba* from British Guiana and *T. nitida* from Brazil.

Theobroma is the name given by Linnaeus meaning "Food of the Gods" (Greek name Theos = Gods, Broma = Food) to the chocolate tree cocoa. *Theobroma bicolor* and *grandiflorum* are other better known species. *T. bicolor* is typical with the inflorescence appearing in the axils of new leaves and the branches bent down as the pods reach maturity. Seeds of *Theobroma bicolor* are used as adulterant. *Theobroma cacao* is a diploid with 2n = 20. *Theobroma cacao* ssp.*cacao* includes Criolla populations of Central and South America and *Theobroma cacao* ssp. *sphaerocarpum* which includes other populations like Forastero and Trinitario (Auxcilia and Shab, 2017). *Theobroma cacao* is a tropical tree native to the Americas. There are about 20 different species in the *Theobroma* family, which came from a common ancestor and share many features. Cacao's siblings *Theobroma bicolor* and *Theobroma grandiflorum* can create a product similar to chocolate. Around ten million years ago cacao diverged from its common ancestor. Since then, evolution and human interference have led to new types and the variation we see today (Frizo, 2018).

Cuatrecasas (1964) proposed that North and South American cacao populations developed into two forms, separated by the Panama Isthmus, and thatthis can be attributed to the great morphological diversity observed in Central as wellas in South America. These populations evolved independently and are recognised as separate subspecies (*T. cacao* ssp. *cacao* and *T. cacao* ssp. *sphaerocarpum*). Furthermore, Cuatrecasas (1964) hypothesised that wild plants from the Lacandon rainforest from Mexico may possibly be ancestors of domesticated cacao. The subspecies proposedby Cuatrecasas correspond to the two morphogeographic groups namely Criollo, which corresponds to *T. cacao* ssp. *cacao,* and Forastero, which corresponds to *T. cacao* ssp. *sphaerocarpum,* proposed by Cheesman (1944). A third hybrid group was called Trinitario, originating from crosses between Criollo and Forastero. The Forastero group is composed of very diverse populations with different geographic origins such as Upper Amazon, Lower Amazon, Orinoco and the Guianas and can be identified according to the pod morphology, for example, the Amelonado type (Bhattacharjee, 2018).

The genus Theobroma comprises more than 22 species, including other cocoa-like fruits, also native to the Amazon basin. These include copoazú (*Theobroma grandiflorum*) and mocambo (*Theobroma bicolor*) (ICCO, 2006; Kunikullaya *et al.,* 2018; Quintero, 2023). Cacao (*Theobroma cacao*) is one of 26 species belonging to the genus *Theobroma* classified under the subfamily Byttnerioideae of the mallow family Malvaceae. In 2008, researchers proposed a new classification based upon morphological, geographic, and genomic criteria: 10 groups have been named according to their geographic origin or the traditional cultivar name. These groups are: Amelonado, Criollo, Nacional, Contamana, Curaray, Cacao guiana, Iquitos, Marañon, Nanay, and Purús (Wikipedia, 2023a). Statistics of the *Plant List* includes 71 scientific plant names of species rank for the genus *Theobroma*. Of these 22 are accepted species names.

Synonyms (Wikipedia, 2023a)

- *Cacao minar* Gaertn.
- *Cacao minus* Gaertn.
- *Cacao sativa* Aubl.
- *Cacao theobroma* Tussac
- *Theobroma cacao f. leiocarpum* (Bernoulli) Ducke
- *Theobroma cacao subsp. leiocarpum* (Bernoulli) Cuatrec.
- *Theobroma cacao var. leiocarpum* (Bernoulli) Cif.
- *Theobroma cacao subsp. sativa* (Aubl.) León
- *Theobroma cacao var. typica* Cif.
- *Theobroma caribaea* Sweet
- *Theobroma integerrima* Stokes
- *Theobroma kalagua* De Wild.
- *Theobroma leiocarpum* Bernoulli
- *Theobroma pentagonum* Bernoulli
- *Theobroma saltzmanniana* Bernoulli
- *Theobroma sapidum* Pittier
- *Theobroma sativa* (Aubl.) Lign. & Le Bey
- *Theobroma sativa var. leucosperma* A. Chev.
- *Theobroma sativa var. melanosperma* A. Chev.
- *Theobroma sativum* (Aubl.) Lign. & Bey

Synonyms (Growables, 2023).

T. cacao subsp. *cacao*;
T. cacao f. *leiocarpum* (Bernoulli) Ducke;
T. cacao subsp. *leiocarpum* (Bernoulli) Cuatrec.;
T. cacao var. *leiocarpum* (Bernoulli) Cif.;
T. cacao subsp. *pentagona* (Bernoulli) León;
T. cacao subsp. *sativa* (Aubl.) León;
T. cacao subsp. *sphaerocarpum* (A. Chev.) Cuatrec.

Biological Varieties: A tree begins to bear when it is four or five years old. A mature tree may have 6,000 flowers in a year, yet only about 20 pods. About 1,200 seeds (40 pods) are required to produce 1 kg of cocoa paste. Cacao trees can be categorised into three major biological varieties, which each possess their own unique properties and qualities. The major varieties are Criollo, Forastero, and Trinitario. Historically, chocolate makers have recognized three main cultivar groups of cacao beans used to make cocoa and chocolate: Forastero, Criollo and Trinitario. The most prized, rare, and expensive is the Criollo group, the cocoa bean used by the Maya. Only 10% of chocolate is made from Criollo, which is arguably less bitter and more aromatic than any other bean. The cacao bean in 80% of chocolate is made using beans of the Forastero group, the main and most ubiquitous variety being the Amenolado variety, while the Arriba variety (such as the Nacional variety) are less commonly found in Forastero produce. Forastero trees are significantly hardier and more disease-resistant than Criollo trees, resulting in cheaper cacao beans (Wikipedia, 2023a). Currently, three main varieties of cocoa are known: Criollo (mainly Caribbean and Central American), Forastero (Amazonian, but mostly grown in Africa) and Trinitario (hybrid). At least ten modern cocoa families are grouped around these three names (Conceptdaily, 2023).

Traditional Classification: There are four main categories of cocoa trees in the traditional classification of world crops: Criollo, Trinitario, Forastero and Nacional. Each of these trees produces beans that are used in a variety of ways, depending on their properties and the conditions in which they are grown **(Fig. 3)** (Chocolate, 2020):

***Forastero*:** This is certainly the most cultivated group of cocoa trees in the world. In fact, it accounts for 80% to 90% of the world's cocoa production. The Amazonian Forastero are so common on cocoa farms because of their resistance to disease and because they mature quickly. This type of cocoa tree has other advantages such as its vigor and high productivity. Forastero trees grow in West Africa, Central America, North and South America, Brazil and Ecuador. Because of its high yield and ease of cultivation, this type of cocoa tree may well become more widely grown in the future. The quality of most Forastero cocoa beans is considered "standard", while the variety grown in Ecuador offers superior cocoa quality. This group of trees is recognizable by its smooth yellow and green pods, its purple-colored almonds and the bitter taste of its cocoa. The cocoa beans of these cacao trees contain a large amount of tannin. This type of tree has 30 to 40 cocoa beans per pod (Auxcilia and Shab, 2017; Wikipedia, 2023). Forastero means ‘foreigner’ in Spanish. It refers to any trees that are not Criollo or a hybrid and which usually produce deep purple seeds (Hebbar *et al.*, 2011). The term encompasses a wide range of distinct populations with unique characteristics and is not a meaningful descriptive term. Forastero is native to the Amazon region and largely grown in West Africa and Southeast Asia. It forms 95% of world cocoa production (Afoakwa, 2010; Fowler, 2009) and is the most widely used due to its higher yield than the Criollo variety. Because of the high genetic variability within this group, Forastero types exhibit greater variability in tree and fruit morphology and are generally more vigorous and less susceptible to disease and pests than are Criollo trees. When ripe, the pods are hard and yellow, have a rounded melon-like shape and contain 30 or more beans ranging in colour from pale to deep purple. Several landraces are particularly well known. Grown mainly in Brazil and Africa, it is hardier, higher yielding and easier to cultivate than Criollo and is used in every blend of chocolate that is produced. The Amelonado type is widely grown throughout Western Africa and produces the majority of ‘bulk cacao’ beans. Although Forastero beans are said to produce chocolate rich in chocolate flavour but low in complex or fruit flavour notes, there are several well-known exceptions. Forastero may be subdivided into Upper Amazonian [wild or semi-wild cacaos as described by Pound (1938) and Lower Amazonian, characterised by a rather uniform pod type called Amelonado (non-pigmented, smooth, melon-shaped pods with a blunt end). Lower Amazonian cacaos now constitute the most prevalent cultivated type worldwide and are grown notably in West Africa and Brazil. These types grow wild in the Guyanas and the eastern Brazilian Amazon and may have been partially domesticated by pre-Colombian Amazonian natives for their aromatic pulp (Barrau, 1979).

***Criollo*:** Criollo cocoa trees stand out for the flavor of their beans. In fact, this family of cacao trees is highly appreciated by chocolate makers for the preparation of luxury products. The cocoa from the Criollo tree group is not very bitter, and has a strong aroma and a remarkable finesse on the palate. Although the sweet flavor of these beans is appreciated in the industry, it isn't produced in large quantities by farmers because these trees are fragile and susceptible to diseases. Today, this type of cocoa tree is much less present on the cocoa market (barely 0.1% of the world production) compared to other species. However, Criollo beans tend to ferment easily. Vegetative propagation, a common reproduction method in cocoa tree cultivation, is not easy with this type of tree (Auxcilia and Shab, 2017; Wikipedia, 2023). The Criollo group refers to genetically similar trees, believed to have been domesticatedby the Mayan civilisation. The seeds (beans) tend to be round in profile and contain whiteor pale purple cotyledons. Young seedlings can be identified by the presence of green cotyledons and by that of leaf stems (petioles) with a horizontally opposed orientation. This variety displays low vigour, poor productivity and high susceptibility to diseases, insects and stress and is therefore less widely cultivated (Afoakwa, 2010). Until the mid-eighteenth century, Criollo was the most commonly cultivated type of cacao; however, the vast majority of these trees have been replaced with more vigorous and hardy trees of hybrid or ‘Forastero’ ancestry. This type is very rare and is only found in old plantations in Venezuela, Central America, Madagascar, Sri Lanka and Samoa (Fowler, 2009). The yield of Criollo plantations is lower than that of Forastero. Notable characteristics include a unique growth habit that frequently lacks the usual whorl of five branches (jorquette) andconsists entirely of plagiotropic stems with occasional bi- and trifurcating branches. Fruits typically have a soft thin husk with a textured surface and usually have some degree of red pigmentation. Chocolate made from Criollo is light in colour and has a subtle or delicatetaste that is low in basic chocolate flavour. Criollo beans are often sold at higher prices,which can somewhat offset their lower yield. Criollo may be translated as ‘native’ or ‘first grown’ in Spanish-speaking countries of the Americas. It should be noted that so-called Criollo cacao in many countries may not have the typical genetic profile of pure Criollo.

Trinitario: The provenance of the Trinitario cocoa group is unclear. However, it is very likely that they are hybrids from a cross between a variety of Criollo and Amazonian Forastero. The quality of their cocoa and their distinctive features seem to indicate that they are the result of a subtle blend between these two groups. The color of the beans, the size of the trees and the shape of the pods can vary depending on the species of Trinitario. The elusive and somewhat intermediate botanical character of this group of cocoa trees is appealing to chocolate makers. The Trinitario cocoa tree accounts for between 10 and 15% of the world's cocoa-producing trees. The different varieties of this group of trees are cultivated in many countries, such as Venezuela, Brazil, Mexico and Cameroon. The Trinitario trees have red pods, like the Criollo, which turn orange as they ripen. On average, 150 pods are produced by one tree in one year, which is equivalent to about 6 kg of cocoa (Auxcilia and Shab, 2017; Wikipedia, 2023). In the strict sense, Trinitario refers to clones, or the progenies, of hybrids originally producedin Trinidad between ‘Criollo’ and ‘Forastero’ trees which originated in the lower Amazon River basin. However, it later spread to Venezuela, Ecuador, Cameroon,Samoa, Sri Lanka, Java and Papua New Guinea. It is believed that it first came into existence on the island of Trinidad, after a hurricane nearly destroyed the local Criollo crops in 1727. Some Trinitario varieties produce cocoa beans with special flavours. They have hard pods and are variable in colour, containing 30 or more beans of variable colour, although white beans are rare. Trinitario is considered to be either an intermediate type between Criollo and Forastero or a group of hybrids displaying characteristics which include the total range of variation (Cheesman, 1944). The Trinitarios combine the best characteristics of the two main varieties: the hardiness andhigh yield of Forestero and the refined taste of Criollo. Trinitario types have not been found under wild conditions. Because Criollos and Forastero types are so heterogeneous, the resulting hybrids might not be distinct from the parental populations, making Trinitariosimpossible to define except by geographical origin.

Nacional: The Nacional variety grows in Ecuador and is believed to have originated from the Amazonian area of Ecuador (Fowler, 2009; Afoakwa, 2010). It has distinct characteristics of aroma and flavour. Although less widely cultivated and contributing to only 5% of global cocoa production, it represents more than 50% of the fine cocoa marketed worldwide every year. Until the beginning of twentieth century, Nacional cultivars were the only type of cocoa cultivated in Ecuador with the unique flavour and aroma, known as ‘arriba’. The fine flavoured quality chocolate products obtained from Nacional cocoabeans are highly valued by chocolate manufacturers. However, the original Nacional cocoa trees are currently in danger of extinction due to the introduction of an external unrelated germplasm (Solorzano *et al.*, 2012). A large genetic admixture between nativeNacional cocoa and foreign germplasm is currently found in modern Ecuador plantations(Solorzano et al., 2009), thus reducing the fine-flavoured cocoa aroma. Currently, pure Nacional cocoa varieties are rare and there is an increasing demand for fine flavour cocoa although Ecuador still represents 6.8% of the supply of 'arriba' flavoured cocoa in the world market (ICCO, 2012).

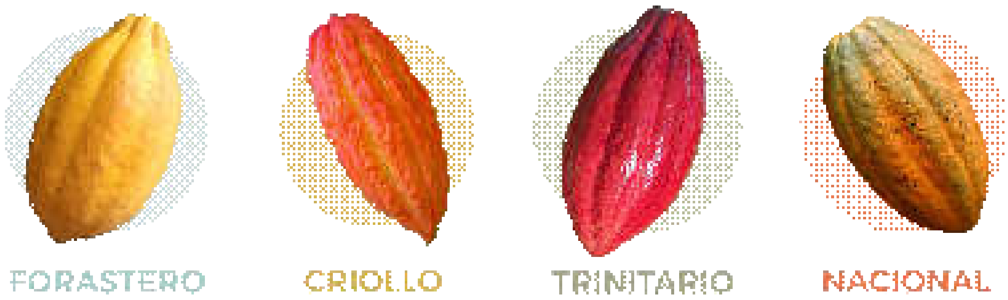


Fig. 3. Four main groups of varieties: Forastero, Criollo, Trinitario, and Nacional

New classification: In 2008, researchers from the study "Geographic and Genetic Population Differentiation of the Amazonian Chocolate Tree (*Theobroma cacao* L)" suggested a new, more accurate classification based on genetic criteria. The ten groups suggested in the study are : Amelonado, Criollo, Nacional, Contamana, Curaray, Cacao guiana, Iquitos, Marañon, Nanay, Purús. This classification is recommended for both wild and cultivated cocoa trees and allows producers to better assess the characteristics of their plantation through the proper identification of the trees (Motamayor *et al.* (2008).

Amelonado: The Amalonado cocoa is unique in that it has dark purple beans. It is quite fatty, but also a bit bitter and releases aromas of coffee, wood and spices (mainly cinnamon and vanilla). The Amelonado gets its name from its round melon-shaped pod. It is mostly found in French Guiana, which suggests an eastern Amazonian origin. It used to be found in West Africa, but it is disappearing, wiped out by the production of hybrid cocoa trees, which are extremely prolific.

Criollo: The Criollo cocoa tree can be found in Venezuela and is characterized by its unique vertical branch. Its pods are warty, which means that they are not smooth, but have protrusions. They are yellow and often turn green or red. Its seeds are large, but rarely exceed the number of 50 per pod, which reduces its chances to reproduce. The Criollo requires a short fermentation time and a quick roasting at low temperatures. It has a delicate flavor and is not very bitter. The Criollo is a very old crop, dating back to pre-Columbian times. It was highly prized by the Mesoamericans, who appreciated its fine taste that could be savored pure. The Criollo has survived for centuries, but it is complicated to cultivate, which has made it somewhat obsolete. Its yields are low, but also variable, which is risky for the growers who choose to grow it. These trees are fragile, particularly because of the thin skin of the pods. The fragility of the cocoa means that it is rare. Nevertheless, the finesse of its aromas is such that it remains a highly coveted cocoa.

***Nacional*:** Nacional is a very fine cocoa with purple-red beans. They can also be pale white, and they darken during fermentation. The tree is medium in size, with oval-shaped yellow-orange pods when they are ripe. Nacional is naturally sweet, not very bitter, nor very fatty. It has a unique bouquet of aromas that combine floral violet, lilac, jasmine and orange blossom. Depending on its origin, it can exude fragrances of black figs and cinnamon. According to its DNA, the Nacional is a distant subspecies of the Amazonian types and is not related to the Criollo. It probably originates from the foothills of the Andes, drained by the rivers of the upper Rio Marañon where it still thrives. The Nacional is considered to be the traditional Ecuadorian cocoa, although it is also present in Peru. However, its vulnerability to disease makes it difficult to cultivate and is being replaced by more resistant species. There have been attempts to transplant it elsewhere with limited success. Trees grown outside Ecuador rarely produce the same floral finesse as in its native territory.

Contamana: Contamana is related to Nacional cocoa. However, it is more robust and its small purple seeds have a slight bitterness. Its flavor reminds us of dried brown fruits and flowers. Contamana was discovered by FJ Pound in 1937 in the Ucayali River Valley in Peru. FJ Pound was an agronomist from the Department of Agriculture in Trinidad. He was looking for a cocoa tree that could resist witches' broom disease. Witch's Broom disease is caused by the Crinipellis perniciosa pathogen and the Nacional is highly susceptible to it. This disease can strike at any time and last for years. The fungi it causes cause an anarchic development of the axillary buds. Pound was satisfied with the Contamana, which has the ability to effectively neutralize the witches' broom disease.

***Curaray*:** Curaray cocoa gets its name from the Peruvian river of the same name. It has similarities with other varieties from the same Amazon region: the Nacional, Contamana and Iquitos. Its genetic structure has common characteristics with those of the Nacional and the Criollo. However, Curaray grows in a small area in the Amazon region of Ecuador, unlike its relatives which tend to cover larger areas. Curaray has not yet been studied enough to determine its specific characteristics and continues to be produced in small quantities. Research efforts, genetic manipulations and hybridizations could be considered to make better use of it.

***Guiana*:** Guiana has a high number of small seeds, which is considered a defect by growers who find it difficult to cultivate it in large quantities. Guiana has a very fine taste with a slight bitterness. Its strong aromatic intensity is attributed to its high content of purine, an organic aromatic compound found in cocoa that delivers delicious flavors. Guina is mostly found around the Camopi, Oyapok and Tanpok river basins in southeastern French Guyana. It is known for its genetic originality and extreme robustness. It is capable of resisting to many diseases, especially the witches' broom.

***Iquitos*:** Iquitos cocoa come from the same region of Peru. Iquitos is a department of the Peruvian Amazon deep in the heart of the forest. These are extremely dense forests where the cocoa tree is very popular. The Iquitos cocoa are quite bitter. Their flat seeds are purple or violet and generate tannins that give body and fullness to the chocolate they produce. However, they require more careful processing (longer fermentation and higher roasting temperature) to reduce the inherent bitterness, acidity and astringency. The final result is of great finesse. When they do not benefit from these additional treatments, these Amazonian cocoa beans do not perform well in the production of low-end confectionery. Iquitos cocoa trees are known for their vigor and resistance to disease. They can grow in the wild or be cultivated on a large scale. These two varieties are grown by two types of producers: those who prefer quantity and those who prefer to limit their production to focus on quality. The flavors stand out during the fermentation and roasting process.

***Nanay*:** Nanay cocoa come from the same region of Peru. The Nanay is a river that flows into the Peruvian Amazon. These are extremely dense forests where the cocoa tree is very popular. The Nanay cocoa are quite bitter. Their flat seeds are purple or violet and generate tannins that give body and fullness to the chocolate they produce. However, they require more careful processing (longer fermentation and higher roasting temperature) to reduce the inherent bitterness, acidity and astringency. The final result is of great finesse. When they do not benefit from these additional treatments, these Amazonian cocoa beans do not perform well in the production of low-end confectionery. Nanay cocoa trees are known for their vigor and resistance to disease. They can grow in the wild or be cultivated on a large scale. These two varieties are grown by two types of producers: those who prefer quantity and those who prefer to limit their production to focus on quality. The flavors stand out during the fermentation and roasting process.

Marañon: Cocoa farming is widespread in the Marañón Canyon. The cocoa from these trees is considered to be of high quality. Marañón has been produced from wild cocoa trees for a long time in this valley. According to historical records, the beans were already harvested at the beginning of the 20th century. Since then, they have been cultivated and selected to produce the finest quality beans. The best quality trees are isolated and then they are used to create new plantations. The farmers follow very closely the potential appearance of diseases to eradicate immediately. The treatments are as organic as possible and the farms are very productive, with harvests of excellent quality. The traditional cultivation of Marañón is very labor intensive. When the rules are followed, the pods are harvested manually and rigorously selected. Almost half of the beans are white (at least 40%). The entire harvest is then processed as naturally as possible, on tables specifically design for fermentation. They are then regularly turned over - always by hand - and dried in the sun under tarps. If this process is respected, farmers can get beans of exceptional quality with a fruity and floral taste, which are then turned into chocolate.

***Purús*:** Purús cocoa is found in Brazil near the rio Purús, in the area surrounding the cities of Maracaju and Boca do Acre and the Arapixi reserve. It grows mostly in the wild, on one of the most fertile lands in the Amazon, characterized by an alluvial and clayey soil. However, the fact that these trees are scattered makes it very difficult to harvest them. Harvesters have to travel in canoes on the Rio Purús. After landing to pick the beans from a few trees, they return to their boat and paddle to another strategic place where other cacao trees are growing. The productivity of their farm is therefore very low. Purús cocoa is known for its intense color. Its pods are quite small and are predominantly yellow. The flavors are quite spicy and very rich. Purús cocoa allows the production of very high quality chocolates, but they are often expensive because they require a lot of labor to be harvested.

Morris (1882) was the first to publish the nomenclature of the cultivars of *Theobroma cacao*. He distinguished two classes, the second of which was divided into the following several varieties:

- Class I: Cacao Criollo (Red)
- Class II: Cacao Forestero
  - Var. a. Cundeamor verugoso Amarillo (rough yellow Cerasee)
  - Var. b. Cundeamor verugoso Colorado (rough red Cerasee)
  - Var. c. Liso amarillo (smooth yellow)
  - Var. d. Liso colorado (smooth red)
  - Var. e. Amelonado amarillo (yellow melon)
  - Var. f. Amelonado colorado (red melon)
  - Var. g. Calabacillo amarillo (yellow calabash)
  - Var. h. Calabacillo colorado (red calabash)

In 1892, Hart modified Morris' classification of the varieties of *T. cacao* and distinguishedthe following classes:

- Class I: Criollo
  - Trinidad Criollo
    - var. a. Amarillo (yellow, thick-skinned, bottle-necked)
    - var. b. Colorado (red, thin-skinned, bottle-necked)
  - Venezuelan Criollo
    - var. a. Amarillo (yellow, thick-skinned, high-shouldered, sometimes pointed)
    - var. b. Colorado (red, thick-skinned, high-shouldered, sometimes pointed)
  - Nicaraguan Criollo
    - var. a. Amarillo (yellow, thick-skinned, high-shouldered, very large beans with light-coloured interior)
    - var. b. Colorado (red, thick-skinned, high-shouldered, very large beans with light-coloured interior)

- Class II: Forastero
  - var. a. Cundeamor verugoso Amarillo (yellow-warted)
  - var. b. Cundeamor verugoso Colorado (red-warted)
  - var. c. Ordinary amarillo (yellow forastero)
  - var. d. Ordinary colorado (red forastero)
  - var. e. Amelonado amarillo (yellow, melon-shaped)
  - var. f. Amelonado Colorado (red, melon-shaped)

- Class III: Calabacillo
  - var. a. Amarillo (yellow, flat-beaned, smooth, thin- or thick-skinned, small pods)
  - var. b. Colorado (red, flat-beaned, smooth, thin- or thick-skinned, small pods)

Theobroma pentagona (alligator cacao: yellow, heavily warted pods with five distinctly raised ribs, large beans having white- or light-coloured interior) (Bhattacharjee, 2018).

In 1944, Cheesman concluded that the whole assemblage of wild, semi-wild and cultivated cacao constitutes one interbreeding population and supported the main division ofcacao into two groups of varieties, Criollo and Forastero. He divided Criollo into Central American and South American Criollos. The Forasteros were divided into Amazonian Forasteros, which can be found wild in Amazonia, and which are widespread in cultivation, and the Trinitarios, possibly originating from the mingling of South American Criollo and Amazonian Forastero stocks. He suggested that *T. pentagonum* was a simple form of *T. cacao*, probably a segregate of the large cross-fertilised population. Cuatrecasas (1964) described 22 species based on the classical method of comparative morphology suchas the structure of fruit and vegetative characteristics. He classified the species into sixsections:

1) ***Andropetalum*** (*T. mammosum* Cuatr. & Leon);
2) ***Glossopetalum*** [*T. angustifolium* Moçiño & Sessé, *T. canumanense* Pires & Fries, *T. chocoense* Cuatr., *T. cirmolinae*Cuatr., *T. grandiflorum* (Willd. ex Spreng.) Schum., *T. hylaeum* Cuatr., *T. nemorale* Cuatr., *T. obovatum* Klotzsch ex Bernoulli, *T. simiarum* Donn. Smith., *T. sinuosum* Pavon ex Hubber, *T. stipulatum* Cuatr., *T. subincanum* Mart.];
3) ***Oreanthes*** (*T. bernouillii* Pittier, *T. glaucum* Karst., *T. speciosum* Willd., *T. sylvestre* Mart., *T. velutinum* Benoist);
4) ***Rhytidocarpus*** (*T. bicolor* Humb. & Bonpl.);
5) ***Telmatocarpus*** (*T. gileri* Cuatr., *T. microcarpum* Mart.) and
6) ***Theobroma***(*T. cacao* L.).

Representative species from all the sections can be found in Brazil, exceptfor *Andropetalum* (*T. mammosum*). The species which occur in, and are restricted to, the Amazon basin of Brazil are: *T. grandiflorum*, *T. obovatum*, *T. subincanum*, *T. speciosum*, *T. sylvestre*, *T. microcarpum*, *T. glaucum*, *T. canumanense*, *T. bicolor* and *T. cacao*, (Cuatrecasas 1964).

From the genetic point of view, cocoa can be subdivided into:

Criollo Cocoa: The plant is very susceptible to pests and diseases, with low yields. However, the high quality of its almonds stands out. Consequently, this type of cocoa, which dominated the market until the middle of the eighteenth century, has been replaced by other more resistant varieties and has reduced the production of pure Criollos, currently representing about 5% of the world market. This cocoa is generally medium to large beans (80 to 90 beans per 100 grams), with a brownish-ivory to very light brown cotyledon, sweet cocoa flavor and a characteristic delicate aroma. Today, Criollo cocoa is not only used to refer to white or light-colored cocoa beans, but also to cocoa grown in cocoa-growing regions that have achieved fame due to the quality of their Criollo cocoa, even though they constitute diverse populations due to subsequent crosses with hybrids and Forasteros. Thus, homozygous Criollo cocoas have recently been called "Old Criollos", referring to the cocoas that were cultivated by the ancient settlers of America, whilethe so-called "Modern Criollos" correspond to hybrid Criollo cocoas.

Forastero Cacao: It is characterized for being a plant more resistant to diseases than Criollo cocoa, and of medium to high production level. It generally produces small to medium kernels (approximately 90 to 110 kernels per 100 grams) and dark cotyledon**.** It is the most produced type of cocoa in theworld, representing approximately 95% of world production, mainly from West African countries.Populations of Forastero cocoa in wild and semi-wild spontaneous state, as well as cultivated, have been found in the Guianas, in the Orinoco and Amazon basins, from the upper basin that originates in the Andes and includes part of the territories of Colombia, Ecuador and Peru, to the lower basin in the Amazon region of Brazil.

National Cocoa**:** It of Ecuador is considered Forastero but presents some Criollo characteristics; since it is very susceptible to the Witches' Broom disease*(Crinipellis perniciosa*); it has practically been replaced by hybrids that show greater tolerance to this disease.

Trinitario Cocoa is more resistant and productive than Criollo, but of inferior quality. It is the result of crossing Forastero and Criollo cocoa.

From a commercial point of view, cocoa can be classified into two categories on the world market

Ordinary Cocoa**:** Corresponds to the Forastero type. They are called "***basic beans***" in the United States and "***bulk beans***" in Europe and are used in the manufacture of cocoa butter and products with a high proportion of chocolate.

Fine or Flavored Cocoa**:** Criollos and Trinitarios beans correspond to what is known in the world market as fine or aroma cocoa. They are known as "fines" in Europe and "***flavor beans***" in the United States. They have distinctive aroma and flavor characteristics in fine chocolates and coatings and are generally used in blends with ordinary or foreign beans to produce specific odors and flavors in finished products.

BOTANICAL DESCRIPTION

Cocoa is a plant with feeder root surface (mostly developing lateral roots near the soil surface). Thickness of rooting zone in the good soil is 30-50 cm. At low soil water, roots grow long and riding the lateral roots into the soil, whereas at high soil water & clay soil, the roots do not grow up riding so deep and lateral roots grow near the soil surface. The original habitat of the cocoa plant is a tropical forest with a canopy of tall trees, rainfall and humidity is high, so the plants grow tall. In the garden, plant height was 3 years at 1.8 - 3 meters and at the age of 12 years reached 4.5 - 7 meters. Cocoa crop is dimorphous (two forms have branches) namely orthotrop branches (branches that grow upward) and plagiotrop (branches that grow sideways). Leaves on main stem and branches have orthotrop formula leaves 3 / 8 and the formula has cabag plagiotrop ½ leaves. 30 cm long and 7.5 cm wide. Flowers are cauliflorous cocoa means growing flowers and fruit grow attached to the stem or branch. Cocoa plant as many as 6000 flowers to bloom, about 5% of the fruit. The flowers are small, reddish-white color and odorless. Consists of 2 groups based on the nature of interest: Self-fertile or self-compatible, the cocoa plant that flowers can be fertilized by pollen from flowers of the plant itself or the self-sterile. Self-sterile or self incompatibel the cocoa plant that only flowers can be fertilized by pollen from flowers of other clones (Sebastian, 2011). Individuals formed from seeds of cocoa tree are erect growth trees, diameter less than 25cm, height greater than 12m, and continuous orthotropic growth flows, have above four flows (possibly in search of light), high pubescence in branches, small leaves, thin secondary and tertiary stems, in some cases where there is high relative humidity, lichens and ferns in stems are seen (makes propagation difficult). The buds have light green and red colors, which is a function of the color of the immature fruit, in both conditions there are seeds with clear tones that range from the color close to white to cream (Yucatán and Chiapas) (Avendaño-Arrazate *et al.,* 2018).

The cocoa tree (or cacao tree) is a tropical tree. It grows best in hot and humid regions of the world. In the wild, it can be found in areas around Ecuador and can grow up to 15 m tall. This is fairly short for these regions, which allows the cocoa tree to take advantage of the shade from other trees which it needs to develop properly. The trunk can measure up to 30 cm in diameter. On the environmental side, the cocoa tree needs deep and very fertile soil, as well as favorable weather conditions that provide a large amount of rain. This is why it generally grows at low altitudes, between 400 and 700 m. The cocoa tree is a cauliflorous tree, meaning that the plant and fruit grow directly on the trunk and large branches (cauliflory phenomenon). The flowers are small, less than a cm long, and grow all year round from the third year. Although it bears fruit all year round, only 1 flower out of 500 will give a pod**.** The fruits of the cocoa tree, also known as cocoa beans, grow inside pods, which are actually large husks. These pods allow the beans to develop while protecting them from any external damage, and they also indicate the ripeness of the fruit. The pod weighs between 300 g and 500 g. The color of the pods changes with the seasons and depends on the type of cocoa tree. Once it reaches its ripe color, it is ready to be harvested and opened to extract the beans. Between 30 and 50 seeds can be found in a pod. After being harvested, the cocoa beans must be dried and roasted before becoming the raw material used to make chocolate (Chocolate, 2020).

A cocoa pod (fruit) is about 17 to 20 cm (6.7 to 7.9 in) long and has a rough, leathery rind about 2 to 3 cm (0.79 to 1.18 in) thick (this varies with the origin and variety of pod) filled with sweet, mucilaginous pulp (called *baba de cacao* in South America) with a lemonade-like taste enclosing 30 to 50 large seeds that are fairly soft and a pale lavender to dark brownish purple color (Wikipedia, 2023). Cocoa is an evergreen tree, always in bloom, which requires hot and humid climates. It usually measures around 7 m if it is cultivated and above 20 in nature. The fruit of the cocoa tree, called "cob", is a large, oval, fleshy berry, whose color ranges from yellow to purple, and is about 30 cm long. Inside each cocoa pod are between 30 and 40 seeds, embedded in a pulp. The fruit it can weigh about 450 g when ripe, which begins to happen after four or five years of the tree's life. Generally, there are two cocoa harvests a year: one towards the end of the rainy season and the beginning of the dry season, and another at the beginning of the next rainy season. Note that we are referring to tropical climates without seasons. Each harvest takes between five to six months (Conceptdaily, 2023).

The fruit of the cocoa tree is commonly called " mazorca". It sprouts from the main trunk and the tops of the trees. Generally, the drupe is ellipsoidal in shape, about 15 to 25 long. However, the number of grooves and shape of the pod will depend on the type of cocoa; the color of the ripe fruit can vary and be red, orange, purple or yellow. Inside, a thick fiber extends from which "almonds" or cocoa beans, covered by mucilage which is a thick white edible layer with a sweet taste, are pressed (Quintero, 2023). Cacao tree or cocoa tree is a small (6–12 m tall) evergreen tree in the family Malvaceae. Its seeds, cocoa beans, are used to make chocolate liquor, cocoa solids, cocoa butter and chocolate. Its leaves are alternate, entire, unlobed, 10–50 cm long and 5–10 cm broad.The flowers are produced in clusters directly on the trunk and older branches; this is known as cauliflory. The flowers are small, 1–2 cm diameter, with pink calyx. The fruit, called a cacao pod, is ovoid, 15–30 cm long and 8–10 cm wide, ripening yellow to orange, and weighs about 500 g when ripe. The pod contains 20 to 60 seeds, usually called "beans", embedded in a white pulp. The seeds are the main ingredient of chocolate, while the pulp is used in some countries to prepare refreshing juice, smoothies, jelly, and cream. Usually discarded until practices changed in the 21st century, the fermented pulp may be distilled into an alcoholic beverage. Each seed contains a significant amount of fat (40–50%) as cocoa butter. The fruit's active constituent is the stimulant theobromine, a compound similar to caffeine (Wikipedia, 2023a).

Cocoa is an evergreen tree with shiny, leathery, egg-shaped leaves that start red and turn green. The young leaves are red and droop to deter herbivores. It is cauliflorous, meaning the tiny, yellowish-white to pale pink flowers grow in clusters directly from the trunk and large branches. The oval fruit are yellow to orange when ripe. The seeds inside the fruit are tightly packed together and surrounded by a white pulp (Kew, 2023). Cocao flowers are produced in clusters directly on the trunk and older branches of the cocoa tree; they are small, 1–2 cm diameter, with pink calyx. The fruit, called a cacao pod, is ovoid, 15–30 cm long and 8–10 cm wide, ripening yellow to orange, and weighs about 500 g when ripe. The pod contains 20 to 60 cocoa seeds, usually called "beans", embedded in a white pulp. Each seed contains a significant amount of fat (40–50% as cocoa butter). Their most noted active constituent is theobromine, a compound very similar to caffeine (Wiki, 2023).

Leaves are found toward the ends of the branches. Leaves are simple with a long petiole, which has a swelling at each end called a pulvinus. The pulvinus allows the leaf to swivel to catch sunlight. Leaves are lanceolate, bright green, and up to 61 cm long by 10 cm wide. Young leaves have a pinkish-red color. They turn green as they mature. As the plant grows new leaves, older ones may drop. Cocoa flowers and fruits on the older branches and trunk (called cauliflorous flowering). One to 5 flowers arise from a special tissue along the leafless parts of the stem, called the cushion. Flowers may arise from this cushion repeatedly. Flowers are small, with 5 petals and sepals and 10 stamens. They are hermaphroditic (they have male and female plant parts).The time from flowering (fertilization) to fruit maturity ranges from 5 to 6 months, depending upon temperatures. Cocoa plants may set a large number of fruit, which may lead to plant decline. In general, only 1 to 2 pods should be allowed to develop at any one flowering cushion on a limb. In other words, if more than 1 of the flowers from a cushion sets a fruit, leave only 1 or 2 to develop. Removing an excessive number of pods will result in faster development and larger pods of remaining fruit. The fruit is called a pod (technically it is a drupe), and the time from flower pollination to a fully developed pod takes 5 to 7 months or more. The pod has a thick peel (pericarp) and may be 10–33 cm long. It may be cylindrical to round shaped with longitudinal ribs. The pod may be green or green-white, turning yellow upon ripening, or it may be red and develop some yellow color upon ripening. The pods are very attractive from an ornamental standpoint. Pods contain 20 to 60 seeds. Seeds are covered with a white, pinkish or brownish, subacid mucilage that is sweet. Seeds may be extracted and the mucilage surrounding the seed consumed. The seeds are processed to make chocolate. Seedling cocoa has a tap root that may extend several feet in deep soils. In addition, secondary, shallow, fibrous roots radiate laterally from the trunk; these roots are the major roots for water and nutrient absorption (Fig. 4) (Growables, 2023).

Floral biology and Pollination: The cacao plant produces up to 125 thousand flowers per year and each flower can produce up to 14 thousand pollen grains and up to 74 ovules. The flowers are hermaphrodite and mainly pollinated by insects of the genus *Forcipomyia*. However, at the end of the period of receptivity (2-3 days after the flower opening), 50 to 75 % of the flowers have no pollen and drops of the tree. As a consequence, usually not more than 2 % of the flowers produced in a plant result in mature fruits. Outcrossing rates in cacao ranges from 18 to 66 %, but up to 100 % in self-incompatible plants.

Growth stages of cocoa tree

Cocoa leaf.

Cacao flower buds and flowers

Closed and open blossom and fruits on the trunk

Flowers on trunk

Cacao fruits on the tree

Harvesting

Beans in pulp in freshly cut pod

Beans: In pulp, in skin, and naked

Dried pod

Fig. 4: Botanical Description

Usually pollination occurs among neighbor plants, but can reach up to 40-60 meters. Pollinations involving a single pollen plant donor are common in cacao, resulting in a reasonable proportion of full-sib families in natural crosses (24-70 %). The species has a strong sexual incompatibility system, controlled by the *S*-locus with modifiers, which limits the production in farms and makes difficult some types of crosses by breeders (Lopes et al., 2011). A mature cacao tree can produce many thousands of flowers each year. These flowers are tiny, only a half inch or so in diameter (1-2 cm). The flowers typically grow in clusters directly from the trunk of the tree or off large branches. Each flower requires pollination to successfully produce a nearly football-sized fruit – a pod containing 30-60 seeds, which can be processed to make chocolate. It sounds straightforward but, in fact, successful cacao pollination is problematic in many regions. Only around 10%-20% of the flowers produced by a cacao tree are successfully pollinated. The rest, up to 90%, never receive pollen – or do not receive enough pollen to create fruits (Shoemaker, 2021).

The cacao tree cannot produce cacao beans unless its flowers are pollinated, making pollination an essential part in the production of chocolate. In biological terms, the pollination of a plant's flowers is the transfer of pollen (male reproductive cells, the plant equivalent of sperm cells) to the plant's ovules (female reproductive cells, the plant equivalent of egg cells) to allow their fertilisation. But since cacao trees are fixed to the ground, they need help to transfer pollen to ovules to fertilise their flowers. It is important to know how the pollination of cacao works because in general, the rate of pollination is only 10% of the thousands of flowers a cacao tree can produce each year. That means that 90% of the flowers are not pollinated! (CP, 2023). A group of German researchers showed that cacao yield can be doubled when pollination is increased by manually pollinating flowers. This indicates that there can be a big pollination gap: sometimes the number of flowers that are pollinated is lower than the maximum number of fruits a cacao tree can produce. If we know how cacao flowers are pollinated, we can find solutions to increase the pollination rate in a natural way, without needing to manually pollinate flowers (CP, 2023). Cacao flowers are very small, typically about 1 cm across, and their reproductive parts are even smaller. The male parts of the flower, where the pollen are located, are covered by hoods and the female part of the flower, where the ovules are located, is in a cage formed by five rods called staminodes. This intricate structure complicates pollination. For example, because of the hoods covering the male parts, the sticky pollen cannot be dislocated by wind. This means that cacao trees need help from insects to pollinate their flowers. But because of the small space inside the hoods and the staminode cage, only insects smaller than 2-3 mm can enter cacao flowers. To be pollinators, these small insects have to first enter the hoods of the flower, where the sticky pollen can get stuck to their body, and they then have to enter the staminode cage to deposit this pollen for the ovules to be fertilised. Many cacao trees are auto-incompatible. This means that their flowers cannot be pollinated with their own pollen; they need pollen from a different tree. Because of this, the pollinators need to be able to move efficiently between trees to fertilise flowers. The short answer is: tiny flies (Diptera) from the families of the biting midges (Ceratopogonidae, including the genus *Forcipomyia*) and to a lesser extent the gall midges (Cecidomyiidae). However, most likely only a small number of the species in these highly diverse families are interested in cacao flowers and an even smaller selection will pollinate. The exact species involved remain unknown for most parts of the world. Although bees can commonly be observed in cacao flowers, they are considered pollen thieves that are not involved in cacao pollination. Some dipteran flies other than biting midges and gall midges, including non-biting midges (Chironomidae), sewer gnats (Psychodidae), fungus gnats (Sciaridae) amongst others, are also known to visit cacao flowers, but thus far there is no evidence that these taxa are cacao pollinators. Besides flies, some parasitoid wasps and ants might be pollinators in some situations, but more evidence is needed. Some studies suggest it may be useful to add breeding habitats (e.g. slices of banana stems) or promote bromeliads in cacao plantations. Since these habitats are used as places where the eggs and the larvae of the pollinators develop, having more of these habits can lead to a higher number of adult pollinators in plantations. This can in turn lead to a higher number of pollinated cacao flowers and a potentially higher yield (Fig. 5) (CP, 2023).

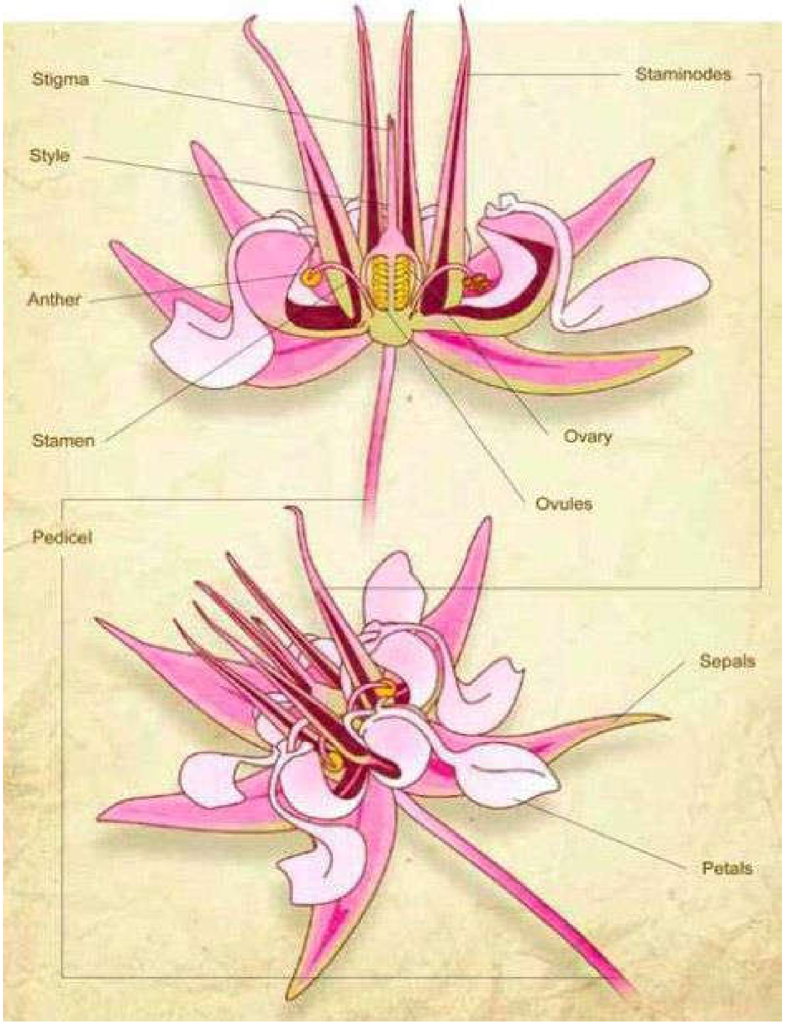


Fig. 5. Parts of cocoa flower

Cocoa is pollinated by crawling and flying insects. Some cocoa types and varieties are self incompatible, requiring cross pollination with a compatible variety. The Amelonado variety is fully self-compatible. Self-incompatibility of cocoa flowers may result in little to no pod production. Therefore either a self-compatible type (variety) should be grown or 2 or more compatible types (varieties), should be grown near each other. Since cocoa is normally pollinated by specific midge species (*Forcipomyia* spp.) that may not be present in Florida, hand pollination is one way to increase the chance of pod formation.

Flowers usually open in the early morning, and hand pollination during the morning hours is best. This may be accomplished by using a small artist's paint brush that is first placed in contact with the anthers of an open flower and then placed in contact with the stigma of another flower (Growables, 2023). We registered floral visitors and potential pollinators on 24 hour schedule on cocoa. Our study was done on cocoa trees in the Magdalena River Valley, one of the most productive areas in cocoa in Colombia. The flowers open for two (2) days, after anthesis the stamens open liberating pollen charges (most of it on the petals) and after one day the stigmas became, flowers wilt on the third day after anthesis. The main floral visitors are insects from the orders Hymenoptera (e.g. bees, ants and wasps), Thysanoptera, Diptera and Coleoptera. Bees were observed not only to visit the flowers but also we registered large pollen loads on their body and legs. Visitors were different from night and day, and we found differences in the taxa present in farms near forests and faraway. We conclude that the pollination of cocoa depends on a diversity of insects that visit the flowers during daytime (Jaime *et al*., 2021).

The insects responsible for pollinating cacao's tiny flowers are, themselves, also tiny, in order to access the flower's reproductive structures. Biting midges from the *Ceratopogonidae* family and gall midges from the *Cecidomyiidae* family are among the most important known cacao pollinators worldwide. The majority of cacao trees are what are known as self-incompatible, meaning they cannot pollinate themselves. Successful pollinators must pick up pollen from the male parts of a flower of one tree and deposit it on the female parts of a flower on another tree. Cacao flowers are also short-lived, typically receptive to pollen for only one or two days. Flowers that do not receive ample pollen die and fall within 36 hours of opening. Evidence suggests improving midge habitat can increase fruit yield. So, in some cacao-growing areas, current farming practices include developing and maintaining suitable ground habitat within and near cacao orchards in an effort to increase the number of midges capable of pollen transmission. The success of artificial or hand pollination, which can more than double yields, shows cacao trees are capable of producing many more pods than they currently do. Workers at a cacao farm in Ghana demonstrate how they hand-pollinate the tree's flowers. It's hard not to wonder: Why aren't midges doing a better job of pollinating cacao flowers? Scientists think part of the answer might be that midges don't solely depend upon cacao flowers for their life cycle. Because they can get sugar from other plant sources, they are likely passive rather than active pollinators of cacao. Scientists also wonder if they are up to the task of flying the significant distances between wild trees (Shoemaker, 2021).

GENETICS AND CYTOGENETICS

In 2008, a formative study by Juan C. Motamayor et al was published that traced genetics in cacao found in the Amazon basin. It concluded that there are actually 10 unique genetic clusters (recently this number increased to 11): Amelonado, Contamana, Criollo, Curaray, Guiana, Iquitos, Marañon, Nacional, Nanay, and Purús. The below map from the study shows where each of these clusters can be found and helps illuminate the complexity of cacao genetics. This new classification more accurately reflects the genetic diversity of cocoa (Fig. 6).

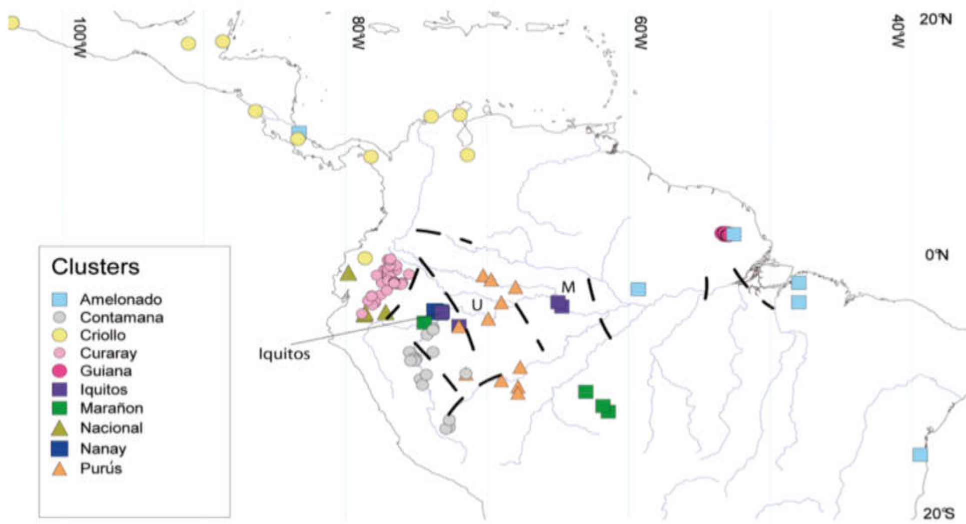


Fig. 6. 10 unique genetic clusters of cocoa

To give more specific context and information: you can see the yellow "Criollo" circles in Belize, Guatemala, and Colombia (where we source cacao, although we are not claiming that there is significant true Criollo in the cacao we source), as well as Mexico, Venezuela, Honduras, Costa Rica, Panama. On farms in the Sierra Nevada, where we source cacao from the Arhuacos community, we do see cacao pods with physical characteristics often attributed to Criollo cacaos: pointy apexes, very lumpy skin, and light lilac or white seeds; but we have not had this cacao genetically tested. The remaining genetic types identified here are mostly considered to be "Forastero." It is a disservice to the biodiversity across these types to label them all under the misnomer of Forastero, as they are varied in flavor, pod shape and size, tree architecture, and bean appearance. Amelonado, for example, is smooth-skinned, football-shaped, and has a rounder tip. Meanwhile, Nacional varietals tend to be more oblong with less smooth skin (although today, it's almost impossible to find a pod that is 100% pure Nacional, with hybridization happening rapidly and naturally among farms in Ecuador). The reality is that many of these genetic clusters are interbred and naturally hybridizing because of proximity to one another, and thus the mix of genetics can't really be defined as "criollo" or "forastero". While there is a lot of interest in cacao genetics from cacao producers, supply chain actors, chocolate manufacturers, and even some ahead-of-the-curve consumers, the reality is that the science of cacao genetics is far behind where it could and should be today. Only very recently has chocolate been "de-commoditized" to demonstrate enough interest in genetic variety, and in the agronomical and flavor characteristics driven by this diversity in genotypes, rather than seeking uniformity across cocoa for the production of homogenous chocolate-flavored confections. As the specialty cacao and premium, single-origin chocolate markets continue to grow, the science of cacao genetics must be further developed and educational materials around the complex nature of cacao genetics must be created and broadly disseminated. We have a long way to go, but the interest we hear in cacao genetics from across the craft chocolate industry is a good sign, and will hopefully drive investment in and development of significantly more advanced science and education in the future (INC, 2020). At the core of cacao genetics are two facts: 1) that cacao trees can be self-compatible or may only be compatible with specific other trees, and 2) they are heterozygous. This means they can self-pollinate and/or cross-pollinate with hundreds of genetic varieties, and thus one pod, or one seed, or one tree, can house a mix of hundreds of genotypes. This makes tracing genetic makeup extremely difficult, and it makes controlling genetic material challenging in cocoa-rich areas (INC, 2020).

Motamayor *et a*l. (2013) sequenced and assembled the draft genome of *Theobroma cacao*, an economically important tropical-fruit tree crop that is the source of chocolate. This assembly corresponds to 76% of the estimated genome size and contains almost all previously described genes, with 82% of these genes anchored on the 10 *T. cacao* chromosomes. Analysis of this sequence information highlighted specific expansion of some gene families during evolution, for example, flavonoid-related genes. It also provides a major source of candidate genes for *T. cacao* improvement. Based on the inferred paleohistory of the *T. cacao* genome, we propose an evolutionary scenario whereby the ten *T. cacao* chromosomes were shaped from an ancestor through eleven chromosome fusions (Argout *et al*., 2011). The genome size of cacao is relatively small, with around 400 Mb, being only double of that of the model plant *Arabidopsis thaliana*. In 2010 the whole genome of two cacao varieties were sequenced, one belonging to the Criollo population and the other to the Forastero population. This opens new perspectives in the identification of genes of interest to breeders and the development of markers more efficient in the identification of segregants in breeding populations, for marker assisted selection (Lopes et al., 2011). The genome of *T. cacao* is diploid, its size is 430 Mbp, and it comprises 10 chromosome pairs (2n=2x=20) (Wikipedia, 2023a). Recently the published genome of the most cultivated type of cacao, *T. cacao* Matina 1-6 clone reports a genome size of 445 Mbp (Motamayor *et al*., 2013).

GENETIC DIVERSITY

Knowledge of genetic diversity is essential for efficient conservation and use of these relic landraces (Motilal *et al.,* 2010). Cocoa (*Theobroma cacao L.*) belonging to the family of *Sterculiaceae.* Therefore, the Amazon basin is an area that harbors genetic diversity and variability of *Theobroma cacao*; scattered populations of wild cacao, cultivated cacao and related species of this genus can be found there (Quintero, 2023). The Northeastern region of Peru is one of the centers of origin of cocoa due to the great diversity of this cultivar (Oliva-Cruz *et al.,* 2022). Mexico has found an important diversity of native cocoas that are distinguished in addition to the different shapes, colors and sizes of the fruits, shapes, sizes of almonds and the white color of cotyledons (60 to 100% inland of the fruits) (Avendaño-Arrazate *et al.,* 2018). It may be cylindrical to round shaped with longitudinal ribs. The pod may be green or green-white, turning yellow upon ripening, or it may be red and develop some yellow color upon ripening. The pods are very attractive from an ornamental standpoint. Pods contain 20 to 60 seeds. Seeds are covered with a white, pinkish or brownish, subacid mucilage that is sweet (Growables, 2023). Pods can be green, white, yellow, purplish or red in color. In the search for new aromas, compounds and flavors that may provide important elements for the cocoa derivatives industry, coupled with the search for biological control agents that are interacting with cocoa in these natural environments, found individuals in which environmental, morphological and genetic aspects are combined that separate them from the rest of the cultivated cocoas and are located as native cocoas, that is to say, cocoas that have been conserved for years in totally isolated environments of commercial populations and have characteristics of hardiness in the form of the fruit and arrangement of the seeds. It shows the close interaction with flora and fauna typical of each place that repeatedly illustrates the meaning it had for the Mayan and Aztec culture "as a sacred tree" or "tree of life." (Avendaño-Arrazate *et al.,* 2018). The structure of the genetic diversity in cacao is quite well studied, not only by using phenotypic traits, but also by molecular markers. Three major populations exist, the Forastero from the Amazon area, being very diverse and rich in genes of resistance to diseases, yield and at some extent quality; the Criollos from Central and North America (Mexico) is usually characterized by its good flavor; and the Trinitario which is a result of the natural cross of the two original populations. Considerable genetic diversity has been observed for many traits in cacao. Overall, germplasms of the upper Amazon (Forasteros) tend to be more diverse than the other groups. However, quite high diversity has been found in most populations (Fig. 7 & 8) (Lopes *et al.,* 2011).

Fig. 7: Genetic Diversity of Cocoa pods for shape, size and color

Fig. 8 : Diversity of pods and seeds of cocoa

The observations of morphotypes have been made on some trees, as there were pods available, thereby providing evidence of the following different morphotypes (Fig. 9) (Adenet *et al.*, 2020):

- Yellow-orange pods at maturity,small size, ovoid with deep grooves,
- Yellow- orange pods at maturity, small size, ovoid with apointed end,
- Yellow-green pod at maturity, biggersize, rounded, smooth,
- Yellow-green pod, mediumsize, large grooves and rounded,
- Yellow–red pod at maturity, large size, elongated with deep grooves and a pointed end,
- Violet-red pod at maturity, large size,elongated, large grooves.

Fig. 9. Pods diversity- NA: North Atlantic, NC: North Caribbean, C: Centre, S: South

Motamayor *et al.* (2008) proposed a new classification into ten major groups within theForastero cacao, based on genetic diversity in varieties from Latin America. These areMarañon, Curaray, Criollo, Iquitos, Nanay, Contamana, Amelonado, Purús, Nacional andGuiana. This new classification more accurately reflects the genetic diversity of cocoa **(Fig.10).** Since 2008, several scientific studies have been carried out to assess the genetic diversity of cacao. However, most of these are limited to only a few geographical locations and to three or four groups (Criollos, Foresteros, Trinitariors and or Nacional or Cacao Nacional Boliviano types). Thomas et al. (2012) used spatial diversity patterns to explain genetic differentiationin cacao through the possible contribution of climate change, geographical locations,history and culture. However, there are several questions which remain unanswered and a comprehensive study combining application of molecular and modelling approaches is needed to understand the entire genetic diversity and population structure ofcacao.

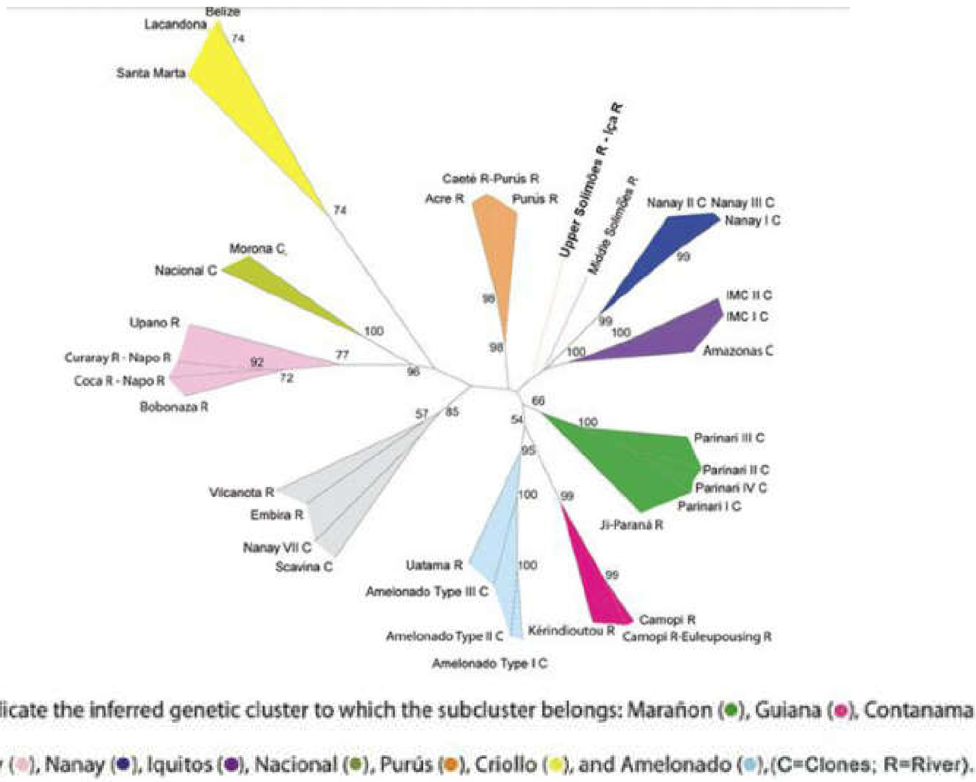


Fig. 10. Neighbour joining treefrom Cavalli- Sforza and Edwards genetic distance (16) matrix among the 36 subclusters identified using STRUCTURE (559 clones)

While this is work that is going to take years and a lot of money, it will be the basis for the next generations of cocoa. Compared with larger crops such as wheat and soy, plant breeding in cocoa is cobbled together with rubber bands, safety pins and duct tape. That's mostly because it's grown by poor people in developing countries.; and because it is complicated. It takes years to get a cocoa tree to maturity. The genetic diversity of cocoa is massive compared with these large bulk commodities that have been closely bred for decades and show high diversity loss. Even in the same pod of cocoa the beans can be germinated by pollen from different varieties, leading to a mix of white and purple beans when you open up the pod in the field (Fig. 11). This is because not all cocoa varieties can pollinate their own flowers, so they need a friendly neighbour to get the job done. Some varieties are sexually incompatible meaning they can't pollinate themselves. Cocoa needs to be grafted so you know exactly what variety can pollinate either itself or the tree in the row next to it (Moloney, 2022).

Fig. 11. A cocoa pod with both white and purple seeds (each pollinated by different male parents)

The average weight of cocoa beans is not generally taken into account during breeding processes, although it is a trait of interest. Several studies indicate that the weight of the beans has a high heritability in *Theobroma cacao*. However, the values obtained from different countries for the same clone often vary. In this study, we analyzed the effect of different factors on the weight of the beans. Apart from the clone effect, three main factors had an impact (Doaré *et al.,* 2020): i) the number of beans per pod: a good filling of the pod with beans tended to limit the weight of the beans,

ii) the position of the beans in the pod: beans in the apical part of the pod were significantly lighter than the others and
iii) the longer the duration of the fructification cycle the heavier the beans were (positive genetics correlation).

These results lead us to propose protocols aimed at normalizing the phenotypic values of the genetic material. To obtain a reliable estimate of the bean weight, the following is proposed: either to use beans obtained from manual pollination to saturate the pods with beans, or to systematically use the number beans in the pods as a covariable.

Recent surveys conducted on Amazonian cocoa trees in their home range are a unique opportunity to assess the aromas, diversity and potential of the Ecuadorian Amazon to create new aromatic cocoa varieties. Our results reveal informations about the diversity and genesis of aromas in Ecuadorian fine cocoa. The great aromatic diversity could enrich cocoa flavour selection programmes and provide Amazonian populations with new income linked to aromatic varieties, which could lead to a '*grand cru*' chocolate. Until now, breeding programmes have been mainly focused on improving characteristics for production, but in recent years cocoa quality has been increasingly examined to meet market expectations (Colonges *et al*., 2022). Indeed, it is the only worldwide source of chocolate, whose consumption is constantly increasing and is studied for its health benefits. It provides a large panel of various aromas highly appreciated, but also offers benefits for human health thanks to its richness in polyphenols. Cacao can be classified into two main classes: bulk cocoa characterised by strong notes of cocoa and fine or flavour aromatic cocoa characterised by fruity and/or floral aromas. Fine or flavour cocoa represents about 12% of the current world production. However, its consumption has continued to rise for decades and sought after by chocolate-makers looking for new flavours. It represents important economic niches for tropical countries producing this type of cocoa. The fine or flavour cocoa varieties currently mostly cultivated are (Colonges *et al*., 2022): (1) the Criollo, well known for its fruity aromas but yet less cultivated due to its low vigour and low resistance to diseases; (2) the Trinitario, which are hybrids between from both the Amelonado and Criollo genetic groups, and (3) the ancestral and modern Nacional known for its floral notes, which are called Arriba.

The study has been undertaken to assess the degree and distribution of genetic diversity present in cocoa germplasm collections from the Cocoa Research Institute (CRIG), seed gardens and materials from farmers' plantations in Ghana, using molecular markers. Two hundred and thirty-five trees representing all the cocoa-growing regions of Ghana were sampled in situ from farmers' fields and grouped as farmers' collection. Another set of 104 trees was collected from breeders' seed gardens, called breeders' collection. Thirty-eight parental clones from the CRIG's collection, used in producing the bi-parental crosses, comprised the third category, called parental clones. The collections were screened with the set of 17 mapped microsatellite markers. Average gene diversity was high in all populations, with mean observed heterozygosity of 0.738. Although the highest was recorded in accessions from breeders' and parental collections, genetic diversity in the farmers' collection was comparable with them. Despite the low level of differentiation I.F 1 = 0.0761 found across all the three groups, sufficient genetic differences existed between them, separating breeders' collection from farmers' collection. The study also revealed the pattern of adoption of available planting materials by farmers on their fields (Opoku *et al*., 2007).

Morpho- agronomic characters of pods and seeds can be used to evaluate the relationship between cocoa genotypes. In the present study, significant variations inthe mean performance of 20 genotypes for 13 traits were observed which revealed that the germplasm collections being maintained have high breeding value. The GCV and PCV ranged from moderate to high. Traits like plant height, first branching height, canopy area, leaf area, pod weight and single dry bean weight recorded high PCV and GCV indicating the high variability. High heritability ranging from 52.81 per cent for number of beans per pod to 99.84 per cent for first branching height was recorded. High genetic advance as per cent of mean was recorded for canopy area (89.33 per cent). High heritability coupled with high genetic advance for all the traits except pod girth, bean length and pod value indicated that all these traits are controlled by additive gene action and has least environmental influence. Further, correlation analysis revealed association of various traits which can be used as selection criteria for efficient planning of cocoa breeding program (Kunikullaya *et al.,* 2018). Study was undertaken to understand the genetic diversity of the current orchards. Our interest in Martiniquan cocoa also comes from very encouraging results on aromatic properties of chocolates made with Martiniquan beans. A total of 161 cocoa trees located from the different regions of the island were genotyped, using a set of SNP markers. Sensory descriptive profiles of the chocolates comings from these trees were carried out by a provider laboratory, according to the sensory method described by AFNOR (French Agency for Standardization) NF ISO 11035 (July 1995). We observed a genetic diversity within the Martiniquan cocoa orchards with a genetic admixture consisting of ancestry of 6 out of the 10 *Theobroma cacao* ancestral genetic groups which testifies to these numerous waves of introduction; the main representative ancestry group is Amelonado, then Criollo. The first tests of sensory analysis revealed a strong aromatic potential of Martiniquan cocoa, probably due to a favorable terroir effect (Adenet *et al.,* 2020).

The objective of this study was to search for different genetic groups of 146 ecotypes of fine-aroma native cacao from the northeastern region of Peru, based on the morphological descriptors of pods, seeds, sensory, yield, and sampling altitude. The data were analyzed using multivariate statistics; a cluster analysis was performed with the numerical and categorical variables, followed by a principal component analysis (PCA) and the DGC (Di Rienzo, Guzmány Casanoves) mean comparison test for the numerical data. Contingency tables and the multiple correspondence analysis (MCA) were performed for the categorical data. We differentiated 5 genetic groups; helpfully, sensory characteristics of the flowers and pod, size and weight of the seeds, and pod index were in fact crucial in separating the groups. The ecotypes of the groups labeled as "Indes" and "Bagüinos" reported the best sensory characteristics with high floral and fruity notes and with a good yield expressed in pod index (13.88 and 11.88, respectively). Furthermore, these ecotypes are found at medium and high altitudes, above 500 m a.s.l., a factor that enables them to express their sensory and yield attributes. On the contrary, the ecotypes known as "Toribianos" and "Cajas" report the highest pod indices (20.77 and 16.78, respectively), resulting in low productivity. In the future, the variability of the ecotypes found will help establish genetic improvement programs that contribute to the development of cocoa farming in general (Oliva-Cruz *et al.,* 2022).

BREEDING

Germplasm: Using 30 microsatellite markers, we characterized genetic diversity in 77 Belize Criollo accessions collected from the Maya Mountains in Belize, and assessed their relationship with 62 cacao accessions including 25 Trinitario accessions. Genetic diversity and heterozygosity were low in Belizean Criollo germplasm. Eleven distinctive genotypes were identified among the Belizean germplasm (Motilal *et al*., 2010). Cocoa germplasm, the "raw material" for plant breeding, is a vital resource for the improvement and sustainability of cocoa production. Access to a genetically diverse range of germplasm is essentialfor plant breeders to select material with stress resistance and good agronomic and quality characteristics (Kunikullaya *et al*., 2018).

In a little more than 2 century, commercial cultivation of cocoa has extended from its centre of origin in South America to West Africa, the Far East and Oceania. It has become an important crop throughout the humid tropics. However, material for commercial plantings has been derived from a very narrow genetic base leading to low productivity in cocoa. Realizing the need to improve the genetic diversity, scientific expeditions were conducted to collect wild cocoa from the natural habitats. The materials collected in these expeditions are now maintained in national and international germplasm collections in Central and South America and in the Caribbeans. Collections at Centro Agronomico Tropical de Investigacion & En-senanza (CATIE), Costa Rica International Cocoa Gene Bank (ICG), Trinidad and CEPLAC, Brazil have been designated as primary collections and the germplasm is freely available to breeders. Transfer of germplasm from International Germ-plasm Centres to user countries is done through intermediate quarantine, of 2 years, with the facilities at Reading University, UK and at CIRAD, Montpellier, France. In order to undertake long-term breeding activities, the International Group for the Genetic Improvement of Cocoa (INGENIC) was created in 1993. In India, cocoa germplasm collections are conserved with further exploration at CPCRI Regional Station, Vittal (291 accessions) and College of Horticulture, Kerala Agricultural University, Vellanikkara (500 accessions).These collections were from Mslsysia, Ghana, Nigeria, Amazon, Trinidad, Brazil, Ecuador, UK, Mexico, Jamaica clones and few local collections from Wynad, Kerala and Shiradi ghats, Karnataka. Presently, germplasm accessions are conserved in field either in the form of seedlings or as clones. The standardized clonal multiplications at various centres have paved the way for multiplication and maintenance of accessions with greater degree of true breeding values (Auxcilia and Shab, 2017).

Breeding Objectives: In terms of breeding targets, these can be divided into two main categories. The first is associated withresistance to biotic stress, as unfortunately, outbreaks of diseases in major cacao growing areas have significantly affected production in South America and Africa. For instance, Witches' broom disease (WBD) caused by the fungal pathogen *Crinipellis perniciosa* has reduced cacao yields in many cultivation areas in South America including Ecuador and Brazil (Brown *et al.,* 2005). Another major disease problem in cacao is *Cacao swollen shoot virus* (CSSV), which is transmitted largely by mealy bugs. Although efforts have been made to eradicate the problem by removing infected trees, this has proved unsuccessful and it is now hoped that a greater understanding of the genetic variation in both the virus and its vector together with studies in more amenable model species will lead to progress in understanding this important disease and related badna viruses (Andres *et al.,* 2017). The second main breeding objective relates to physiological traits, as in addition to major pest and disease outbreaks, cacao cultivation is also affected by several other factors, which include altered short term climatic variation (*e.g.* El Niño), longer term global warming, high labour costs, depletion of soil fertility, poor plant productivity, lack of breeding strategies to develop and distribute improved varieties, and outdated farming practices (Zhang and Motilal, 2016). Specific breeding objectives reported in one recent study include dwarfism or semi-dwarfism, which might enable smaller trees to be planted at higher density, and photosynthetic efficiency, an important determinant of yield (Pereira *et al.,* 2017). As an alternative approach to breeding efforts to increase yields in the major production areas, some cocoa producers are now considering new regions that might allow an extension in the area under cultivation (Wickramasuriya and Dunwell, 2017).

By far, bean yield and disease resistance are the traits that receive most attention of cacao breeders, despite some emphasis be also put on sexual compatibility and bean quality (flavor, chemical composition). Yield is usually measured as the weight of the dry (often wet and converted to dry) beans produced per plant or area. The three components of yield are the number of pods per tree or area, the number of beans per pod and the weight of individual beans. Some diseases of cacao, under high severity pressure can cause losses up to 100 %. Witches´ broom is the most important disease of cacao in Brazil, being responsible for large losses in Bahia and in the Amazon region. Ceratocystis wilt (*Ceratocystis cacaofunesta*) is another important disease in Brazil, being a very serious problem for some susceptible varieties (Theobahia). Black pod rot, caused by *Phythophthora* spp, is the most widely distributed and important disease of cacao in the world and also causes losses in some regions of Brazil. Moniliasis (*Moniliophthora roreri*) occurs in most producer countries in South America, except Brazil, being a constant threat to the country´s cacao plantations. Sexual incompatibility is also an important limiting factor of cacao yield. Many germplasms useful to breeders, including most of those with resistance to diseases, are self-incompatible. Therefore, some programs have put a considerable effort in eliminating self-incompatible plants from their populations, particularly when the final objective is the development of clones. More recently, with the growing interest of the industry for high quality chocolate, some breeding programs have dedicated time also to traits related to flavor. For example, the Ecuadorian breeding program has concentrated a lot of effort in breeding for the *Arriba* flavor in the *Nacional* population. More recently, the Brazilian breeding program has also involved many fine flavor germplasms, particularly aiming to explore the European market of fine chocolate (Lopes *et al.,* 2011).

Breeding strategies: Importantly in terms of breeding strategies, cacao has a relatively longer juvenile period, namely 3-5 years. This makes selection of fruit-specific traits in breeding programs more time-consuming and expensive, as the trees must be maintained for a longer period of at least three years to visually observe such characters in pods. Moreover, this crop is primarily out breeding and therefore many populations are mostly heterozygous. This makes generation of inbred lines from crosses more labour intensive, and doubled haploid lines are not easily generated. Moreover, the self-incompatibility that exists in some of the cultivated cacao clones means that breeding populations are often highly heterogeneous with a wide range of yields. However, it should also be noted that genetic variability does exist in cacao populations, and there are several self-compatible cacao clones, such CCN 51 and ICS 6. Cacao trees also require a large area of land and high input of resources, including labour, for their maintenance under field conditions. These characteristics have made this crop less attractive as a model system, it has a relatively small genome. Because of the recalcitrant (do not survive drying) nature of its seeds the germplasm of this allogamous tree crop must be conserved in field gene banks as a living collection (Motilal *et al.,* 2013).

Breeding Methods: Progress in cacao breeding has been hindered by a long-generation cycle, limitations in land availability for large-scale breeding trials, and challenging abiotic and biotic stress factors, including several major diseases. Cacao tends to be out breeding and cocoa production is often reduced by the incompatibility status of planting material and pollination inefficiency. The complex breeding mechanisms in cacao and difficulty in predicting the performance of promising selections as parents also pose challenges to breeders. Reciprocal recurrent selection schemes have been most successful to date. The advent of breeding with genomics and the unravelling of the cacao genome portend unprecedented advancements in cocoa breeding (Bekele and Phillips-Mora, 2019). Cacao （*Theobroma cacao* L.） trees are heterozygous with wide spectrum of agronomic traits in a population. To reduce production cost and to propagate rapidly, cacao trees were grown from seeds in Taiwan while the technique for vegetative propagation was not mature yet. However, cacao beans with varied pod maturity and size cause the challenges in management, harvest and processing. To improve cacao industry in Taiwan, new solutions for breeding and vegetative propagation are necessary. This project addresses selections for high yield and quality cacao trees based on antioxidants analysis. Furthermore, the project will establish the vegetative propagation methods. The projected goal is to produce cacao trees having high yield and producing good quality beans in a large scale. Eventually, it will help to improve productivity and processing for the cacao industry. This year, we developed vegetative propagation method of cacao seedlings and preliminary selection of 51 good yield performance cacao trees (Fig. 12) (TSS, 2023).

1- cutting the scion to wedge shape; 2- cut off the rootstock and slitting it along the cambium; 3- put the scion and the rootstock together. 4- fix the combination place; 5- cover the scion by paraffin; 6- complete.

Fig. 12. Grafting of cocoa seedlings

Crop Improvement (Auxcilia and Shab, 2017)

The cocoa germplasm has been utilized for crop improvement. They are

- Evaluation and selection of superior clones which are adapted to the locality with desired traits like higher bean yield and resistance/ tolerance to biotic and abiotic stresses, testing their performance in comparative yield trials and large-scale production of clonal materials from elite clones.
- Production of first-generation hybrids of self-incompatible high-yielders, assessment of their performance and selection of superior hybrids. The important biotic factors considered are resistance to black pod disease and vascular streak dieback and drought tolerance among abiotic stresses.

Selection criteria in cocoa (Auxcilia and Shab, 2017).

- Trees with medium canopy under intercropping system
- Earliness in bearing
- Vigor and yielding efficiency
- Compatibility reaction
- Trees bearing lot of fruits with 70 – 100 pods/tree/year
- Medium to large pods of not less than 350 g weight, smooth or shallow furrows on the surface without prominent constriction at the neck
- Pod value (Number of pods required to produce 1 kg beans) to be not more than 12

- Husk thickness of pods to be more than 1 cm
- Number of beans per pod should be more than 35
- Bean weight should be more than 1 g
- Dry bean yield should be more than 1 kg/tree/year
- Shelling percentage- 10 -15%
- Fat content > 50%
- Resistance breeding (India) – Black pod disease (Phytophthora), Vascular Streak Die back, Ceratocystis wilt, tea mosquito bug and drought.

It is generally agreed that very little progress has been achieved in cocoa breeding to date. Too high an emphasis on breeding for disease resistance, heterozygosity of hybrids' parental clones and insufficient use of proven breeding methods were described as some of the possible reasons for the poor progress. To be successful, a breeding programme should be comprehensive, balanced and of sufficient magnitude of scale. Continuity and sustainability of the breeding activities are of utmost importance. Those involved with the cocoa breeding programme in Papua New Guinea have attempted to follow these general guidelines since 1994. As hybrid clones are unfamiliar to cocoa farmers in Papua New Guinea, representing a new production system, particular emphasis was placed on adaptive research and preparation of extension materials in anticipation for the release to the farmers of the first varieties of hybrid clones in early 2003 (Efron *et al*., 2003). "Trinitario" has potential value for germplasm enhancement, since it contains germplasm selected in on farms Ecuador in the 1920s and 1930s among cacao seedlings, which showed no symptom of Witches' Broom disease despite high disease pressure (ICCO, 2006). The potential productivity of cocoa is determined partly by the size of cocoa beans and the bean number per pod, but actual production is often limited by pests and diseases. The diverse germplasm at the International Cocoa Genebank, Trinidad (ICG,T) is a valuable source of genes for cocoa genetic improvement in terms of productivity and disease resistance. In the last decade, programmes have been undertaken by the Cocoa Research Unit, using the genetic resources of the ICG,T, to produce populations with enhanced resistance to Black Pod and Witches' Broom diseases (BP and WB) from which selections can be made with good potential productivity. The expected outcome is a reduction in the cost of cocoa production for farmers through the development of high-yielding, resistant cultivars. Initially large numbers of genotypes from the ICG,T were screened for resistance to BP and WB. Bi-parental crosses were made between resistant parents and the seedling progeny were screened for resistance using innovative techniques developed at the Cocoa Research Unit. Selected genotypes were planted in field trials, where possible under old cocoa with high inoculums pressure for the diseases. Analysis from screening tests for BP shows a marked increase in the frequency of resistant individuals in the progeny populations and confirms the effectiveness of the selection criteria and the overall strategy being adopted in the programme. A similar shift is expected for WB. As the evaluation exercise progresses, more promising genotypes are being identified, which incorporate good yield potential with combined resistance to BP and WB. Selections from these populations will be used by plant breeders in Trinidad and other cocoa producing countries throughout the world as a source of resistance genes that can be incorporated into locally adapted commercial varieties. This will negate the need for heavy use of fungicides that are expensive, may pose risks to human health and are often deleterious for the environment, and will thus facilitate more sustainable cocoa production systems (Iwaro *et al.,* 2010). Seeds of Theobroma cacao are worldwide in use for production of cocoa butter and confectionary products. The production of raw cocoa from fresh seeds is based on a complex fermentation process, which leads to the aroma precursors. This process enhances the amount of peptides and free amino acids in the seeds, but it also reduces the amount of phenolic compounds, especially the proanthocyanidins. These antioxidative compounds are mostly composed of catechin and epicatechin monomers and oligomers up to decamers. The fermentation has to take into account that both factors, production of aroma precursors as well as maintenance of health-supporting phenolic factors, are guaranteed. The worldwide rising consumption of high-quality cocoa leads to strong international efforts to develop elite clones of trees with high field performance in resilience, quality, and yield (Lieberei *et al.,* 2013). The average weight of cocoa beans is not generally taken into account during breeding processes, although it is a trait of interest. Several studies indicate that the weight of the beans has a high heritability in *Theobroma cacao*. However, the values obtained from different countries for the same clone often vary. In this study, we analyzed the effect of different factors on the weight of the beans. Apart from the clone effect, three main factors had an impact: i) the number of beans per pod: a good filling of the pod with beans tended to limit the weight of the beans, ii) the position of the beans in the pod: beans in the apical part of the pod were significantly lighter than the others and iii) the longer the duration of the fructification cycle the heavier the beans were (positive genetics correlation). These results lead us to propose protocols aimed at normalizing the phenotypic values of the genetic material. To obtain a reliable estimate of the bean weight, the following is proposed: either to use beans obtained from manual pollination to saturate the pods with beans, or to systematically use the number of beans in the pods as a covariable (Doaré *et al.,* 2020).

Clones and Hybrids: Four decades of cocoa research paved way for identification of potential clones and development of varieties suitable for different agro climatic conditions and tolerant to both biotic and abiotic stresses. The achievements are well recognised by International cocoa research communities especially in the Asia Pacific region which is mainly on coconut based cropping models. The challenges of management of genetic resources in the introduced environment coupled with long term breeding strategies resulted in positive achievements to take Indian cocoa to satisfy the requirement of chocolate industries. Supply of quality planting material of elite clones and hybrids encouraged cocoa cultivation in non traditional areas as well (Malhotra and Apshara, 2017). Several high-yielding varieties/hybrids have been released from India, Indonesia, Trinidad and Costa Rica.

Varieties released from Cadbury-Cocoa Research Project, Kerala Agricultural University, Thrissur, Kerala, India (Auxcilia and Shab, 2017)

CCRP I: Pods are medium-sized, green which changes to yellow on ripening, constricted at the base, blunt beak and moderately deep ridges and furrows. The trees are self-incompatible. Mature pods weigh 385 g, with 46 beans and 0.8 g oven-dry bean weight. On an average, a tree yields 56 pods /year, with an yield potential of 72 pods.

CCRP II: It is a single plant selection from local population. It has spherical pods with obtuse apex. No ridges and furrows in the pods and yields 54 pods /tree /year.

CCRP III: It is a selection from open pollinated seedling of T76/1224/1201 (Amazon). It has elliptic pods with moderate ridges and furrows. It yields 68 pods per tree with 42 beans /pod.

CCRP IV: Pods large, purple tinged, turning yellow on ripening, beaked with acute tip, basal constriction shallow or absent, pericarp deeply rugose with deep ridges and furrows. The trees are self -incompatible. Mature pods weigh 402 g with 45 beans and 1.1 g oven-dry bean weight. On an average, a tree yields 66 pods/ year with a yield potential of 93 pods.

CCRP V: Pods large, elliptical, green when immature turn yellow on ripening, moderately deep ridges and furrows, apex acute. Trees are self-incompatible. Mature pods weigh 425 g with 45 beans and 0.8 g oven-dry bean weight. Average yield is 38 pods/tree/year with a yield potential of 55 pods.

CCRP VI: Pods very big, green turning to yellow on ripening, thick rind, elliptical without basal constriction, apex obtuse, pod surface rugose with shallow ridges and furrows. Trees are self-incompatible. Mature pods weigh 895 g with 48 beans and 1.9 g oven-dry bean weight. Average yield is 50 pods/tree/year with an yield potential of 180 pods.

CCRP VII: Pods large, elongated, green, turning to yellow on ripening, beaked with acute apex, slight basal constriction, pod surface rugose, moderately deep ridges arid furrows. The trees are self-incompatible. Mature pods weigh 526 g with 47 beans and 0.9 g oven-dry bean weight. Average yield 78 pods/tree with an yield potential of 95 pods.

CCRP 8: Hybrid between CCRP 1 x CCRP 7. Trees are self-incompatible. Pods green, medium sized, turning yellow on ripening, apex attenuate, base intermediate, rugosity intermediate. Mature pods weigh 389 g with 49 beans and 0.88 g oven dry bean weight. Average yield 90 pods/tree giving 11.40 kg wet beans.

CCRP 9: Hybrid between CCRP 1 x CCRP 4. Trees are self incompatible. Pods green, medium sized, turning yellow on ripening, apex attenuate, base strong, rugosity intermediate. Mature pods weigh 370 g with 37 beans and 0.8 g oven dry bean weight. Average yield 106 pods/tree giving 8.97 kg wet beans.

CCRP 10: Hybrid between CCRP 3x GVI 68. Trees are self incompatible. Pods green, medium sized turning yellow on ripening, apex attenuate, base intermediate, rugosity intermediate. Mature pods weigh 332 g with 41 beans and 1.1 g oven dry bean weight. Average yield is 80 pods/tree giving 8.15 kg wet beans

Varieties released from Central Plantation Crops Research Institute, Regional Station, Vittal (Karnataka), India (Fig. 13) (Auxcilia and Shab, 2017; TNAU, 2023):

- VTLCC-1 Vittal Cocoa Clone 1
- VTLCS-1 Vittal Cocoa Selection 1
- VTLCS-2 Vittal Cocoa Selection 2
- VTLCH-1 Vittal Cocoa Hybrid 1
- VTLCH-2 Vittal Cocoa Hybrid 2
- VTLCH-3 Vittal Cocoa Hybrid 3
- VTLCH-4 Vittal Cocoa Hybrid 4
- VTLCH-5 Vittal Cocoa Hybrid 5 (Nethra Centura)

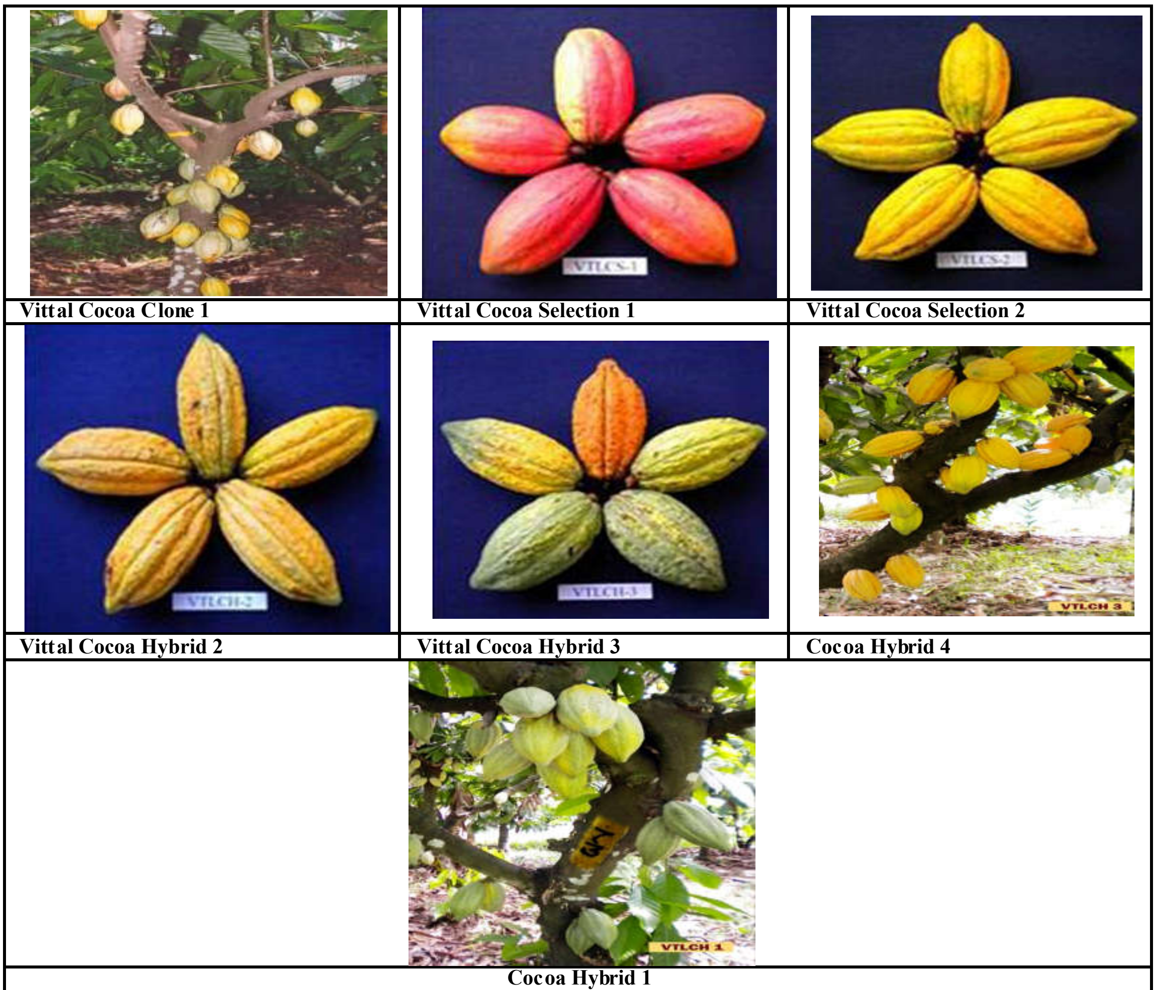


Fig. 13: Clones and Hybrids of Cocoa

Varieties released from Indonesia (Auxcilia and Shab, 2017): DR-1, DR-2, DR-21 and DR-35 are resistant to cocoa moth.

Varieties released from Trinidad (Auxcilia and Shab, 2017): ICS-l, ICS-45 and ICS-92 are high yielding selections, showing varying degrees of tolerance to 'witches broom' . Hybrids; ICS-1 x SCA-6; (ICS-1 x SCA-6) x SCA-12; ICS6 x SCA-6, (ICS-6 x SCA-6) x SCA-12 and TSH-999 are high-yielding hybrids released from the Tropical Research Station, Trinidad.

CULTIVATION AND PROCESSING OF COCOA BEANS

Cultivation: Cocoa can be propagated by seeds. Seeds are to be extracted from pods. Cocoa pods take 150-170 days from pollination to attain the harvest stage. The stage of maturity is visible from the change of pod colour from green to yellow (Forestero) and red to yellow (Criollo). Collection of seeds from biclonal or polyclonal seed gardens involving superior self-incompatible parents is recommended to ensure genetic superiority of planting materials. In TNAU coconut nursery, a poly clonal seed garden with 7 improved clones of KAU (CCRP1 to CCRP7) and Vittal cocoa clone 1 and 4 hybrids namely VTLCH1 to VTLCH4.

Criteria for selection of mother plants for collection of seeds (TNAU, 2023):

- Forastero type (green- immature, yellow- ripe) having medium to large pods of not less than 350 g weight, smooth or shallow furrows on the surface without prominent constriction at the neck can be selected.
- Husk thickness of pods should be less than 1 cm.
- Pod value (number of pods to give 1 kg wet beans) should be less than 12.
- Number of beans per pod has to be more than 35.
- Bean dry weight to be more than 1 g.
- The best seeds for sowing are those from the middle of the pod.

Harvested seed pods can be stored in shade upto one week. Viviparous germination is reported in ripe cocoa which may affect the percentage of germination if it is stored beyond one week. Seeds are to be sown immediately after extraction from the pods. Viability of the beans can be extended for some more days if freshly extracted seeds are stored in moist charcoal and packed in polybags. Other alternative is extracting beans, removing the testa and packing in polythene bags. As the seedling progenies showed wider genetic variability, to maintain true to types, asexual or vegetative propagation is followed. Grafting and budding are being followed in multiplication of cocoa. It also ensures multiplication of identified high yielding clones in large quantities. Though vegetative propagation of cocoa by budding, rooting of cutting and grafting are feasible, the widely accepted methods in India are budding and grafting (Table 1) (TNAU, 2023).

Table 1. Vegetative propagation of cocoa

Vegetative propagation	Rootstock	Scions	Success (%)
Budding: Patch budding	10-12 month old seedlings	Bud patch of 2.5 cm length and 0.5 cm width from the bud wood	85
Grafting: Soft wood grafting	3-4 month old seedlings	Scion stick of 12- 15 cm length with 2- 3 buds	70

When seedlings are used as planting, select vigorous and healthy seedlings from polyclonal garden. The planting material should be of 4-6 month old seedling or grafted or budded plant. The seedling/grafted/budded plant should be planted in the centre of the pit, not too deep. While planting grafts, polythene strip tied over graft joint should be removed and the joint should be above the soil (Fig. 14) (TNAU, 2023).

Seedlings	Budded plants	Budded plants

Fig. 14 : Budded plants

Pruning of grafted plants is done, after first year of planting, primary pruning should be done to obtain a supporting framework of one or more upward growing main stems. Then drooping or inward growing branches are to be removed. Secondary pruning is suggested to develop well-shaped canopy and desired canopy should be maintained in umbrella shaped form with about 3.8 m to 4.2 m spread and 2.7 m height depending upon the space and main crop in which cocoa is under planted/grown. Pruning is usually done annually in August- September (TNAU, 2023). The proper pruning of cocoa ensures adequate ventilation in garden; maintain tree height, makes spraying and harvesting operations easier. It also prevents damage during the harvesting operation for the companion crop. To prevent the entry of fungi, fungicides are to be applied (Bordeaux paste) immediately after the pruning. Generally pruning is done after harvesting (TNAU, 2023). Newly planted trees should be allowed to grow to 0.3–0.6 m. If no branching occurs, then the top should be cut back to initiate branching. Three to 4 main branches should be allowed to develop. Remove all others. Plant height should be limited to 1.8–2.4 m to facilitate care and make protection from winds, excessive light, and cold temperatures easier. Periodically, selected branches should be removed to allow an increase in light and air movement inside the plant canopy. This will enhance pod production and reduce fungal disease problems. Damaged or diseased branches should also be removed regularly. Pruning should be done at the end of the summer to prepare the tree for the following crop (Growables, 2023).

Vegetative propagation is followed in cocoa to produce true to type trees. Vegetative propagation is mainly through soft wood grafting. Soft wood grafting is a more preferred vegetative method for production of planting material. The material consists of cleft grafting of scions to 2-3 month old seedlings root stocks. The scion sticks should be 12-14 cm long and secured to root stock cleft by 1.5 cm wide polythene tape. Graft union takes place within one month. The grafts will be ready after 3 months for planting (Vikaspedia, 2020). Propagation is by seed, airlayering, cuttings or grafting. Seeds germinate in 5-10 days, but lose viability quickly if they dry out. Seedlings should be grown under 50% shade. Cacao may be cleft or patch grafted. Propagation may be by cuttings, buddings or graftings, but seeding is cheaper. Seeds germinate at maturity, and are viable only a short time. They may be stored 10–13 weeks if moisture content is kept at 50% (Growables, 2023). Cocoa is planted either under forest trees or other crops. It can be established under forests by thinning the forest to desirable shade levels. Cocoa seedlings are planted in pits of 50 cm3 filled with compost. The pot mixture should consist of top soil, sand and FYM in the ratio of 2:1:1 for good growth of seedlings or grafts. Fertilizers can be applied if required which enhances vigour of seedlings. Application of urea at the rate of 0.5 – 2.0 g per plant is practiced. Foliar application of urea at 1.5% concentration can also be adopted. Need based spraying of insecticides and fungicides has to be taken up depending on the outbreak of specific pest or disease incidence.

Cocoa nursery requires adequate shade, irrigation and wind protection. It is ideal to have 50% shade in the nursery. The land should be leveled and free from rodents and pathogens. Irrigation is given through micro sprinkler.

It can be planted either in the beginning of South-West monsoon (May-June) or end of monsoon (September). Cocoa is planted either under forest trees or other crops. It can be established under forests by thinning the forest to desirable shade levels. Cocoa seedlings are planted in pits of 50 cm3 filled with compost.

- Under forests spacing of 2.5 x 2.5 m to 3.0 x 3.0 m are found suitable.
- In areca garden, cocoa is planted in 2.7 x 5.4 m spacing, where main crop is planted at 2.7 x 2.7 m

When grown as intercrop with coconut, two systems are usually followed viz., single hedge of 2.7 m apart or double hedge of 2.5 m apart (Vikaspedia, 2020).

Cocoa was evolved as an under-storey crop in the Amazonian forests. Thus commercial cultivation of cocoa can be taken up in plantations where 50 per cent of light is ideally available. In India, coconut and arecanut gardens are suited best for cultivating Cocoa. Under arecanut 30-50% of sunlight penetrates through their canopy which can be intercepted by cocoa. Cocoa requires 100 g N (220 g urea), 40 g P2O5 (200 g rock phosphate) and 140 g K2O (235 g muriate of potash) per year. One third of the fertilizer is applied in May - June and two third during September-October. The cocoa tree is to be pruned regularly to maintain good canopy. In young cocoa it is necessary to have formation pruning. This is done mainly to adjust height of first jorquette. The jorquette is allowed to form at a height of 1-2 m, which will help in undertaking cultural operations. Pruning in mature cocoa includes two types viz., sanitary pruning and structural pruning. In sanitary pruning, diseased or unnecessary branches are removed. Structural pruning is done to shape the canopy to desired size and architecture. Maximum leaf area should be maintained with pruning practices to avoid self-shading of leaves. Cocoa grows in a series of storeys. The chupon or vertical growth of plant terminates at the jorquette where 4-5 fan branches develop. Further chupon develops just below jorquette and continues vertical growth till another jorquette is formed. When grown as intercrop of palms, it is desirable to restrict the height of canopy to two storey level. In studies on spacing and pruning, it has been found that a spacing of 2.7 x 5.4 m and a canopy area of 15-20 m2 was found to give highest bean yield. Cocoa is usually grown in areas where water availability is adequate. But in some areas although plenty of water is received, long periods of dry spells ranging from 3-6 months are common. Since cocoa plants are sensitive to drought, irrigation in such cases are essential. During summer, as it exists in Southern India, the crop is irrigated at weekly intervals. When it is grown as mixed crop with arecanut, the crop is to be irrigated once in a week during November-December, once in 6 days during January-March and once in 4-5 days during April-May with 175 litres of water. Cocoa responds to drip irrigation well. Maximum yields are obtained in cocoa irrigated through drip with 20 litres/day/tree (Vikaspedia, 2020).

The cocoa tree can yield up to one ton of beans per hectare each year, depending on the size of the trees and pods, their maturity, and the conditions in which it grows. Harvesting takes place all year round on the equator, and the further away you go, the more the seasons are distinct. In Ivory Coast, for example, there is a difference between the "big harvest" which happens from October to February, and the "small harvest", from March to June. Cocoa farming is still an ancestral practice, despite technological advances in all areas. It requires both expertise and human intervention in order to maximize yields. This is why harvesting is generally done by hand in two steps. First, the harvesters cut the pods from the tree to make them fall, then they open them to get the cocoa beans from the inside. De-hulling is the process of opening the pod to get the beans out. Although the Maya were the first to consume it, most of the cocoa tree production is concentrated in Ivory Coast, which accounts for more than a third of the world's production. Other major producing countries are located in Asia and North America (Chocolate, 2020).

The Colombian cocoa on the left is grown at altitude, is hand pollinated, fertilized, shaded, irrigated, and grown by a group that has been breeding cocoa for over 50 years. I took the photo on the right in 2012 along the side of the road to San Pedro, the Ivory Coast's key port for exporting cocoa. The tree has a virus that is spreading throughout the West African cocoa crops (Fig. 15) (Moloney, 2022). Pods should be harvested soon after developing their characteristic yellow or red and yellow peel color. The pods should be clipped off carefully. Pulling them off may damage the cushion and reduce pod production. The pod may be opened with a knife and the mucilaginous seeds removed (Growables, 2023).

Cocoa bean processing: After the beans are harvested from the pods, they undergo fermentation to allow the unique flavour of the cacao bean to develop. They are then dried, cleaned, and finally packaged for transport to various manufacturing plants to be made into a variety a of cacao-based products (Selenohealth, 2023). Major cocoa bean processors include Hershey's, Nestlé and Mars, all of which purchase cocoa beans via various sources. Chocolate can be made from *T. cacao* through a process of steps that involve harvesting, fermenting of *T. cacao* pulp, drying, harvesting, and then extraction. Roasting *T. cacao* by using superheated steam was found to be better than conventional roasting (use of ovens) because it resulted in same quality of cocoa beans in a shorter amount of time **(**Wikipedia, 2023a**).** Cocoa can be propagated sexually (by botanical seed) or asexually (by cutting or grafting). The predominant technological pattern for cocoa production is characterized by a plantation system that uses traditional agronomic practices and rudimentary technology. Cocoa processing or post-harvest handling mainly involves harvesting, fermentation and drying. Once the cocoa beans are harvested, they are transferred to the fermentation place (in the case of those producers who carry out this process of great importance for the development of the aroma and flavor of chocolate). The grains must be distributed inside the fermentation box (although some producers place them on the floor on polyethylene bags), and then covered to increase the temperature of the mixture and protect the grains. The duration of the fermentation process will depend on the type of cocoa; in general, Criollo types require two to three days; three to five days for Trinitario cocoa; six to seven days for Forasteros.

Fig. 15: Cocoa tree **Cocoa infected with Swollen Shoot Virus**

In the corresponding time frame for each type of cocoa, the beans must be removed to ensure good quality. Once the beans are fermented, they are transferred to the drying patios and must be stirred constantly for approximately three days; then the cocoa is roasted, which accentuates the flavor and aroma characteristic of the chocolate (Quintero, 2023).

Cocoa beans are the most important raw material for the chocolate industry and an essential product for the economy. Their price mainly depends on their quality, which is determined by various aspects, such as good agricultural practices, their harvest point, and level of fermentation. The entities that regulate the international marketing of cocoa beans have been encouraging the development of new classification methods that, compared to current techniques, could save time, reduce waste, and increase the number of evaluated beans. In particular, hyperspectral images are a novel tool for food quality control. However, studies that have examined some quality parameters of cocoa using spectroscopy also involve the chemical evaluation of cocoa powder and liquor and the interior of the beans, which implies an invasive analysis, longer times, and waste generation. We obtained hyperspectral images of 90 cocoa beans in the range between 350 and 950 nm in an optical laboratory. In addition, each cocoa bean was classified according to its fermentation level: slightly fermented (SF), correctly fermented (CF), and highly fermented (HF). We compared this classification with that carried out by experts from the Colombia National Federation of Cocoa Growers and reported in the Colombian technical standard No. 1252. The results show that the level of fermentation of dried cocoa beans can be estimated using noninvasive hyperspectral image acquisition and processing techniques (Sánchez *et al*., 2021).

Cocoa bean quality: It is also important to maintain or enhance bean quality. Recently, several bean quality attributes, both physical and chemical, that are required by the cocoa manufacturers/buyers, have been documented indetail to encourage the cacao community towards the production of better quality cocoa. These quality characteristics include flavour, purity orwholesomeness (*e.g.* free from bacteria, infestation, allergens, mycotoxins, heavy metals and pesticideresidues), physical characteristics (*e.g.* consistency, yield of edible material bean, bean size and uniformity, shell content, fat content and moisture content) and cocoa butter characteristics (*e.g.* free fatty acid content). Some of these bean quality attributes, such as total fat content, acidity, total phenols, organic acids, heavy metals, amino acids, caffeine, theobromine, pH, sugars, macro andmicro nutrient content, have been considered in the proposed Cocoa Quality Index (CQI) for Forastero type beans. Such an indexing system may represent a useful tool in research programmes designed to improve bean quality for sustainable cocoa production (Wickramasuriya and Dunwell, 2017). The flavour profile of beans is a key quality measure in cocoa. For instance, the clone CCN 51, which is planted extensively in Ecuador, exhibits many attractive agronomic traits like disease resistance, high butter content and high productivity; however, it is less popular among fine flavour chocolate manufacturers, especially due to the lack of fine flavour trait. In addition to the cacao genotype, several other factors such as location where the trees are grown (i.e. soil condition), the age of trees and post-harvest treatments (fermentation, drying and roasting) also affect cocoa bean flavor (Wickramasuriya and Dunwell, 2017). Good pre-harvest and post-harvest practices are key to maintaining many of the above mentioned bean quality descriptors. For instance, selection of suitable planting materials or the desired genetic background for cultivation is necessary to maintain the required flavour, yield, bean size and colour, and cocoa butter content. Furthermore, the quality of soil in which the cacao plants are grown is also a concern today as there is some evidence for the presence of heavy metals, especially cadmium, in cocoa beans produced in some parts of the producing countries (Wickramasuriya and Dunwell, 2017). Cocoa bean quality is also influenced by post-harvest practices, especially the fermentation and drying processes. For example, controlled drying of the fermented cocoa beans is a crucial step to avoid development of off-flavours that may affect quality of beans. High-throughput molecular analysis tools could be used for rapid and efficient identification of microbial population diversity during cocoa fermentation and drying, and for development of microbial markers associated with the process (Wickramasuriya and Dunwell, 2017). Another important factor that influences the quality of cocoa beans is the specific environmental condition in which cacao plants are cultivated. The increasing atmospheric temperature and evapotranspiration caused by global warming are likely to have a profound impact on global cacao cultivation (Oyekale *et al*., 2009).

Additionally, the climate in cacao growing regions has a considerable impact on cocoa fermentation and drying processes. Läderach *et al*. (2013) have projected that by 2050, the present cacao farming areas or cacao-favoured growing areas in Côte d' Ivoire and Ghana may shift to areas with higher altitudes due to progressive increase in temperatures. A more recent detailed study of this topic is that by Schroth *et al.* (2016). If the predicted climate and weather variability continues, this may have an impact on the economic status of cocoa farmers and major cocoa producing countries; as result, global chocolate and confectionery industry is likely to be affected due to a cocoa shortage. Breeding for climate-smart cacao varieties is vitally important to long-term sustainability of cocoa production (Wickramasuriya and Dunwell, 2017).

Classification of cocoa beans based on quality: The high-quality cocoa beans are about 22 mm long, about 8 mm thick, and have full grains, with an average weight of about 104 g per 100 grains. Different types and varieties of cocoa beans have different particle sizes. Generally, cocoa beans contain a certain amount of moldy beans, broken beans, insect-eaten beans, sprouted beans and deflated beans, and blue-gray stiff beans that are not fully fermented. The classification of cocoa bean grades is to divide cocoa beans into four grades according to the proportion of defective beans and blue-gray beans:

- First class cocoa beans: not more than 5% defective and blue-gray beans
- Secondary cocoa beans: not more than 10% defective and blue-gray beans
- Grade 3 cocoa beans: no more than 10% for defective beans and no more than 20% for blue-grey beans.
- Grade 4 cocoa beans: no more than 10% defective beans, no regulations for blue-gray beans.

Note: Generally only first-grade cocoa beans and second-grade cocoa beans are accepted in international trade (Machinery, 2022).

Definitions of several defective beans:

- Moldy beans: Cocoa beans that are moldy inside can be seen by the naked eye.
- Stiff beans: the naked eye can see that half or more of the cut surface is blue-gray cocoa beans.
- Insect-eaten beans: no matter which development period, as long as the cocoa beans with insect-eaten or visible signs of pest damage are found inside.
- Germinated beans: The germination of the germ breaks through the shell, and the shell becomes a cracked or broken cocoa bean.
- Flat beans: cocoa beans whose cotyledons are so thin that the cotyledon section cannot be formed when cut.
- Smoked beans: Cocoa beans that can be tasted or smelled or have signs of smoking.
- Broken beans: The broken part is less than half of the cocoa beans (Machinery, 2022).

To produce 1 kg of chocolate, around 300 to 600 cocoa beans are processed. The beans are roasted, cracked, and deshelled, resulting in pieces called nibs, which are ground into a thick paste known as chocolate liquor or cocoa paste. The liquor is processed into chocolate by adding cocoa butter, sugar, and sometimes vanilla and lecithin. Alternatively, cocoa powder and cocoa butter can be separated using a hydraulic press or the Broma process. Treating cocoa with an alkali produces Dutch process cocoa, which has a different flavor profile than untreated cocoa. Roasting can also be done on the whole bean or nib, affecting the final flavor. Cocoa contains phytochemicals like flavanols, procyanidins, and other flavanoids, and flavanol-rich chocolate and cocoa products may have a small blood pressure lowering effect. The beans also contain theobromine and a small amount of caffeine (Wikipedia, 2023). The harvested pods are opened, typically with a machete, to expose the beans. The pulp and cocoa seeds are removed and the rind is discarded. The pulp and seeds are then piled in heaps, placed in bins, or laid out on grates for several days. During this time, the seeds and pulp undergo "sweating", where the thick pulp liquefies as it ferments. The fermented pulp trickles away, leaving cocoa seeds behind to be collected. Sweating is important for the quality of the beans, which originally have a strong, bitter taste. If sweating is interrupted, the resulting cocoa may be ruined; if under done, the cocoa seed maintains a flavor similar to raw potatoes and becomes susceptible to mildew. Some cocoa-producing countries distill alcoholic spirits using the liquefied pulp. A typical pod contains 30 to 40 beans and about 400 dried beans are required to make 450 g of chocolate. Cocoa pods weigh an average of 400 g and each one yields 35 to 40 g dried beans; this yield is 9–10% of the total weight in the pod. One person can separate the beans from about 2000 pods per day. The wet beans are then transported to a facility so they can be fermented and dried. The farmer removes the beans from the pods, packs them into boxes or heaps them into piles, then covers them with mats or banana leaves for three to seven days. Finally, the beans are trodden and shuffled about (often using bare human feet) and sometimes, during this process, red clay mixed with water is sprinkled over the beans to obtain a finer color, polish, and protection against molds during shipment to factories in other countries. Drying in the sun is preferable to drying by artificial means, as no extraneous flavors such as smoke or oil are introduced which might otherwise taint the flavor. The beans should be dry for shipment, which is usually by sea. Traditionally exported in jute bags, over the last decade, beans are increasingly shipped in "mega-bulk" parcels of several thousand tonnes at a time on ships, or standardized to 62.5 kilograms (138 lb) per bag and 200 (12.5 metric tons (12.3 long tons; 13.8 short tons) or 240 (15 metric tons (15 long tons; 17 short tons)) bags per 20 feet (6.1 m) container. Shipping in bulk significantly reduces handling costs. Shipment in bags, either in a ship's hold or in containers, is still common. (Wikipedia, 2023).

Harvesting of cocoa beans can proceed all year, but the bulk of the crop is gathered in two flush periods occurring from October to February and from May to August. The ripe seed pods are cut from the trees and split open with machetes. The beans, removed from the pods with their surrounding pulp, are accumulated in leaf-covered heaps, in leaf-lined holes dug in the ground, or in large shallow boxes having perforated bottoms to provide for drainage. The pulp of common grades (Forastero) is allowed to ferment for five to seven days, and the pulp of the more distinctively flavoured grades (Criollo) for one to three days. Frequent turnings dissipate excess heat and provide uniformity. During fermentation, the juicy sweatings of the pulp are drained away, the germ in the seed is killed by the increased heat, and flavour development begins. The beans become plump and full of moisture, and the interior develops a reddish brown colour and a heavy, sharp fragrance. The fermented beans are sun-dried or kiln-dried to reduce moisture content to 6–7 percent and bagged for shipment (Russell Cook *et al.,* 2023). Cocoa beans are subjected to various cleaning processes to remove such contaminants as twigs, stones, and dust. Roasting develops flavour, reduces acidity and astringency, lowers moisture content, deepens colour, and facilitates shell removal. After roasting comes a cracking and fanning (winnowing) process, in which machines crack the shells and then separate them from the heavier nibs by means of blowers. The cell walls of the nibs are in turn broken by grinding, releasing the fat, or cocoa butter, and forming a paste called chocolate liquor, or cocoa mass. If alkalized chocolate liquor is to be produced, the cocoa beans may be winnowed raw; the raw nibs will be alkalized and then roasted prior to grinding (Russell Cook *et al.,* 2023). Conching, a flavour-developing, aerating, and emulsifying procedure performed by conche machines, requires from 4 to 72 hours, depending on the results desired and the machine type. Temperatures used in this process range from 55 to 88 °C

(130 to 190 °F) and are closely controlled to obtain the desired flavour and uniformity. In molding, the chocolate is cast in small consumer-size bars or in blocks weighing about 4.5 kg (10 pounds) for use by confectioners and is then subjected to cold air to produce hardening (Russell Cook *et al.,* 2023). Cocoa powders are produced by pulverizing cocoa cakes, made by subjecting the chocolate liquor of about 53 to 56 percent cocoa butter content to hydraulic pressing to remove a predetermined amount of cocoa butter. The cocoa butter content remaining in the powder may range from 8 to 36 percent, with the most common commercial grades in the United States containing 11, 17, or 22 percent cocoa butter. In the United Kingdom, cocoa sold for beverage use must contain a minimum of 20 percent (Russell Cook *et al*., 2023).

Chocolate products: Know about the MIT Laboratory for Chocolate Science dedicated to the science, history, politics, and economics of chocolate. Chocolate products usually require the addition of more cocoa butter to that already existing in the chocolate liquor. The various forms of chocolate are available in consumer-size packages and in large bulk sizes for use by food manufacturers and confectioners. Most European confectioners make their own chocolate; other confectioners buy chocolate from chocolate-manufacturing specialists. For large commercial orders, chocolate is shipped, warm and in liquid form, in heated sanitary tank trucks or tank cars (Russell Cook *et al.,* 2023).

Baking (bitter) chocolate, popular for household baking, is pure chocolate liquor made from finely ground nibs, the broken pieces of roasted, shelled cocoa beans. This chocolate, bitter because it contains no sugar, can be either the natural or the alkalized type (Russell Cook *et al*., 2023).

Sweet chocolate, usually dark in colour, is made with chocolate liquor, sugar, added cocoa butter, and such flavourings as vanilla beans, vanillin, salt, spices, and essential oils. Sweet chocolate usually contains at least 15 percent chocolate liquor content, and most sweet chocolate contains 25–35 percent. The ingredients are blended, refined (ground to a smooth mass), and conched. Viscosity is then adjusted by the addition of more cocoa butter, lecithin (an emulsifier), or a combination of both (Russell Cook *et al*., 2023).

Milk chocolate is formulated by substituting whole milk solids for a portion of the chocolate liquor used in producing sweet chocolate. It usually contains at least 10 percent chocolate liquor and 12 percent whole milk solids. Manufacturers usually exceed these values, frequently going to 12–15 percent chocolate liquor and 15–20 percent whole milk solids. Milk chocolate, usually lighter in colour than sweet chocolate, is sweeter or milder in taste because of its lower content of bitter chocolate liquor. Processing is similar to that of sweet chocolate. "Bitter chocolate" refers to either baking chocolate or bittersweet chocolate. Bittersweet is similar to sweet chocolate but contains less sugar and more chocolate liquor. Minimum percentages of chocolate liquor are fixed by law in some countries, such as the United States (Russell Cook *et al*., 2023).

Chocolate and cocoa grades: In chocolate and cocoa products, there is no sharp difference from one grade or quality to the next. Chocolate quality depends on such factors as the blend of beans used, with about 20 commercial grades from which to choose; the kind and amount of milk or other ingredients included; and the kind and degree of roasting, refining, conching, or other type of processing employed. Chocolate and cocoa products are only roughly classified; there are hundreds of variations on the market, alone or in combination with other foods or confections (Russell Cook *et al.,* 2023). Chocolate and cocoa require storage at 18–20 °C (65–68 °F), with relative humidity below 50 percent. High (27–32 °C, or 80–90 °F) or widely fluctuating temperatures will cause fat bloom, a condition in which cocoa butter infiltrates to the surface, turning products gray or white as it recrystallizes (Russell Cook *et al*., 2023). High humidity causes mustiness in cocoa powder and can lead to mold formation in cocoa powder or on chocolate. Excessive moisture can also dissolve sugar out of chocolate, redepositing it on the surface as sugar bloom, distinguished from fat bloom by its sandy texture (Russell Cook *et al*., 2023). The native peoples of Mesoamerica prepared hot and cold beverages by mixing cocoa with corn, achiote, chili or anise (Quintero, 2023).

Chocolate production: To make 1 kg of chocolate, about 300 to 600 beans are processed, depending on the desired cocoa content. In a factory, the beans are roasted. Next, they are cracked and then deshelled by a "winnower". The resulting pieces of beans are called nibs. They are sometimes sold in small packages at specialty stores and markets to be used in cooking, snacking, and chocolate dishes. Since nibs are directly from the cocoa tree, they contain high amounts of theobromine. Most nibs are ground, using various methods, into a thick, creamy paste, known as chocolate liquor or cocoa paste. This "liquor" is then further processed into chocolate by mixing in (more) cocoa butter and sugar (and sometimes vanilla and lecithin as an emulsifier), and then refined, conched and tempered. Alternatively, it can be separated into cocoa powder and cocoa butter using a hydraulic press or the Broma process. This process produces around 50% cocoa butter and 50% cocoa powder. Cocoa powder may have a fat content of about 12%, but this varies significantly. Cocoa butter is used in chocolate bar manufacture, other confectionery, soaps, and cosmetics. Treating with n alkali produces Dutch process cocoa, which is less acidic, darker, and more mellow in flavor than untreated cocoa. Regular (non-alkalized) cocoa is acidic, so when cocoa is treated with an alkaline ingredient, generally potassium carbonate, the pH increases. This process can be done at various stages during manufacturing, including during nib treatment, liquor treatment, or press cake treatment. Another process that helps develop the flavor is roasting, which can be done on the whole bean before shelling or on the nib after shelling. The time and temperature of the roast affect the result: A "low roast" produces a more acid, aromatic flavor, while a high roast gives a more intense, bitter flavor lacking complex flavor notes (Wikipedia, 2023).

Nutritive value of chocolate: Uncover the chemical facts about why eating chocolate in moderation is good for the mind, body, and soul. Cocoa, a highly concentrated food providing approximately 1,000 calories per kilogram, provides carbohydrates, fat, protein, and minerals. Its theobromine and caffeine content produce a mildly stimulating effect. The carbohydrates and easily digested fats in chocolate make it an excellent high-energy food (Russell Cook et al., 2023). A cocoa bean contains a huge amount of nutrients, such as proteins (11.5%), starches (7.5%), tannins (6%), water (5%), salts and trace elements (2.6%), organic acids (2%), theobromine (1 , 2%), caffeine (0.2%), among others. It has a moderate stimulating effect (due to theobromine) and provides the amino acids for the composition of serotonin (troptophan). Cocoa can be toxic to cats and dogs (Conceptdaily, 2023) Cocoa products are given in Fig. 16.

USES

Cacao residues on pottery in Ecuador suggest that the plant was consumed by humans as early as 5,000 years ago. The tree was likely domesticated in the upper Amazon region and then spread northward. It was widely cultivated more than 3,000 years ago by the Maya, Toltec, and Aztec peoples, who prepared a beverage from the bean (sometimes using it as a ceremonial drink) and also used the bean as a currency. Christopher Columbus took cocoa beans to Spain after his fourth voyage in 1502, and the Spanish conquistadores, arriving in Mexico in 1519, were introduced to a chocolate beverage by the Aztec. The Aztec beverage was made from sun-dried shelled beans, probably fermented in their pods. The broken kernels, or nibs, were roasted in earthen pots and then ground to a paste in a concave stone, called a *metate*, over a small fire. Vanilla and various spices and herbs were added, and corn (maize) was sometimes used to produce milder flavour. The paste, formed into small cakes, was cooled and hardened on shiny leaves placed under a tree.

Chacolate

Chacolate

Powder

Cocoa butter

Cocoa powder drink

Chacolate milk

Fig. 16. Cocoa products

The cakes were broken up, mixed with hot water, and beaten to foamy consistency with a small wooden beater, a *molinet*, producing the beverage called *xocoatl* (from Nahuatl words meaning "bitter water"). Too bitter for European taste, the mixture was sweetened with sugar when introduced to the Spanish court. Although Spain guarded the secret of its *xocoatl* beverage for almost 100 years, it reached Italy in 1606 and became popular in France with the marriage of the Spanish princess Maria Theresa to Louis XIV in 1660. In 1657 a Frenchman opened a London shop, selling solid chocolate to be made into the beverage, and chocolate houses, selling the hot beverage, soon appeared throughout Europe. By 1765 chocolate manufacture had begun in the American colonies at Dorchester, in Massachusetts, using cocoa beans from the West Indies. In 1828 C.J. van Houten of the Netherlands patented a process for obtaining "chocolate powder" by pressing much of the cocoa butter from ground and roasted cocoa beans. In 1847 the English firm of Fry and Sons combined cocoa butter, a by-product of the pressing, with chocolate liquor and sugar to produce eating chocolate, and in 1876 Daniel Peter of Switzerland added dried milk to make milk chocolate. The proliferation of flavoured, solid, and coated chocolate foods rapidly followed (Russell Cook *et a*l., 2023).

This perennial shade grown tree crop provides biodiversity benefits. It is cultivated either as monocultures or in association with other crops such as fruit crops. Cocoa beans are the key raw materials in the production of chocolate and other cocoa-based products. However, the freshly harvested cocoa beans do not contain the determinants of chocolate aroma or flavour, and hence, post-harvesting processing of raw beans (fermentation, drying and roasting) is essential for optimum flavour formation. The process of cocoa bean fermentation is trigged by action of microorganisms (*e.g.* yeast, acetic acid bacteria and lactic acid bacteria) and the flavour precursors such as organic acids, reducing sugars and free amino acids are produced at the end of the process. In addition, the process of fermentation involves significant reduction in polyphenols (epicatechin and catechin) and alkaloids (methylxanthines caffeine, theobromine) found in raw cocoa beans that give rise to bitterness and unpleasant astringency (Wickramasuriya and Dunwell, 2017).

Most production of cocoa takes place in the tropics, and the beans produced in this region used to be principally processed elsewhere into cocoa powder and cocoa butter (Wood and Lass, 1985). Now, although most of the cocoa grindings (38%) are carried out in the Europe and Russia region (principally the Netherlands), the remainder is processed close to production areas in the Americas (22%), Asia and Oceania (21%) and Africa (19%). In addition to its use in confectionery, cocoa products are also considered to have other functional properties and are used in a range of pharmaceutical and cosmetic products. Cacao seeds are a rich source of polyphenolic antioxidants and consequently, it has been reported that cocoa-based products contribute a greater proportion of the dietary intake of phenolic antioxidantsthan do green tea, wine, soy beans and blueberries, which are known antioxidant rich food products and beverages. The antioxidant properties of cocoa, particularly the high flavonoid content are now of great interest due to its profound effects on human health. Specifically, the claim that cocoa polyphenols could prevent cancer or delay/slow down the progression of cancer (chemo- preventive agents) has received increased attention (Martin *et al.,* 2013). Furthermore, flavonoids extracted from cocoa have been shown to play a pivotal role in mediating innate and acquired immunity and also have been shown to have an effect on diet induced obesity and insulin resistance. Emerging data support the suggestion that cocoa flavanols may serve as cardioprotective agents. These compounds have been reported to modulate mediators of inflammation. Cocoa flavanols and procyanidins have been shown to have beneficial effects including decreased platelet aggregation through increasing concentration of epicatechin and catechin in the plasma. Furthermore, cacao shell is a rich source of theobromine and vitamin D. The pods contain a high level of potash that is used in soap production (Wickramasuriya and Dunwell, 2017).

Cocoa beans (fermented or not) that are produced and marketed are processed industrially or by hand to obtain by-products (cocoa paste, butter and powder) and final products (chocolates, chocolates, chocolates, chocolate drinks, coatings, among others). The cocoa paste, mass or liquor is obtained from the grinding of the bean. When the cocoa is subjected to pressure (pressing), a solid part or cake is obtained, which is crushed and pulverized to produce cocoa powder, which is used to make chocolates, chocolates and other confectionery products. In turn, pressing yields a liquid part, the fat, which is filtered and deodorized to become cocoa butter, which is used in the production of chocolate and other related confectionery, as well as in the pharmaceutical and cosmetics industries. Other parts of the cocoa fruit can also be used, such as the cob, which is used as organic fertilizer or for animal feed. Even the husk of the grain is used as an infusion. On the other hand, it highlights the possibility of developing potential from the mucilage or the fruit in general. Finally, a distinction must be made between mass consumption and fine or select chocolate products. In this last category, the quality of the cocoa (from fine or aromatic cocoa) and its origin, as well as other ingredients, the knowledge and innovation of the master chocolatier, the final art in the presentation of the product, and the high cocoa content (which translates into dark chocolate) are relevant. All this generates differentiated attributes to the final product, which constitute an edge of its competitiveness in both domestic and international markets (Quintero, 2023). Cacao butter, a product from cacao beans, is sometimes added to lip salves and face creams as it nourishes dry skin and lips. Chocolate has long been considered a romantic gift. Historically, the Mayans and Aztecs used chocolate in engagement and marriage ceremonies and religious rituals. Cacao beans are used to make cacao solid, cacao butter, and chocolate. They were first consumed in Central and South America as a liquid treat mixed with spices like chilli and vanilla. The flesh of cacao fruit has a tropical taste like passion fruit and mango. It is used in some countries as an ingredient in juices, smoothies, jellies, jams, and ice creams (Kew, 2023). Cocoa butter is used in confections and in manufacture of tobacco, soap, and cosmetics. Cocoa butter has been described as the world's most expensive fat, used rather extensively in the emollient "bullets" used for haemorrhoids (Growables, 2023).

HEALTH BENEFITS

Cocoa seeds and leaves are used in traditional medicine to cure various ailments, such as asthma, diarrhea, weakness, parasitism, pneumonia, colic, cough, etc. The oil extracted from its seed, on the other hand, known as *Cocoa butter*, it is a usual topical remedy for treating wounds, rashes, dry or chapped lips, skin conditions and even malaria and rheumatism (Fig. 17). At the same time, the consumption of cocoa can trigger gastrointestinal effects and is associated with the incidence of migraines (Conceptdaily, 2023).

	
Cacao was used as a sacred plant medicine by the ancient tribes of Central and South America	**Cocoa butter is a common topical remedy for treating wounds**

Fig. 17: Health benefits of cocoa

Cocoa derivatives belong to the group of foods called Stimulants. Chocolate, an emblematic by-product, is highly energetic, with a high fat and sugar content; it also contains minerals (potassium, phosphorus, magnesium, iron and zinc); flavonoids; biogenic amines; methylxanthines (caffeine and theobromine); cannabinoid fatty acids; vitamins A and B complex; among others. Therefore, moderate consumption of chocolate - especially dark chocolate or chocolate with a high proportion of cocoa- has beneficial cardiovascular and other health protection effects. Thus, for example, several scientific studies report its positive effects on the reduction of blood pressure and cholesterol**,** with improvements in the endolethal function of blood vessels. It also induces favorable effects on people's mood and combats depression; it also reduces the risk of Alzheimer's disease among others. On the other hand, they highlight the benefits of chocolate in cosmetology and hair and skin care, given its moisturizing and antioxidant effects, as well as its anti-inflammatory power (Quintero, 2023). Cacao beans are rich in antioxidants which help protect cells from damage. They are also known to increase endorphins, a hormone which boosts happiness (Kew, 2023).

Cacao contains many bioactive compounds and essential minerals that work together to support immune and cardiovascular health, enhance cognitive function, elevate mood, and improve nutritional health. Flavanols in cacao possess antioxidant properties to reduce oxidative stress and mediate our inflammatory response. This is important in conditions associated with chronic inflammation, such as acne, obesity, and allergies, and is also important for mediating immune function. Theobromine is a mild stimulant in cacao that is derived from caffeine and exerts similar effects, amongst other unique ones. While it also interacts with adenosine receptors throughout the body to produce an uplifting effect, studies have shown that theobromine can also reduce blood pressure in patients with elevated blood pressure. Cacao also contains the essential amino acid, tryptophan, and its related metabolite, tryptamine. Both of these compounds are important biological precursors for neurotransmitters, melatonin, serotonin, and for vitamin B3. They can also interact with the same receptors as our natural neurotransmitters and modulate our serotonergic pathways. Similarly, phenylethanolamine (PEA) interacts with our dopaminergic pathways, which are associated with feelings of pleasure and reward. These compounds are able to work together to elevate mood, enhance cognitive function and improve mental health. Finally, cacao possesses essential minerals including magnesium, calcium, zinc, phosphorus, and iron. These minerals are crucial for normal physiological function, brain signalling, enzyme function, bone and skin health, cardiovascular health, and more. Cacao can be taken to help supplement for any mineral deficiencies and prevent the development of common associated symptoms and conditions, such as anaemia, bone loss, chronic fatigue, and more (Selenohealth, 2023). The health benefits of cacao are vast and scientific studies have shown cacao can assist with many symptoms and conditions by interacting with our natural biochemical and physiological pathways. Cacao can be taken to improve mental health, immunity and oxidative stress, cardiovascular health, metabolic syndrome, inflammatory conditions, fatigue, nutritional deficiencies, skin health, bone health, and even cancer. It is a versatile and all-natural food that can help to assist in one's personal health journey. Cacao has been shown to benefit the health related conditions (Selenohealth, 2023).

- Mental health
- Immunity and Inflammation
- Cardiovascular health
- Metabolic syndrome
- Fatigue
- Nutritional deficiencies
- Cancer
- Skin health
- Bone health

In general chocolate and cocoa is considered to be a rich source of antioxidants such as procyanidins and flavanoids, which may impart anti aging properties. Chocolate and cocoa also contain a high level of flavonoids, specifically epicatechin, which may have beneficial cardiovascular effects on health (Growables, 2023).

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