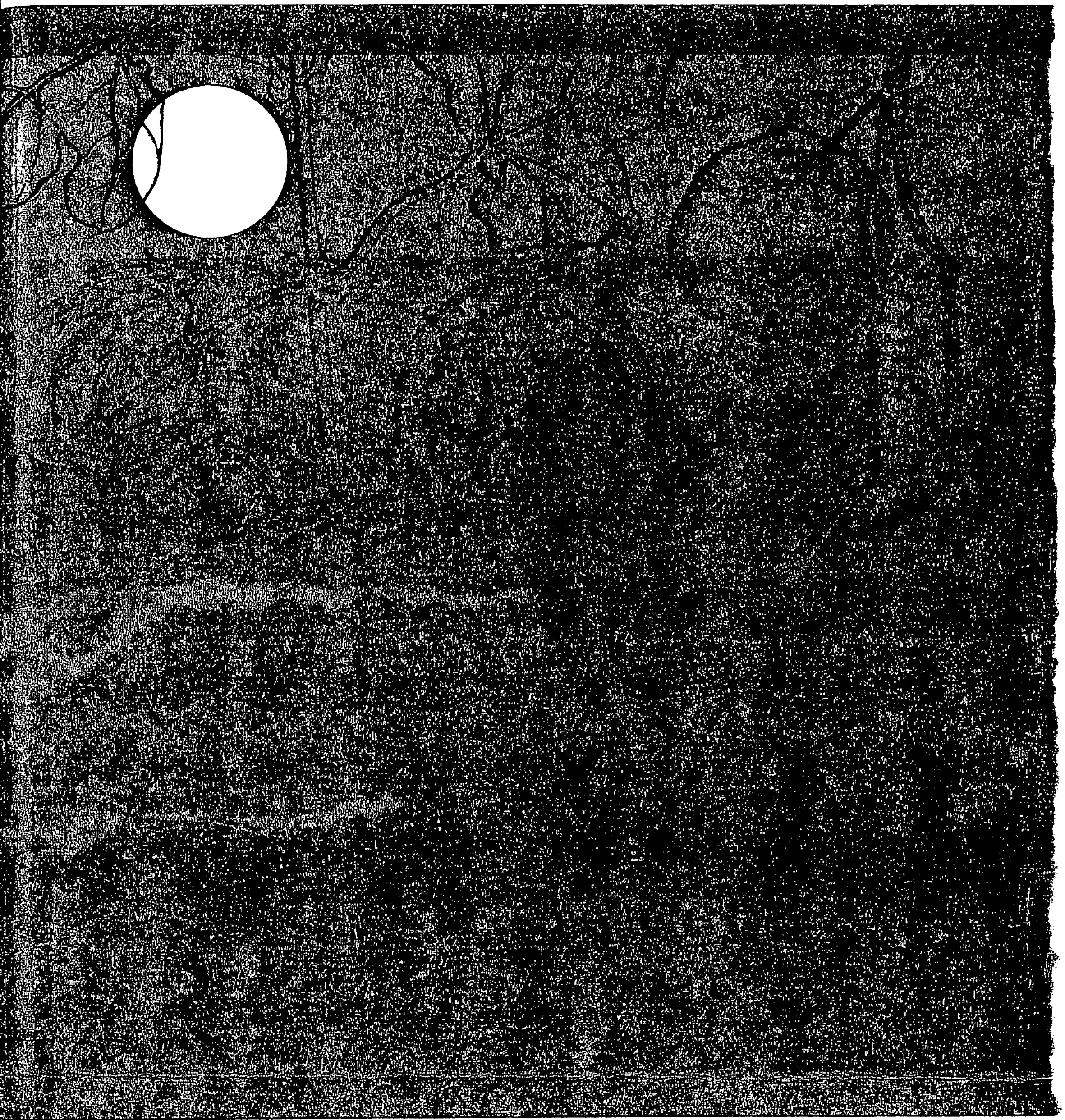
Tropical Crops
Dicotyledons



J W Purseglove

pronounced pulvini. Fls small, solitary, paired, or in compressed cymes on trunk and main branches (cauliflorous) or axillary on young branches; sepals 5; petals 5 with ligule; stamens 5 forming short tube with 5 staminodes which may be subulate or petaloid; ovary sessile, with 5 loculi with many ovules; style filiform. Frs large indehiscent drupes; seeds surrounded by pulp derived from ovule integuments, exalbuminous, cotyledons convoluted.

In the closely related genus, *Herrania*, lvs compound-digitate and normally with unbranched habit.

T. cacao (q.v.) is the only sp. of economic importance. *T. bicolor* H. & B., occurring from Mexico to Brazil, is cultivated outside its natural range for the edible pulp round seeds and seeds are used like those of cocoa. The seeds of *T. angustifolium* Moc. & Sesse are sometimes mixed with cocoa in Mexico and Costa Rica; the pulp round the seeds of *T. grandiflorum* (Willd. ex Spreng.) K. Schum. is used for making a drink in parts of Brazil and is also eaten.

Theobroma cacao L. (2n = 20) COCOA

NOTE: The word 'cacao' is often used for the tree and its parts and the word 'cocoa' for the products of manufacture. In this account the word 'cocoa' is used throughout, both for the tree and its products.

USES

The crop is of ancient cultivation in Central America (see below) and the Indians believed it to be of divine origin; hence the generic name *Theobroma* given by Linnaeus, meaning the 'food of the gods'. Well-to-do Indians made a thick beverage by pounding roasted cocoa beans with maize and *Capsicum*. The beans were also used as currency; 100 beans would buy a slave. Tribute to the Aztec emperor from the lowland people was made in cocoa beans. Large quantities were found in Montezuma's palace when he was defeated by Cortez in 1519.

Cocoa beans, obtained from a canoe off Central America, were taken by Columbus to Europe as a curiosity. The Spaniards did not appreciate the Indian method of preparation, but soon learnt to make it palatable by mixing the ground roasted beans with sugar and vanilla; exports to Spain in this form soon began, Cortez recognizing its possible commercial value. Later the unprocessed dry beans were exported and the first chocolate factories were opened in Spain. Cocoa beverage became popular in Italy and France early in the 17th century and soon afterwards in Holland, Germany and England. Chocolate houses appeared alongside the coffee houses and were used as clubs. At this time cocoa was very expensive, over £1 per lb, and consumption was limited to the wealthier classes.

In 1828 van Houten, a Dutch manufacturer, invented a method of expressing much of the fat from the bean, thus making it more palatable and digestible. References to defatted cocoa had been published in France in 1763 and in Italy in 1769. The fermented beans are roasted, when water and acetic acid are driven off, and the characteristic aroma of chocolate is produced. The beans are then cracked to form nibs and the shell (12 per cent) and embryo (1 per cent) are removed by winnowing. The nibs are ground to make the cocoa mass and from this cocoa powder is made by reducing the fat content from 55 to 24 per cent. The expressed fat is used for making chocolate or sold as cocoa butter. In the manufacture of chocolate the cocoa mass is ground with sugar and extra cocoa fat is added; lecithin may also be added to increase fluidity. In the manufacture of milk chocolate, discovered by M. D. Peter in Switzerland in 1876, dried or powdered milk is incorporated. Cocoa butter is also used in cosmetics and pharmaceutical preparations; its melting point is a little below blood heat.

The cocoa shell (testa) is used in stock feed or as manure; it is a source of theobromine, shell fat and vitamin D.

ORIGIN AND DISTRIBUTION

The centre of origin is placed by Cheesman (1944) on the lower eastern equatorial slopes of the Andes, where the greatest range of variation in natural populations exists. Cocoa has been cultivated since ancient times in Central America, from Mexico to the southern Costa Rican border, possibly for over 2,000 years. It is probable that it was never truly wild in this region and was introduced in early times from South America; the theory of divine origin and its use as currency would appear to support this view, as it is unlikely that a wild tree would be held in such high esteem. This Central American cocoa is Criollo cocoa (see below).

Cuatrecasas (1964) assumes that 'in early times a natural population of *Theobroma cacao* was spread throughout the central part of Amazonia —Guiana westwards, and northwards to the south of Mexico (and) that these populations developed into two different forms geographically separated by the Panama isthmus'.

It is possible, however, that the Criollos originated as mutations and the fixing of homozygous recessive characters in populations on the periphery of distribution, and were then maintained through geographic isolation and selection.

After the arrival of the Spaniards cocoa spread rapidly in the New World. Criollo cocoa, presumably from Central America, was taken to Venezuela and Trinidad, introduction into the latter being in 1525. Jamaica, Haiti and the Windward Islands became important producers and there were extensive plantations in Jamaica when the island was captured by the British from Spain in 1655. In 1727 much of the cocoa in Trinidad was destroyed by a 'blast', which may have been a hurricane or an epidemic outbreak of pests or disease. Some 30 years later Trinidad obtained planting material of the darker-beaned cocoa of the Amazonian Forastero type or admixture, possibly from Eastern Venezuela, and this hybridized with the remnants of the original white-beaned Criollo introduction to produce the heterogeneous Trinitario cocoas. The latter were introduced into Venezuela about 1825 and gradually supplanted the Venezuelan Criollo as they were hardier and more productive. Amazonian Forastero cocoas, with cotyledons paler than is normal in this group, were taken over the Andes to Ecuador, and became the Cacao Nacional of that country.

The variability of *Theobroma cacao* decreases as one goes further down the Amazon from the centre of origin on the slopes of the Andes and self-compatible trees are encountered (see below). The Amelonado forms of Amazonian Forastero with dark purple cotyledons were taken into cultivation in Bahia in Brazil. These were introduced by the Spanish and Portuguese to islands in the Gulf of Guinea in the 17th century. One or a few Amelonado pods were taken to Ghana in 1879 from Fernando Po and gave rise to the large West African industry. There is evidence that cocoa was grown at mission stations in Ghana before this date. The West African Amelonado shows little variability, as might be expected from a very limited introduction of self-compatible material, and is very uniform in bean size and flavour.

Cocoa was introduced into South-east Asia by the Spaniards (Philippines in 1670) and the Dutch in the 17th century. The Germans took it to Samoa and New Guinea in the 18th century. Uganda obtained seedlings from the Royal Botanic Gardens, Kew, in 1901.

It has been shown above that the cvs in the different countries varied with the region from which they were introduced and the amount of hybridization. The general names used are based on Venezuelan terminology, namely, Criollo = native, Forastero = foreign, and Trinitario = native of Trinidad.

SYSTEMATICS

Cuatrecasas (1964) recognizes two subspecies of *Theobroma cacao*, of which one has four forms as shown below:

T. cacao L. subsp. *cacao* f. *cacao* = *T. sativa* (Aubl.) Lign. & Le Bey.

The original Central American Criollo and the type of the Linnean sp. Frs oblong, tapering and pointed, surface warty, 5 deep narrow furrows with 5 shallower furrows between, immature pods green or dark red; woody mesocarp thin; seeds rounded in cross section; cotyledons white. Highest quality. Mexico and British Honduras.

T. cacao L. subsp. *cacao* f. *pentagonum* (Bern.) Cuatr. = *T. pentagona* Bern.

'Alligator cocoa'. Frs oblong-oval, about 20 × 9 cm, 5 ribs, prominent and continuous, surface warty, immature pods reddish yellow, mesocarp not woody; seeds large, round; cotyledons white. High quality. Known only in cultivation, originally in southern Mexico and Central America. Distinctive pod-sculpturing is probably a recessive character, as 'alligator' forms segregate from the selfing of 'non-alligator' cocoas like 'ICS 45'.

T. cacao L. subsp. *cacao* f. *leiocarpum* (Bern.) Ducke = *T. leiocarpa* Bern.
Frs ovoid, shallowly 5-furrowed, almost smooth, shell thin; seeds plump; cotyledons white or pale violet. High quality. Known only in cultivation, mainly on Atlantic coast of Guatemala. A segregate form or mutant. 'Porcelaine Java Criollo' may be this form.

T. cacao L. subsp. *cacao* f. *lacandonense* Cuatr.
A wild half-vine known only from the type locality near Chiapas in Mexico. Frs ovoid-oblong. 10-angled.

T. cacao L. subsp. *sphaerocarpum* (Chev.) Cuatr. = *T. sphaerocarpum* Chev. = *T. leiocarpum* sensu Pittier; 'Amazonian Forastero'; 'Amelonado'.
Frs ovoid, smooth, shallowly 10-furrowed, rounded at both ends; unripe pods green; pericarp very thick, mesocarp woody; seeds ovoid, compressed, cotyledons dark purple. Quality variable, but lower than subsp. *cacao*. Native in South America; found spontaneous in the Hylaea from the Guianas and middle Amazon north and westward to the Andes. Now extensively planted throughout the tropics. The dark purple colour of the cotyledons is dominant to the absence of pigment.

The above forms and subsp. interbreed readily to give fully fertile F_1 hybrids and have given rise to a large number of recognizably distinct local populations.

The most satisfactory classification (Cheesman, 1944) is to divide the cultivated and wild cocoas into 3 main groups, based on the Venezuelan trade names.

1. CRIOLLO: Pods yellow or red when ripe, usually deeply 10 furrowed, often markedly warty, usually conspicuously pointed, pod wall thin in section, so that pod compresses under hand pressure; seeds large, plump and almost round in section; cotyledons white or pale violet, which give a cocoa lacking any astringent characteristics. Beans ferment quickly; yields comparatively low. It produces the highest quality of all cocoas; only small quantities are now available on the world market. It can be subdivided into:

(a) CENTRAL AMERICAN CRIOLLO: Unripe pod wall predominantly green, ripening to yellow. The original cocoa cultivated in Central America and Mexico and subjected to human selection for a long period, probably over 2,000 years, resulting in fixing the recessive white cotyledons, with no astringency and requiring little fermentation. No genuine wild trees known.

(b) VENEZUELAN CRIOLLO: Exhibits greater tree to tree variation in colour, size and shape of pods, consistent with its position nearer the centre of origin. Unripe pod wall usually red. Probably introduced into Venezuela from Central America, followed by slight subsequent admixture.

2. AMAZONIAN FORASTERO: Unripe pods whitish or green, ripening yellow, usually inconspicuously ridged and furrowed, surface often smooth (rough, warty pods in headwaters of Amazon, smoother towards mouth), ends rounded or very bluntly pointed; pod walls relatively thick and often

with a woody layer difficult to cut; seeds flattened; fresh cotyledons deeply pigmented and dark violet in cross-section; usually giving an astringent product. Trees hardier, more vigorous and higher yielding than Criollo types. Occurs naturally throughout the basin of the Amazon and its tributaries; variation decreasing nearer the mouth. Members of the group were taken into cultivation in Brazil and the Amelonado form was subsequently taken to West Africa, where it gives a highly uniform population. The quality is lower than in other forms and it was accident rather than selection that this group now supplies the bulk of the world's cocoa. The Forastero cocoa taken to Ecuador in the 18th century has plumper seeds and paler cotyledons; it became known as Cacao Nacional and in the trade is a 'Fine Forastero'.

3. TRINITARIO: A wide range of hybrids between Criollo and Amazonian Forastero, occurring typically in Trinidad (see above); very heterogeneous and exhibiting a wide range of morphological and physiological characters. Colour of unripe pod may be whitish, green, red or purple, ripening yellow, orange or red, variable in shape and wall thickness; surface ranging from complete smoothness to heavy sculpturing; beans range from plump to flat; pigmentation of cotyledons from white to nearly black. Introduced into Venezuela about 1825 and subsequently into most cocoa-growing countries. Hardier and more productive than Criollo, the best clones combining the vigour of Amazonian Forastero with much of the quality of Criollo; other clones very inferior. Trinitario cocoas are of great importance in breeding, the only definable unit being the clone. In the trade it is regarded as a 'fine' cocoa.

ECOLOGY

In its natural habitat *Theobroma cacao* is a small tree in the lowest storey of the evergreen tropical rain-forest of South America. It usually grows in groups along river banks, where it may often stand for 6 months in water, but the water must be running to supply the necessary oyxgen. Its status as an under-storey tree led to the belief that cocoa must be grown under shade, but, as with many other economic crops, the natural environment where it grows in competition with many other species does not necessarily give the best conditions for growth and high yield when cultivated; heavily-shaded wild cocoa often carries little fruit.

It is a strictly tropical crop. The limits of cultivation are 20°N and S, but the bulk of the crop is grown within 10°N and S. It is grown mainly at low elevations, usually below 1,000 ft, but it is cultivated at up to 4,000 ft in the Venezuelan Andes and at 3,000 ft in Colombia. Areas of tropical evergreen rain-forest and semi-evergreen rain-forest are the most suitable ecological zones for cocoa. The optimum temperature range is 70–90°F, with small seasonal and diurnal range. Rainfall in the cocoa belt varies from 40–100 in., but most cocoa, without irrigation, is grown with a rainfall above 50 in. The rainfall should be well distributed, preferably with 4 in.

or over per month, and with the absence of a marked or intense dry season with less than 2·5 in. per month.

Cocoa can survive in its natural habitat in dense shade which would kill many species, but it can also survive considerable exposure. Photosynthesis is reduced by shading, but is partly compensated for by the larger leaf area under shade. The stomata remain open and transpire freely in full sunlight provided the water supply is adequate. Seedlings grow best under shade with approximately 25 per cent of full sunlight. Self-shading occurs in mature trees, thus modifying the light relations. The amount of light may gradually be increased to 50 per cent as growth occurs in the young trees. Later, provided that the crop has optimal conditions of rainfall, drainage, soil aeration and nutrition, overhead shade may be gradually removed and the crop can be grown in full sunlight when considerable self-shading has been attained. When shade trees are suddenly removed in mature cocoa, or when environmental factors fluctuate excessively or are not optimal, or when diseases and pests attack the tree, the outer layer of the canopy in unshaded cocoa becomes disrupted and leaf-shedding and die-back occur. High winds may cause considerable mechanical damage, particularly to young cocoa trees, and windbreaks are desirable. Flowering and leaf-flushing do not appear to be affected by photoperiod.

In cultivation cocoa requires a well-drained, well-aerated soil with good crumb structure and adequate supplies of water and nutrients. The soil should possess ample root room; it should be deep and easily penetrable by roots to at least 5 ft and with a good top humic layer. The best soils are aggregated clays or loams or sandy loams, often red or reddish-brown in colour, developed over coarse crystalline igneous or metamorphic rocks, or rocks of recent volcanic origin. The best cocoa soils in West Africa are derived from igneous rocks; those in Trinidad are formed from marine sediments containing calcium carbonate and glauconite and rich in potassium and phosphorus; those of the Pacific are mainly of volcanic origin. The optimum pH is around 6·5.

STRUCTURE

Small under-storey tree, 6–8 m, but sometimes reaching 12–14 m in Nacional cocoa in Ecuador and Amelonado in West Africa.

ROOTS: Tap-root of seedling tree grows straight downwards to a depth of 2 m in well-aerated soil, but much less in compact soils or where the permanent water table is high. It may bifurcate on reaching a clay layer. There is a definite collar at the junction of tap-root and trunk and below this most of secondary roots arise to a depth of 15–20 cm and grow out in humic layer to a length of 5–6 m, giving rise to a dense mat of surface-feeding roots. Middle of tap-root usually devoid of secondary roots, but these may arise lower down and either grow upwards to surface mat or downwards into lower layers of soil. There is probably an association with mycorrhiza.

BRANCHES: Tree shows dimorphic branching. Seedlings form a single main stem or chupon, 1–1·5 m high at about 14 months. The terminal bud then breaks up into 3–5 meristems to give the so-called jorquette (the bud being used up in the process), and grow out into lateral plagiotropic fan branches, which may be almost horizontal. Further increase in height is made by an axillary bud just below the jorquette and this produces an orthotropic sucker or chupon which grows up vertically between the fan branches and then repeats the growth pattern by forming another jorquette and a second whorl of fan branches. In this way, several successive chupons arise sympodially, each producing a tier of branches, the lowermost of which tend eventually to dry and fall. Plantation practice varies as to the number of tiers which will be kept, unwanted chupons being removed by pruning.

Trunks or stems below a jorquette produce only chupons; these are morphologically the same as the trunk, are determinate in growth and have a phyllotaxy of $\frac{3}{8}$. Rooted chupon cuttings have the same habit. Fan branches from the jorquette give rise to further fan branches and are indeterminate in growth, bearing lvs alternately in two ranks with a phyllotaxy of $\frac{1}{2}$. Fan branch cuttings may produce chupons when they are pruned or accidentally wounded. The habit of a budded tree depends on the type of bud used—fan or chupon. Both chupon and fan branches bear fls and frs. Mucilage cells occur in the pith and cortex.

LEAVES: Large, simple, dark green when mature; petiole 1–4 cm long, longer on chupons, pubescent, well-marked pulvinus at each end; stipules lanceolate, 5–20 × 1–2 mm, pubescent, early deciduous, except when chupons about to branch when they form a brush at tip; lamina elliptic- or obovate-oblong, entire, usually glabrous, 12–60 × 4–20 cm, being largest in middle of tree where they receive least light, base rounded and obtuse, apex acuminate; main vein prominent; lateral veins pinnate, 9–12 pairs; axil spot correlated with red pod, absence of spot with green pod.

Lvs on fan branches produced in flushes, young lvs being produced in rapid succession by burst of activity of terminal buds, which then return to dormant condition and new growth hardens. Young lvs soft and limp and hang down vertically, pale green or various shades of red depending on clone or cv. Period between flushes depends on temperature and tree's nutrition. If temperature too high or nutrition faulty, flushes appear in rapid succession, which debilitate the tree. Under good conditions lvs persist in healthy functional condition, and new flushes appear only 2–4 times per year. Lvs usually persist through 2 further flushes and are dropped on the third. Stipules of terminal bud leave characteristic scars on twigs when growth resumed so extent of successive flushes is evident on examination.

INFLORESCENCES: Cauliflorous on older leafless wood of main stem and fan branches, never on recent flushes. Much compressed cincinnal cymes with branches greatly reduced, originating from buds in axil of reduced prophylls, which are minute sessile lvs at base of branch arising from axillary bud of an ordinary lf. Branch does not usually grow out, but its shortened and twisted branches broaden into a cushion, which may bear up to 50 fls in one season; peduncles and bracts pubescent. When inflorescence stimulated by witches' broom disease the cushion grows out into leafy shoots.

FLOWERS: Regular, pentamerous, hermaphrodite. Pedicels 1–2 cm long, greenish, whitish or reddish, with sparse hairs and constricted abscission layer at base. Sepals 5, pink or whitish, 7–10 × 1·5–2·5 mm, triangular, rather fleshy, valvate, shortly united at base. Petals 5, smaller than sepals; base obovate 3–4 mm long, expanding into concave, cup-shaped pouch, white with 2 prominent purple guide lines; end of petal spatulate, 2–3 mm long, yellow, bending outwards and backwards and attached to pouch by narrow connective. Androecium with 5 outer staminodes, opposite sepals, erect, pointed, with dark purple centres and whitish ciliate margins and form ring round style; 5 inner fertile stamens with 4 pollen sacks which dehisce longitudinally; filaments bend outwards so that anthers are concealed in pouch of corresponding petal. Ovary superior; carpels 5; ovules numerous, anatropous; deeply penetrating stylar canal makes placentation axile at base of ovary and parietal above; style single, 2–3 mm long, hollow, shorter than surrounding fence of staminodes, divided at tip into 5 stigmas which are often more or less adherent.

FRUITS: Usually considered a drupe, but is commonly called a pod; indehiscent, variable in size, 10–32 cm long, in shape from nearly spherical to cylindrical, pointed or blunt, smooth or warty, with or without 5 or 10 furrows; young pods white, green or red and ripening green, yellow, red or purple (see SYSTEMATICS above). Pericarp (= husk) usually fleshy and thick with mesocarp varying in degree of lignification. Pods attain full size 4–5 months after fertilization and require a further month for ripening when colour may change. 20–90 per cent of fruits fail to develop fully, drying out being most prevalent at 50 days when about 5 cm long.

SEEDS: Usually called beans; 20–60 per pod, Forastero cvs having more than Criollo cvs; usually arranged in 5 rows; variable in size, 2–4 × 1·2–2 cm, in shape ovoid or elliptic, and with white to deep purple cotyledons (see SYSTEMATICS above). Embryo develops late in seed using up endosperm. At maturity seed consists of two large convoluted cotyledons, a small embryo, a thin membrane which is the remains of the endosperm and a leathery testa (= skin or shell). Fresh seeds surrounded by mucilaginous, whitish, sugary, acid pulp which develops from the outer integument of the ovule; this pulp is removed during fermentation and drying. As seeds

Fig. 90. **Theobroma cacao** : COCOA. **A**, jorquette with young fan branches (× $\frac{1}{4}$); **B**, cauliflorous inflorescence (× 1); **C**, flower in longitudinal section (× 4); **D**, fruit (× $\frac{1}{3}$); **E**, seed in longitudinal section (× $\frac{1}{2}$); **F**, seed in transverse section (× $\frac{1}{2}$).

A
B
C
D
E
F

are of short viability and indehiscent pods remain on tree unless harvested, natural dispersal is by monkeys, squirrels, rats and other animals which break through husk, suck off sweet pulp and disseminate the unpalatable seeds. Seeds constitute 25 per cent by weight of mature fruit; 250–450 dry fermented beans per lb.

POLLINATION

The flowers are ill-adapted for pollination by more regular methods or for self-pollination and they are devoid of scent and nectar; the pollen is too sticky for wind-pollination; the position of the anthers hidden in pouched petals and the ring of staminodes hindering access to the stigma. A certain amount of self-pollination may be effected by crawling insects such as thrips, ants and aphids. When these are excluded, pollination still occurs and some clones are self-incompatible and yet fruit well. Thus some insects which can fly or be carried by wind must be responsible. It is now believed that the main pollinating agents are ceratopogonid midges; in Trinidad *Forcipomyia quasi-ingrami* Macfie and *Lasiohelea nana* Macfie; in Ghana *Forcipomyia ingrami* Carter, *F. ashantii* Ingram & Macfie and *Lasiohelea litoraurea* Ingram & Macfie. These midges appear to be attracted by, and to feed on the purple tissues of the staminodes and guide-lines of the petal pouches and would then present their backs in turn to stigma, style and pollen. Most pollination takes place in the first 2–3 hours after dawn except during or after heavy rain. In Ghana 2–5 per cent of flowers only are pollinated and a fairly large number of these fail to set seed. Later during the season, when flowers are fewer, pollination may rise to 50–75 per cent. Fertilization takes place 7–8 hours after pollination. Unpollinated flowers drop 24 hours after opening. The pollination efficiency is low, but this is compensated for by the large numbers of flowers produced; it is estimated that only one in every 500 flowers matures to a ripe fruit. Fruit setting is further complicated by self- and cross-incompatibility.

In artificial pollination a flower bud, which will open the following day and is recognized by its whitish colour and swollen appearance, is selected and covered with a glass or plastic tube, 5 × 1·5–2 cm, which is sealed to the bark by plasticine. The plasticine should be applied to embrace the flower pedicel and all crawling insects removed from the bud and its pedicel before the tube is applied. The tube is covered by cheese cloth at the top, kept in place with a rubber band. This ensures circulation of air and exclusion of insects. Small, nylon-gauze, tent-shaped hoods attached with pins may be used instead of the glass tube. The stamens are carefully removed from inside petal bases and the anthers are dabbed directly onto the stigmas, one or two staminodes having been pinched out to give access to the stigmas. Emasculation should not be necessary in cross-pollination if the flowers are not roughly handled. In order to prevent undue shedding and wilting of fruits from these pollinations it is usual to remove all the developing fruits on the tree produced by natural open-pollination. The tubes are removed 24 hours after pollination and in 3–5 days fertilization is ascertained by swelling of the ovary. It may be necessary to spray the developing pods against fungal diseases and to protect them against vermin.

INCOMPATIBILITY

Self-incompatibility in cocoa was first reported in Trinidad by Harland in 1925 and again by Pound in 1932. Self-incompatible Trinitario clones have so far shown themselves to be cross-incompatible, but are cross-compatible with self-compatible trees. The clone 'ICS 1' is self-compatible; 'ICS 60' is self-incompatible.

Cope (1962a) has shown that the site of incompatibility is in the embryo-sac and not in the stigma and the style, thus providing the first example in the Angiosperms of incompatibility of this type. Pollen tubes in incompatible matings grow as fast as those in compatible pollinations and deliver their gametes into the embryo-sacs in a perfectly normal fashion. The embryo-sac is in no way abnormal and incompatibility is due to the failure of the male nuclei to unite with the egg and polar nuclei and is genetically controlled. In incompatible matings the flowers are shed 3–4 days after pollination. In incompatible pollinations the proportion of ovules showing non-fusion averages 25, 50 or 100 per cent. Fusion or non-fusion is controlled by a series of alleles operating at a single locus (S), showing dominance or independence relationships, *e.g.* $S_1 > S_2 = S_3 > S_4 > S_5 > S_6$. They are the same in both male and female parts of the flower so that reciprocal pollinations give the same results. The diploid constitution of both parents decides whether the cross is compatible or incompatible, encounters between the gametes being a random process. Incompatible crosses involve parents with the same dominant allele, *e.g.* $S_{1.2} \times S_{1.3}$, $S_{2.4} \times S_{2.5}$, or a genotype with independent alleles and another where one of these independent alleles is dominant, *e.g.* $S_{2.3} \times S_{2.4}$, $S_{2.3} \times S_{3.5}$. In the case of $S_{1.2}$ selfed or $S_{1.2} \times S_{1.3}$, the proportion of non-fusion ovules is 25 per cent because S_1-bearing gametes meet in one-quarter of all gametic encounters; $S_{2.3}$ selfed ($S_2 = S_3$) gives 50 per cent because one-quarter are between S_2-bearing gametes and one-quarter between S_3-bearing gametes; $S_{2.2}$ selfed or $S_{2.2} \times S_{2.2}$ give 100 per cent non-fusion because of selfing or crossing homozygotes. The S locus appears to have its action both before and after meiosis. Progenies arising from crosses between certain self-compatible clones, *e.g.* 'ICS 1' × 'ICS 45' give all self-incompatible progeny. To account for this it appears that in addition to the S locus two other complementary loci A and B are involved, the role of which is to produce a non-specific precursor to which the S alleles impart their specificities to prevent fusion between gametes carrying the same S allele in certain circumstances. Genotypes homozygous for inactive alleles at one or more of the A, B and S loci will be self-compatible.

Cope (1962b) has shown that self-compatible and self-incompatible genotypes cannot exist in equilibrium in an isolated population, and that, on theoretical grounds, the self-compatible trees will ultimately displace the self-incompatible genotypes, a process which is hastened by greater fruitfulness of the self-compatible trees. Nevertheless, in a wild population there appears to be some strong selective discrimination against self-compatible types. Thus near the centre of origin of the species on the eastern equatorial slopes of the Andes all clones so far collected have proved to be uniformly self-incompatible. The further removed from the centre of origin the greater is the proportion of self-compatible trees, a feature which would help the spread into new habitats. West African Amelonado, which is believed to have originated near the mouth of the Amazon, is uniformly self-compatible.

GERMINATION

Seeds will germinate immediately on reaching maturity and are viable for only a short time, dying quickly when dehydrated or fermented or subjected to extremes of temperature; they are killed in 8 minutes at 4°C and often during air transport. Germination may take place in the pod. Removal of the testa speeds up germination by a few days, but such seeds lose viability rapidly if allowed to dry out. The moisture content of the cotyledons should be kept at about 50 per cent. Under suitable conditions with free access of air and protection against water loss seeds may be stored for 10–13 weeks without losing viability. Seeds may be transported or stored in charcoal powder of 30 per cent moisture content in perforated containers; polythene bags have proved very satisfactory.

Seeds may be rubbed with sand, wood ash or coconut fibre to remove the mucilage before planting, but this is not essential. They are usually planted 1–2 in. deep with the hilum scar downwards or horizontally and germinate in 2–3 weeks. Germination is epigeal. The cotyledons and hypocotyl develop chlorophyll and the first true leaves appear 15–20 days after germination.

CHEMICAL COMPOSITION

	Forastero Cocoa Beans Fresh weight per cent			Cocoa Products Oven dried per cent			
	Cotyledons	Pulp	Testa	Fresh Kernel	Cured and Dried nibs	Cocoa powder	Bar chocolate
Water	35·0	84·5	9·4				
Starch	4·5		46·0	7·7	7·4	22·2	4·1
Sugars	6·0	13·4		1·8	0·7	4·3	54·4*
Fat	31·3		3·8	54·0	57·3	26·5	29·1*
Protein	8·4	0·6	18·0	14·8	6·7	22·2	1·5
Fibre	3·2		13·8				
Theobromine	2·4			2·3	1·7	1·3	1·1
Caffeine	0·8						
Polyphenols	5·2		0·8				
Acids	0·6	0·7					
Inorg. Salts	2·6	0·8	8·2				
Other substances				19·4	26·2	23·5	9·8

From Hardy (1960).

* In part added.

The polyphenols consist of catechins, complex tannins, leuco-cyanidins and cyanidin glycosides. Forsyth and Quesnel (1963) state that 'the chocolate aroma precursors are formed immediately after the death of the seed (during fermentation) when the proteins and polyphenol compounds come together, react, and are subjected to the action of hydrolytic enzymes. Later oxidative condensations render the astringent catechins and other polyphenols insoluble. Loss of the bitter purines by exudation also changes the taste characteristics of the final product'.

PROPAGATION

SEED: Propagation by seed is the cheapest method. Seed may be planted at stake, which is the usual custom in West Africa, where 3 seeds per hole are planted and later thinned to one plant. Seedlings may also be grown in nursery beds with natural or artificial shade, which should allow approximately 50 per cent sunlight. Lateral shade and wind protection should also be provided. Seed is usually planted 12 in. apart in the beds, but much closer spacing is used in Ghana. Seedlings may also be raised in baskets made of fibre, cane or bamboo, and have the advantage that there is little root disturbance on transplanting. In Trinidad baskets are made of stems of *Ischnosiphon arouma* (Aubl.) Koern. (Marantaceae). Baskets should be large enough to allow sufficient root room for a 4–6 months' old seedling, the usual time for planting out, and a useful size is 9 in. deep, 7–9 in. wide at the top and 6–7 in. at the base. Polythene bags, 12 × 7 in., with drainage holes in the sides and base have proved very cheap and efficacious, but must be removed before planting. A good potting mixture is 7 parts loam with a pH not higher than 6·5 (a higher pH results in iron chlorosis), 3 parts dried cattle manure, 2 parts sharp sand and 1 oz double superphosphate per basket. As in the nursery, seedlings in baskets or pots must be raised under shade, which is later reduced before transplanting (also see GERMINATION above).

CUTTINGS: Environmental conditions for the successful rooting of cuttings depend upon the following factors: (1) Reduction of the leaf area to cut down transpiration, to prevent mutual over-shading and to economize in space in the bins, but sufficient leaf for the production of enough carbohydrates by photosynthesis to supply the developing roots and continued life of the cutting. Thus with cuttings with 6–8 leaves, 2–3 of the lower leaves are removed and the remainder trimmed by cross-cuts to ½–⅓ of the original length. (2) Controlled light and temperature so that the rate of photosynthesis exceeds the rate of respiration. This is given with about 10–15 per cent of incident sunlight obtained by overhead shading and with cloth covers over the glass or polythene in the bins, and a temperature not higher than 87°F, obtained by spraying the cuttings and cloth covers with water. In open bins or beds continuous mist spraying is necessary. Too low a light intensity causes starvation and yellowing of the leaves; too high a light intensity causes destruction of the chlorophyll. (3) 100 per cent humidity of the atmosphere to reduce transpiration and to ensure maximum turgor of the leaf cells; this is obtained by frequent or continuous watering. (4) An optimum air/moisture relationship at the base of the cutting with adequate aeration and free drainage and yet sufficient moisture to maintain cell turgidity. A saturated soil atmosphere, particularly when oxygen is lacking, results in rotting, or the development of rods of callus from the lenticels. Inadequate watering and too high an oxygen concentration leads to callus formation at the base and delay in rooting. The most suitable rooting media are composted sawdust, coconut fibre dust or sand of uniform particle size of 1–2 mm. (5) Absence or control of pathogens by sterilization of rooting medium and application of fungicides. (6) Stimulation of root development by growth hormones; the ends of cuttings being dipped in β-indole-butyric acid and α-naphthalene-acetic acid in equal proportions of 8 mg per ml in 50 per cent alcohol.

NURSERY FOR CUTTINGS: Cuttings are usually obtained from young vigorous healthy trees in gardens specially maintained for the purpose; the trees are planted 5–6 ft apart; they should be free from mineral deficiencies, and should be grown on well-drained, loamy soil of pH 5–6·5, rich in organic matter. Shade trees, *e.g. Gliricidia sepium* or bananas at 10 × 6 ft or *Erythrina poeppigiana*, are planted to give approximately 50 per cent sunlight. No cuttings are taken in 1st year, but 20–30 cuttings per tree in 2nd and 3rd years and 40–50 cuttings per tree in 4th and 5th years can be taken, after which it is usual to replant in 6th–8th year. In taking cuttings 2 buds are left at base of branches to produce new shoots and it is essential to maintain the plants in an actively growing condition. Trees should be given 1–1½ lb of complete fertilizer per tree per annum and foliar sprays of of 1 per cent urea. They should be irrigated in the dry season.

PREPARATION OF CUTTINGS: Cuttings are taken from recently matured flushes of fan branches when the leaves are fully green and wood semi-hard with upper surface of stem brown and lower surface still green. Cuttings are taken at right angles, usually just above a node, but this is not essential, and they should be 5–12 in. long with 3–9 leaves. They should be made early in the morning and placed in water or wrapped in damp cloth or paper until set. The bottom leaf or leaves are removed by a clean cut close to stem and remaining leaves are trimmed (see above), the base dipped in hormone and inserted 2–4 in. deep in the rooting medium with a backward slant in staggered rows with about 30 cuttings per sq. yd. Cuttings may also be rooted directly in baskets with a core of sand, sawdust and other rooting medium, thus obviating the need for transplanting and reducing cost. Single-leaf cuttings may be used where material is limited and these are obtained by cutting up stem cuttings ½ in. above a node, usually while still green; the hormone dip is used at half strength. The ease of rooting stem and single-leaf cuttings varies with the clone. The average take varies from 50–90 per cent.

PROPAGATORS: Various types are available:

CLOSED-BIN PROPAGATORS (for designs see Hardy, 1960): These consist of a bin or battery of bins of brick, stone, concrete or wood with close fitting lids of glass or polythene, covered with calico to reduce light and which is kept moist. A convenient size of bin is 4–5 ft × 3 ft and 3 ft deep. Holes in the base and a layer of stones facilitate drainage. The stones are covered with pebbles and a 9 in. layer of rooting material is placed on top. Watering is by automatic sprays within the bins or by hand. Overhead shade at 6–7 ft of saran netting, wood slats or split bamboo reduces incident light to 25–30 per cent and this is further reduced by the cloth on the lids.

OPEN-SPRAY BEDS with continuous mist spray during the day and overhead shade as above. This method is cheaper in labour, but it uses more water and is less efficient.

HUMIDIFIED GREENHOUSES with tiers of movable shelves 2 ft apart. A continuous fine spray is produced during the day by a centrifugal humidifier. The greenhouse is shaded to give 25 per cent incident light. A greenhouse 20 × 12 × 8 ft will hold 2,500 plants in 6 in. baskets.

UNDER POLYTHENE SHEETS: Cuttings, usually 2-leafed, are planted in cored baskets (see above) and are covered with polythene sheets weighted at the edges. Overhead shade is also provided. The method has been found to be very efficient in Ghana and it is much cheaper than the previous methods.

IN POLYTHENE BAGS: Cuttings are wrapped round with wet sawdust held in coconut fibre, placed in polythene bags 20 × 11 in. A little water is added and the neck is tied with string. The bags are hung up in a shady place with 7 per cent sunlight. They are ready for planting in the field in 22 days. The method is cheap and economical of labour and transport; it is suitable for the production of small numbers of plants.

HARDENING-OFF AND STORAGE: Rooted cuttings in bins or other propagators are hardened off after 28 days by gradually increasing light and reducing humidity. Except when cuttings have been planted direct into cored baskets (see above), rooted cuttings are potted up in fibre baskets or pots of bamboo, asphalt paper or polythene bags. A good potting mixture is 2 parts of slightly acid soil and 1 part of sawdust compost to which 4 oz sulphate of ammonia, 1 oz superphosphate and 2 oz muriate of potash per bushel of soil has been added 7–10 days prior to use. Hardening-off can be in the propagators or in bins with an expanded metal shelf over water, or in a humidified greenhouse, and takes approximately 10 days. Plants are then moved to the storage area, which may consist of a house with a concrete floor, glass and aluminium roof, and with open sides protected by growing plants. Watering needs careful attention. Lime in the water or an alkaline potting mixture will induce iron chlorosis. Sulphate of ammonia, 2 g per basket, or a foliar spray of 1 per cent urea may be applied every 3–4 weeks. Pests and diseases must be controlled, particularly *Phytophthora* with Bordeaux mixture, 2–2–50. Cuttings should have at least one hardened flush before transplanting into the field, and the usual time taken from cutting to planting is about 6 months. In commercial production the average losses are 20–30 per cent during rooting, 3–10 per cent during hardening and 10–30 per cent in field.

OTHER METHODS OF PROPAGATION: Cocoa can be propagated by budding, the patch-bud method usually being employed. It is highly economical of planting material and budwood can be kept up to 7 days if properly stored, thus permitting transport by air. It is useful for clones which are difficult to propagate by cuttings. Budwood is prepared by cutting petioles and is taken after petiole stumps have fallen. Seedling stocks are usually used, 6–12 months old and 1–3 cm in diameter. It is advisable to bud below the cotyledons scar to prevent chupon growth from the stock.

Saddle- and wedge-grafting of leaf-bearing shoots are possible, as is marcotting, but these methods have little commercial application.

HUSBANDRY

PLANTING: As has been shown above under ECOLOGY, cocoa is an exacting crop in regard to its environment, particularly the soil conditions, so that the amount of land suitable for cocoa is limited. In West Africa the peasant cultivators achieved success by growing cocoa widely and, where it grew well, planting more of it.

Forest areas may be selectively thinned, as is done in West Africa, leaving 2–3 tall trees and 15–20 smaller trees per acre. Nurse shade is established and 3 seeds are planted at stake, approximately 5 ft apart; later thinned to one plant per stand. As the trees grow the stand will be thinned. In some areas such as Trinidad the forest is completely felled, followed by lining, holing and draining. Permanent or temporary shade and ground cover are established before planting the cocoa, which may be seedlings or cuttings. Soil should not fall away from the roots of the transplants as cocoa will not stand planting with bare roots. Cocoa is usually planted at 12 × 12 ft. The optimum spacing will depend upon the environmental conditions and cv. grown. Closer spacing usually gives greater yields in the early years, although yields tend to even out later; it also provides a quicker closed canopy. Close spacing in the early years, followed by selective thinning, will probably give maximum yields over a long period. A spacing of 8 × 8 ft gave higher yields than 12 × 12 ft in experiments in Trinidad in early years. In Ceylon, New Guinea and Samoa spacing is usually 15 × 15 ft. Except when planting at stake, holing is usually advocated and with the addition of organic manure. A Trinidad experiment has shown no advantage of large over small holes. It is important that the soil should not sink on planting or water may collect.

Cocoa is occasionally interplanted with other crops such as bananas, *Hevea* rubber, oil palm or coconuts.

SHADE AND WINDBREAKS: For advantages provided by shade and good characteristics of shade tree spp. see coffee (pp. 471–472).

It is usually considered essential that cocoa should be given adequate shade from planting until it becomes self-shading or permanent overhead shade has become established, and that ground shade should be planted to protect the soil and provide temporary lateral shade. Later, permanent overhead shade is considered necessary, except where the cocoa is growing under very favourable conditions. Shade reduces photosynthesis, transpiration, metabolism and growth and therefore the demand on soil nutrients and so enables a crop to be obtained on soils of lower fertility. On fertile soils with liberal fertilizers, particularly nitrogen, shade may be gradually removed altogether as has been shown in Trinidad, and later in Ghana, provided it is possible to maintain a closed canopy of cocoa (see ECOLOGY above and MANURING below).

Bananas planted at 10 × 10 ft or 12 × 12 ft before planting cocoa are most frequently used as temporary shade, but other plants also used include *Crotalaria* spp., particularly *C. anagyroides* Kunth., *Tephrosia* spp., such as *T. candida* DC., *Leucaena glauca* (L.) Benth. (also used as permanent shade), *Carica papaya* L. (papaya), *Manihot glaziovii* Muell.-Arg. (tree cassava) and *Cajanus cajan* (L.) Millsp. (pigeon pea). Some of the above also provide temporary lateral shade, as do *Xanthosoma* spp. (tannias), *Colocasia* spp. (dasheen and eddoes)—both known as cocoyams in West Africa, and *Manihot esculenta* Crantz (cassava). They also provide good ground shade.

Permanent shade may be provided by selective thinning of the original forest, intercropping with other economic trees or specially planted shade trees, which may be planted before or at the same time as the cocoa. In areas where swollen shoot disease is present, alternate hosts of the virus such as spp. of Sterculiaceae and Bombacaceae should be avoided. Trinidad has relied upon *Erythrina poeppigiana* (Walp.) O. F. Cook, mountain immortelle, on the hillsides and *E. glauca* Willd., swamp immortelle, in the flatter wetter areas. Both have spiny trunks. They are usually planted at 24 × 24 ft and later thinned to 48 × 48 ft. The yield of cocoa under immortelles has been consistently higher than under many other shade trees which have been tried. Immortelles have been shown to have over 4 per cent nitrogen in the root nodules, 2–3 per cent in the leaves and 3–6 per cent in the flowers, flower fall alone contributing 20 lb of nitrogen per acre per annum. Unfortunately *E. poeppigiana* is now attacked by a witches' broom disease, probably caused by the fungus, *Botryodiplodia theobromae* Pat., and *E. glauca* by a bark-destroying fungus, *Calostilbe striispora* (Ell. & Eberh.) Seaver. The falling of dead or diseased trees causes considerable damage to the cocoa. *Gliricidia sepium* (Jacq.) Walp. (madre de cacao) is an alternative; the branches may be cut back before the dry season which results in new flushes and prevents the flowering leafless state.

Elsewhere the following spp. are used as permanent shade: *Erythrina subumbrans* (Haask.) Merr., dadap, in western Samoa and Ceylon, of which thornless forms occur, and which can be planted as large cuttings; *Albizia* spp., *Peltophorum* spp., *Terminalia superba* Engl. & Diels (in Congo), *Inga* spp., *Leucaena glauca* (L.) Benth. and *Musanga cecropioides* R. Br., which is very quick growing.

Cold and drying winds have an adverse effect on cocoa and it is usual to provide windbreaks. These can be provided by leaving strips of forest 50–100 ft wide between fields or by the planting of artificial windbreaks for which the following evergreen spp. may be used: *Dracaena fragrans* Gawl., *Mangifera indica* L. (mango), *Eugenia caryophyllus* (Sprengel) Bullock & Harrison (clove), *E. malaccensis* L. (pomerac), *Myristica fragrans* Houtt. (nutmeg), *Calophyllum antillanum* Britt. (galba), *Manilkara achras* (Mill.) Fosberg (sapodilla) or *Anacardium occidentale* L. (cashew).

CARE AND MAINTENANCE. Hand weeding round the seedlings ensures that the plants can be seen when cutlassing. Ground shade must be controlled and may be removed in the 3rd year. All gaps in the stand of cocoa and permanent shade should be supplied as soon as possible; replants after 5 years are difficult to establish because of shading. It has been shown that there is a highly significant correlation between the diameter of the trees at 3½ years old and subsequent yields. Successful establishment and vigorous early growth is thus of great importance. In the early years overhead shade should be maintained at 50 per cent of full sunlight and should be kept growing more rapidly than the cocoa; temporary overhead shade such as bananas is gradually removed in the 4th year. For further treatment of shade see above.

Weeds have a deleterious effect on the growing cocoa and may be partially controlled by the degree of shade. They may be controlled by cutlassing, but the use of herbicides is superseding this in some areas. When the cocoa is established cultivation is not usually practised; in fact in Trinidad any form of soil cultivation reduced yields. Mulching is sometimes advocated, but in Trinidad a sawdust mulch depressed yields and a bush mulch increased yields, but not sufficiently to be economic.

PRUNING: The main objects of pruning are to allow the development of a framework of branches which will give a tree in the shape of an inverted cone, to remove unwanted growth, and to obtain a closed canopy. Drastic pruning reduces early yields and should be kept to a minimum. In a seedling tree it is usual to leave 3 or 4 branches at the jorquette. Unwanted chupons are removed and growth is controlled at the first or second jorquette. In West Africa upper chupons are usually allowed to grow, thus giving tall trees, but the lowest jorquette branches are usually removed to facilitate movement on the farm. Fan cuttings may be allowed to grow to form 3–4 branches at the base or a chupon may be allowed to come up from ground level and the first fan branches are then removed. Subsequent pruning in seedling and vegetatively propagated trees consists of removing diseased or dead wood, including witches' brooms, cutting out mistletoes (Loranthaceae), removal of basal and unwanted chupons at an early stage, and providing any further shaping that may be necessary. Old and senile trees may be rehabilitated by allowing a chupon to come up from the base, and by putting earth on its base it will develop its own roots.

MANURING: Cocoa grown under shade is seldom manured and manurial trials under these conditions have usually been inconclusive. It is doubtful whether the application of fertilizers would be economic when mature cocoa is grown under adequate shade, although increase in yields of 20–30 per cent has been obtained in Ghana from 40 lb P_2O_5 per acre per annum; other minerals giving no response. In the establishment of cocoa in Trinidad it is recommended that ½ lb per tree of NPK 1 : 1 : 1 mixture should be applied in the 1st year, gradually increasing to 2 lb per tree per annum in the 4th year.

When grown under favourable conditions with no shade spectacular responses to nitrogen have been obtained. Murray in Trinidad has shown that 450 lb per acre of ammonium sulphate has little or no effect under shade, but in one experiment gave 519 lb increase in dry beans per acre in the absence of shade; similar but smaller effects were shown for P and K. Cunningham in Ghana obtained yields of Amelonado planted at 8 × 8 ft of 3091 lb of dry beans per acre with fertilizers and no shade, compared with 1211 lb with shade and the same dressings of fertilizers. He recommends (Cunningham, 1963) annual dressings of 2 cwt urea, 1 cwt triple superphosphate and 4 cwt potassium sulphate per acre and states that this can maintain yields around 2,000 lb dry cocoa per acre in unshaded, vigorous, high-yielding cocoa. The extra expenditure and work associated with clear-felling and growing unshaded cocoa with larger amounts of fertilizer would probably only be justified when yields of 3,000 lb per acre and over are obtained.

HARVESTING: Pods are produced throughout the year, but the main harvest usually begins at the end of the wet season and continues for a period of about 3 months; in West Africa during October–January; in Trinidad during November–February; followed by a minor harvest early in the rains. Ripe pods assume a distinctive colour and the seeds rattle inside; green-podded Amelonado turn yellow and red pods usually turn an orange shade. The pods remain in a suitable condition for harvesting for 2–3 weeks; beans from unripe pods give poor fermentation; over-ripe beans may germinate in the pod. Pods should be cut off with a sharp knife, care being taken not to damage the cushion. The pods may be kept for up to a week before breaking and extracting the beans for fermentation. Pods are usually opened by cutting the husk with a cutlass, but they can also be cracked with a wooden mallet or by striking two pods together. The number of pods required to produce one pound of dry cocoa varies from 7 to 14, depending on the pod size, the thickness of the wall, etc.

FERMENTATION: During this process the mucilage round the seeds is removed, the purple pigment diffuses through the cotyledons, the precursor of the chocolate flavour is produced, and astringency disappears. The time taken to ferment Criollo is less than for Forastero. In West Africa cocoa is fermented in heaps or in baskets, usually covered with banana leaves. The beans are left for 4–7 days depending on the season. They may be left undisturbed or may be turned once or more times. In most other countries fermentation is done in wooden sweat boxes which should not be more than 3 ft deep in order to permit aeration. The other dimensions vary and a good average size is $6 \times 5 \times 3$ ft; they are usually built in batteries. The base should be slatted to permit aeration and free drainage of the sweatings. Fermentation takes 6–7 days. During this process the beans are transferred to a second box after 2–3 days, then to a third box after a further 2–3 days and remain there for a further 2 days. At the C.R.I. in Ghana a method has been devised of fermenting in trays 3×4 ft and 4 in. deep with slatted bottoms and these are stacked to a depth of 10 trays and covered with sacking. With this method Amelonado fermented in 3 days without any mixing and the same trays can be used for drying. Methods have also been devised for fermenting small batches of cocoa for experimental purposes.

During the first 36 hours of fermentation the temperature rises to about 96°F; there is very limited aeration and under these conditions yeasts develop and convert the pulp sugar into alcohol and CO_2. Temperatures then increase to about 120°F. As the pulp cells collapse, air enters the mass and there is a rapid oxidation of the alcohol to acetic acid by acetobacter bacteria. The beans are killed mainly through the penetration of alcohol and acetic acid into the cotyledon tissues. Diffusion from the polyphenol storage cells then occurs followed by enzyme attack on the anthocyanins. Proteins are hydrolysed to amino-acids. The colour of the tissues becomes progressively paler and then pale brown. The brown colour deepens; the cotyledons shrink from the testa and separate. There is a gradual development of aroma and flavour and loss in astringency.

DRYING AND POLISHING: After fermentation the beans are spread on mats, trays, or drying floors and dried in the sun. They should be covered over by mats or by sliding roofs during rain and often for the hottest part of the day. The beans are stirred to ensure uniform drying and in sunny weather this is completed in about 7 days. During the process of drying, enzymic action continues and the moisture content is reduced from 56 to 6 per cent. In some countries artificial driers are used. During the whole process of fermentation and drying the loss in weight is 55–64 per cent.

The beans may be polished mechanically or by feet; the latter is known as dancing the cocoa in Trinidad. The beans are wetted and trampled with bare feet, care being taken not to crush the beans but rather to rub one against the other.

GRADING: Shells, broken beans and extraneous matter may be removed by hand or by machines. The number of dried cured beans per pound is approximately 350–450.

The quality of the cured beans is judged by the following characters: (1) The beans should be plump and of even size and usually of not less than 1 g fermented dry weight, when the amount of shell is about 10 per cent. The proportion of shell increases with small beans and may rise to 12–16 per cent. (2) Shells should be intact, free from mould, of a uniform brown colour and should not be shrivelled. (3) Cotyledons should be separated, friable, with a crisp break, of open texture, chocolate brown in colour and on roasting should develop the characteristic chocolate flavour. (4) They should have a fat content of not less than 55 per cent.

The following characteristics are undesirable: (1) Internal mouldiness or diseased beans. (2) Violet or slaty cotyledons denoting under-fermented beans. (3) Off-flavours denoting improper curing, faulty drying, or picking up of taints during storage and shipping. (4) Broken beans. (5) Flat immature small beans. (6) Germinated beans. (7) Beans attacked by insects such as the tobacco weevil, *Lasioderma serricorne* (F.), the beetle *Araecerus fasciculatus* (Deg.) or the moth *Ephestia cautella* (Wlk.).

Cocoa beans of commerce may be classified into: (1) Fine cocoa such as the Criollo of which negligible quantities are now produced. (2) Flavour cocoas as produced in Central America and the West Indies. The flavour of Trinidad cocoa is probably due to a mixture of a large number of genotypes of Trinitario origin and is somewhat astringent. (3) Ordinary Forastero or Amelonado as produced in West Africa and Brazil, which usually has a bland flavour. Cocoa beans are normally shipped in jute bags.

YIELDS: These vary enormously and depend on local environmental conditions, spacing, age of tree, pests and diseases, and the genotype. In Trinidad average yields of old unselected seedling plantations are about 200 lb dry cocoa per acre and that of selected cuttings 600–1,000 lb. Hybrid seedlings of Trinitario–Amazon parentage may yield over 2,000 lb per acre. In West Africa the average yield of peasant Amelonado is said to be about 200 lb dry cocoa per acre and 600 lb is considered good. Crosses between Upper Amazon, Amelonado and local hybrids have yielded over 2,000 lb per acre. Fertilized unshaded cocoa with the control of weeds, pests and diseases has yielded over 3,000 lb per acre.

MAJOR DISEASES

Black pod, *Phytophthora palmivora* (Butl.) Butl., a facultative parasite and the most widely distributed disease of cocoa. Infection usually at either end of pod causing chocolate-brown necrotic spots which spread rapidly; later turning black with a very sharp line of demarcation between diseased and healthy host tissue; beans partially or wholly destroyed by brown-coloured rot; also affects cherelles and young leaves; it can cause flower-cushion and stem cankers; it also attacks seedlings. Fungus sporulates on surface of pod and infection is mainly by contact, raindrops or wind. Temperatures below 70°F and high humidity are conducive to its spread. Regular and frequent harvesting and removal of infected pods reduce loss. Controlled by copper sprays at intervals of not more than a month when wet, cold conditions prevail.

Witches' broom, *Marasmius perniciosus* Stahel,* affects meristematic tissue in active stage of development on vegetative shoots causing proliferation of branches and hypertrophied shoots with broom effect; infected flower cushions produce vegetative brooms; destroys cherelles and young pods; mature pods become hard and woody and internal tissues destroyed by dry brown rot. The sporophores, small pink mushrooms, are produced during the rainy season on tissues killed by fungus. Confined to the Caribbean and South America; originated in Amazon valley; first reported in Surinam in 1895, in Trinidad in 1928 and in Grenada in 1948. Best controlled by planting resistant clones and by removal of brooms which should be burnt.

Ceratostomella wilt, *Ceratocystis fimbriata* Ell. & Halst., confined to New World and recently spreading in Trinidad. Fungus causes death of branches or of entire tree; dead leaves remain attached to branches for long time and affected wood is discoloured. Usually associated with small beetles, *Xyleborus* spp., which tunnel into wood and also spread the disease.

Monilia disease, *Monilia roreri* Cif. & Par., causes considerable losses in Ecuador and Colombia and has spread to other South American countries. Attacks young pods, producing internal watery rot.

Virus diseases: Swollen shoot was first observed in Ghana in 1936 and Posnette in 1938 showed that it was caused by a virus. Swellings occur on branches and twigs, with greater development of phloem and xylem, followed by die-back. In Ghana swollen shoot killed over 5 million trees per year in period 1939–1945. It also occurs in Nigeria and the Ivory Coast. It has been shown to be a complex of viruses of varying virulence, New Juaben strain being one of the most virulent. All these viruses produce varying leaf pattern symptoms with red bands along veins and chlorotic mosaic effects, causing early senescence and leaf shedding; some strains do not produce swollen shoots; light and dark green mottling may occur on unripe fruit. Transmitted by mealy bugs, of which *Planococcoides* (*Pseudococcus*) *njalensis* (Laing) is the commonest vector, and these are distributed by attendant ants, particularly *Crematogaster striatula* Emery. Alternate hosts include *Cola* spp., *Adansonia digitata* L. (baobab) and *Ceiba pentandra* (L.) Gaertn. (kapok). Controlled by cutting out infected and contact tree; the trunk being severed below ground level to prevent regeneration. Up to 1957, 70 million cocoa trees had been cut out in Ghana. No cvs are immune, but some exhibit tolerance and degree of resistance to infection. Complete eradication is unlikely. Mild virus diseases are recorded in Trinidad and Ceylon.

Cherelle wilt: Although this condition may be caused by fungi (black pod) and insects, unless these are epidemic they are only of secondary importance.

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* = *Crinipellis perniciosa* (Stahel) Singer.

It is a natural physiological process and is a fruit thinning mechanism, whereby a limited number of pods are brought to maturity depending on the food reserves of the tree. Approximately 20–90 per cent, usually about 80 per cent, of the number of fruits set become dry and shrivel with cherelle wilt and finally turn black; as no abscission layer is formed they usually stay on the tree for some time. Maximum wilt occurs at 50 days when the cherelles are about 6 cm long; during this period most of the nutrients are transported in the xylem of the peduncle and in wilted pods these vessels are blocked by mucilage occlusions, followed by oxidative breakdown within the pericarp. As this period coincides with the division of the zygote nucleus, control must be by the maternal tissues. Wilt may also occur during the next 30 days. During the third stage of a further 50–70 days wilting does not occur and the fruits mature and ripen; food transport in the phloem becomes effective, new vascular bundles are formed in the inner pericarp, together with enlargement of the cells of the vessels, and is initiated by seed auxins.

MINERAL DEFICIENCIES

Nitrogen: Lvs pale or yellowish in colour, reduced in size; older lvs showing tip scorch; younger lvs small with entire lamina, including veins, yellow or almost white; internodes compressed.

Phosphorus: Mature lvs paler towards tip and margin, followed by tip and margin scorch; young lvs reduced in size often with interveinal pallor; stipules frequently persisting after leaf abscission.

Potash: On older lvs pale yellow areas in interveinal areas near lf. margin, quickly becoming necrotic.

Magnesium: On acid soils. Old lvs pale green with necrotic areas between veins near lf. margin, quickly fusing into continual marginal necrosis.

Iron: Induced by pH of 7 or over and free $CaCO_3$. Young lvs show darker green veins against paler green background or green-tinted veins against whitish background; develop tip scorch.

Zinc: Induced by high pH. Young lvs showing prominent, distorted veinlets; lvs often narrow, sometimes sickle-shaped with wavy margin.

MINERAL TOXICITY

Aluminium: On very acid soils. Pale interveinal region near tip of older lvs followed by necrosis and tip scorch.

Manganese: On very acid soils. Youngest lvs with irregular pale areas on darker background; no marginal scorch.

Chlorine: Often near sea. Pale yellow areas along margin, quickly fusing to form continuous scorch.

MAJOR INSECT PESTS*

Capsids are the most important insect pest in Ghana, of which *Distantiella theobroma* (Dist.) and *Sahlbergella singularis* Hagl. cause the most damage. In feeding they produce lesions which become infected with the fungus

* See Entwistle, P. F. (1972). *Pests of Cocoa*. London: Longman.

Calonectria rigidiuscula (Berk. & Br.) Sacc. The effect is most severe on young, tender, green shoots. On mature cocoa damage may be (a) 'blast' in which the fans die, (b) 'stag-headed cocoa' in which a persistent and weak flushing occurs, followed by death of the crown, (c) 'capsid pockets' in which canopies of up to 100 trees are destroyed and chupons grow up which are again attacked. Alternate hosts include *Ceiba pentandra* (L.) Gaertn. and *Cola* spp. Losses from capsids may be 20 per cent or more. Damage is more prevalent when the canopy is incomplete. Controlled by chlorinated hydrocarbons, notably gamma BHC.

Thrips, *Selenothrips rubrocinctus* (Giard), cause damage in the West Indies.

Cocoa beetles, *Steirastoma* spp., may do serious damage to the trunks and branches in some regions.

IMPROVEMENT

AIMS

1. Yield improvement: In many parts of the world cocoa plantings are old and yields are poor on this account, and also because unimproved, unselected seedling material may have been used. Average yields in Trinidad are about 200 lb dry cured beans per acre and consequently cannot pay for better cultural treatment. To do this yields of 800 lb are required. Although some new hybrids have given yields of up to 3,000 lb per acre in experiments, capital is not generally available for replanting or to carry over the required time for new plantings to come into bearing.

2. Resistance to diseases and pests: Particularly to black pod in all regions, to witches' broom, *Monilia* disease and *Ceratocystis fimbriata* in the New World, and to viruses in West Africa.

3. Retention of traditional flavour: Each cocoa-growing area has a characteristic flavour associated with its product which is demanded by the manufacturers for blending purposes. Amelonado has a characteristic flavour, particularly suited for milk chocolate; the 'flavour' cocoas are in demand for higher grade chocolates, *e.g.* Trinidad cocoa.

4. Adaptation to local environment: Some clones will only yield well on good soil and cvs for marginal soils may be required. It may be necessary to breed cvs which will give the optimum yield under shade and those that will give the highest yield without shade and with manuring and improved management.

5. Early and sustained bearing: A tree which is vigorous and precocious and which will maintain high yields for many years under satisfactory conditions is an obvious advantage.

6. Tree shape: Low growing trees for convenience of harvesting and pest control are desirable in West Africa where little pruning is done.

7. Pod size: A tree with large pods with a large proportion of beans would be better than one which produces the same weight of cocoa from a larger number of small pods, and this would reduce harvesting and breaking costs.

8. Bean characteristics: Plump beans of even size, with a low proportion of shell (testa), and which will produce the traditional flavour after curing and roasting are desirable qualities.

METHODS AND RESULTS

SELECTION AND VEGETATIVE PROPAGATION: In the period 1930–1934 Pound made a survey of cocoa in Trinidad and Tobago and selected 100 mother trees, Imperial College selections (ICS), using as his criteria of selection: (a) yield of not less than 1 ton of dry fermented beans per acre per annum over a period of years, based on the yield of the tree and the area it occupied. (b) Wet bean weight of not less than 3·5 g (= about 1·4 g per dry bean). Only the first 90 selections fulfilled both criteria and ICS 90–100 had smaller beans, but were very high-yielding. These selections were made in Trinitario cocoa which is very heterogeneous and the selections included both Criollo types and ranging all the way to Forastero-like types. Due to the selection for large beans many of the selections would have some Criollo ancestry. They included self-compatible and self-incompatible clones.

At the same time Pyke developed in Trinidad the technique of rooting semi-hard wood cuttings (see PROPAGATION above). After the mother trees had been propagated in nurseries, clonal cuttings were taken and planted in a trial in River Estate in 1937. The clones showed large differences in growth, tree size and yielding ability. The best clones such as ICS 1, 39 and 40 were associated with little or no weed growth, while the poor clones did not suppress weeds.

Of the 100 selections, only 15 of them gave good results under River Estate conditions of good drainage and reasonable soils. These clones gave good yields of about 1,000 lb of dry cocoa per acre in the 6th–8th years, reaching a maximum of about 1,400 lb in the 12th year. On the heavy clay soils, more typical of cocoa areas in Trinidad, only 5 of the 15 clones continue to perform well, and of these 4 are near-Criollo types which are very susceptible to witches' broom disease on the vegetative parts, although the pods are only very lightly attacked. Thus of the ICS 100 series there is only one general-purpose clone for use in Trinidad, namely 'ICS 95'; it is self-compatible. These clones either alone or in mixture of a few clones produce the bland chocolate flavour which lacks the astringency of genuine Trinidad cocoa.

In 1937 Pound collected planting material in the Amazon region of Ecuador and Peru and obtained clones which were resistant to witches' broom disease; of these two from the Scavina Estate, SCA 6 and 12, are immune, high-yielding, self-incompatible, but with poor bean size. A clone from the Iquitos area, 'IMC 67', is vigorous and early-yielding, suited to a wide range of conditions, has some resistance to witches' broom, and is self-incompatible. Pound visited this region again in 1942 and made more selections. The Anglo-Colombian Cacao Collecting Expedition of 1952–1953 collected a wide range of material including Forastero types from the tributaries of the Amazon, Criollo crosses from Magdelena and Cauca, and selections from plantations. Clones have also been introduced from Central America, Grenada and from elsewhere.

Since 1945 the Trinidad and Tobago Cocoa Board have distributed over 10 million rooted clonal cuttings, and they usually distribute a mixture in which not more than ¼ is of a single clone and at least ⅓ is self-compatible. These cuttings are expensive to produce and transport; hybrid seed is much cheaper (see below). Cuttings of ICS clones yield earlier and more than ICS hybrid seedlings in the first years of cropping. The most popular vegetatively propagated clones were 'ICS 95' (about 35 per cent of all plantings), 'ICS 1' and 'IMC 67'. Hybrid seedlings are now replacing rooted cuttings.

In Ghana where the Amelonado was from a very limited introduction of self-compatible types, selection has produced little variation in pod or bean characteristics and none has been very high-yielding.

HYBRIDIZATION: Hybrid vigour between parents showing good combining ability can be readily exploited in hybrid cvs. The technique of hand-pollination is given in POLLINATION above. Large numbers of single crosses have been made in Trinidad and the potentialities of the parents have been assessed. Crosses within the ICS series did not produce any high-yielding hybrids and there seems to be little relationship between the performance of a clone as cuttings and that of its progeny in crosses. In an attempt to obtain resistance to witches' broom, 'SCA 6' and 'SCA 12' which are immune to the disease, were crossed with 'ICS 1', 'ICS 6' and 'ICS 60'. The progenies were found to have a high resistance, particularly when 'SCA 6' was one of the parents. Progenies from these crosses have been outstanding in regard to yield, particularly 'ICS 6' × 'SCA 6', which is now being planted commercially. They come into bearing early in 2 years and are capable of yielding at the rate of 1,000 lb fermented dry cocoa per acre in their 4th year and over 3,000 lb per acre in their 7th year. There is an improvement in pod and bean size over the Amazon parents. Mixed samples of beans from the 6 reciprocal crosses have a flavour not entirely Trinidadian in nature, but more acceptable than that of the ICS clones.

By interplanting SCA clones, or any other self-incompatible parent, with the desired cross-compatible male parent in isolated blocks, with 1 of the latter to 4 of the former, all pods on the self-incompatible parent can be reaped for seed purposes. It is estimated that 4 acres of this planting will yield 1 million seeds annually at full bearing, a very much cheaper form of propagation than cuttings. The first distribution of hybrid seedlings began in Trinidad in 1958 and it is likely that hybrid seed will soon supersede all cutting material. If both parents are self-incompatible, but cross-compatible, *e.g.* 'SCA 6' × 'IMC 67', hybrid seed can be obtained from both parents.

In West Africa, crosses between selected upper Amazon clones with the local Amelonado are precocious and vigorous, and have given high yields;

they are of an acceptable flavour. No immunity has been discovered to the virus complex in West Africa, but some upper Amazon clones exhibit tolerance and a degree of resistance to infection.

A long term programme in Trinidad has now begun to produce inbred breeding material, with the aim of breeding single crosses between parents of good general or specific combining ability and the production of parents which are homozygous for disease resistance, etc. Much of the Trinitario cocoa is very heterozygous as a result of hybridization. It is desired to reduce variability, and at the same time maintaining the best features of the parents. In some cases inbreeding has been shown to depress yields, *e.g.* 'ICS 1', but this is not always the case, *e.g.* 'ICS 98'. Polycross seed and synthetic cvs are also being produced (Bartley, 1957).

PRODUCTION AND TRADE

As was shown under USES, exports of cocoa to Spain began shortly after the Spanish conquest of Mexico. Production was then extended to Venezuela and Trinidad. The defatting of cocoa and manufacture of chocolate in the 19th century led to an increasing demand for the crop. For many years cocoa production was confined to the Western Hemisphere. It was introduced into Ghana in 1879. In 1900 world production was approximately 100,000 tons, of which the New World produced 81 per cent and West Africa 16 per cent; the latter now produces over 60 per cent of the world's raw cocoa. World production first exceeded 1 million tons in 1960. Of the world's cocoa, Ghana produces about 30 per cent, Nigeria about 15 per cent, other African countries about 13 per cent, South and Central America 30 per cent, of which Brazil is the biggest producer with 20 per cent, West Indies 5 per cent (Dominican Republic 3·5 per cent, Trinidad 0·7 per cent), and Asia 2 per cent, where the largest producers are New Guinea and Western Samoa.

Over 75 per cent of the world's raw cocoa is consumed in seven countries, of which the United States consumes about 25 per cent, Germany 13 per cent, United Kingdom about 10 per cent and the Netherlands 9 per cent. Europe as a whole takes over 50 per cent and American countries about 40 per cent of the world crop.

Cocoa is produced by comparatively few countries, all of them tropical, but the product is processed and consumed mainly in temperate countries.

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