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COCOA GROWERS' BULLETIN – MAILING LIST

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Editorial

Historically, the greater part of world cocoa production has been grown on smallholdings of a hectare or two in size. The current trend is towards larger holdings and plantations with several thousand hectares of cocoa are now not uncommon especially in Brazil, Malaysia and other parts of South East Asia. With this trend towards larger units comes the need for cost effective systems of fermentation and drying large quantities of cocoa. In this issue we have taken the unprecedented step of publishing one major article of a technical nature on this subject. It is entitled "Cocoa drying – a review".

The senior author has had considerable recent experience as an engineer in the practical problems of drying cocoa in Brazil. We apologise to readers for the length and complexity of this article, but it seemed a very valid contribution towards improving the efficiency of these large scale holdings while being mindful of the problems of the quality of the cocoa produced. The next issue will be in our more usual format with a number of shorter articles.

We would be very grateful if all recipients of the Cocoa Growers' Bulletin who wish to continue to receive it would return the card enclosed with this issue as soon as possible to ensure that their names are not deleted from our mailing list.

R.A. Lass, Editor.

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Review of Production and Consumption

July 1981

A.B. Cook – Cadbury Schweppes Limited

Production

Gill and Duffus's latest forecast of 1980/81 production is a record 1,632,000 tonnes, just exceeding the latest estimate of the 1979/80 crop.

The increased production is once again expected to come mainly from the Ivory Coast and Brazil. However in Brazil the damage caused by the heavy rains at the end of March has caused substantial reductions from the initial forecasts for the Temporão crop.

The position in Ghana and Nigeria is much less encouraging, with both countries expected to produce less than last year, although a little more than in 1978/79. In addition to this, Ghana is having severe problems in evacuating her production to the ports.

Malaysian production is still expected to increase rapidly, although the advent of the cocoa pod borer may well reduce the rate of expansion. However, an active research programme is now in progress to produce control recommendations for this pest.

Consumption

Gill and Duffus forecast that 1981 world consumption will be 1,539,000 tonnes, the highest level since 1973. The unbroken decline in prices from the beginning of 1980 to June 1981 has meant that, in spite of cocoa butter prices continuing very steady, manufacturers now have a real reduction in material costs and consequently have been able to stimulate consumption.

Stocks

The Gill and Duffus estimate of world stocks at the end of the 1980/81 season is 708,000 tonnes, the highest level since 1965.

Prices

Month end prices for nearby Ghana shipment cocoa have been:–

1980	July	£1078/tonne
	August	£1015/tonne
	September	£1014/tonne
	October	£993/tonne
	November	£972/tonne
	December	£981/tonne
1981	January	£955/tonne
	February	£1017/tonne
	March	£1040/tonne
	April	£1064/tonne
	May	£965/tonne
	June	£911/tonne

With world stocks expected to be the highest for 16 years, prices have continued to move lower throughout the first half of 1981, although in the table above this is somewhat masked by the fact that Ghana cocoa has been at a significant premium to other grades because of the evacuation difficulties. Also the decline has been much less rapid in sterling terms than in dollar terms because of the strength of the dollar.

The market fell increasingly rapidly during May and June, reaching a five and a half year low on June 24th. Since then it has staged a significant recovery following the Cocoa Agreement talks in Geneva on June 29th and 30th.

International Cocoa Agreement

By the 31st May deadline less than 50% of consumers (versus 70% required) and only 72% producers (versus 80% required) had ratified the proposed new International Cocoa Agreement. Major absentees included, on the producers side, the Ivory Coast, and on the consumers side, the United States and West Germany, although West Germany subsequently ratified to bring the level of consumer acceptances up to 62%. Those countries which had ratified were invited to a meeting in Geneva on June 29th/30th to decide how to proceed. At that meeting all the producers present, together with a small number of consumers, principally the Eastern Bloc, Scandinavia and Switzerland, agreed to bring the new agreement into force from 1st August. The EEC was unable to commit itself at that meeting but has since given its support to the decision subject to the buffer stock funds being transferred intact from the old agreement to the new agreement.

Although the new agreement will come into force on 1st August there is some doubt about just how quickly the economic provisions, including the levy collection and buffer stock operation, can be implemented. At the present time the most likely date seems to be the 1st October.

WORLD COCOA PRODUCTION AND GRINDING DATA
Reproduced from Gill and Duffus Market Report
Dated July 1981
(Thousand Metric Tons)

Production

	1978/79	1979/80 (Estimate)	1980/81 (Forecast)
Africa	854	1021	1005
America	509	491	503
West Indies	47	35	42
Asia and Oceania	71	79	82
WORLD TOTAL	1481	1626	1632
Principal Countries			
Ghana	250	290	270
Nigeria	137	169	152
Ivory Coast	312	379	405
Cameroun	106	124	118
Equatorial Guinea	6	6	8
Brazil	314	294	334
Ecuador	90	98	75
Dominican Republic	33	27	33
Venezuela	17	17	18
Colombia	31	30	35
Mexico	37	34	27
New Guinea	28	31	30
Malaysia	26	32	35

Grindings

Western Europe	509	537	566
Eastern Europe and U.S.S.R.	202	213	212
North America	170	154	194
Central and South America	338	365	336
Australia and New Zealand	15	14	15
Asia	57	74	81
Africa	145	139	135
WORLD TOTAL	1436	1496	1539
Principal Countries			
United States	160	142	180
Germany (Federal Republic)	142	151	156
Netherlands	127	133	137
United Kingdom	61	65	75
U.S.S.R.	120	130	125
France	43	43	47

Cocoa Drying — A Review

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1. INTRODUCTION

During the early years of this century, the drying phase of the on-farm cocoa processing operation sometimes in conjunction with the fermentation phase was referred to as 'curing'. Perhaps 'curing' is the best description of this, an operation which involves both the removal of water and complex biochemical changes upon which the end product quality depends (38).

In the 1900's, large increases in cocoa production occurred and in many cases the sun drying facilities could no longer handle the whole crop satisfactorily. The problem was especially severe in regions with heavy rain during the harvest period. To overcome this, artificial methods of drying were developed to dry cocoa rapidly at elevated temperatures and the conflict between the physics of water removal and the biochemistry of flavour development was soon noted. Both processes are temperature dependent, but while drying rate can be expected to increase continuously over a wide range of temperature, the biochemistry of flavour development sets an upper temperature limit which cannot be exceeded without detrimental effects on flavour. In recent years interest has moved from the biochemistry of the cocoa beans to an engineering appraisal of the many types of drier now available.

This review attempts to provide a complete picture of cocoa drying theory and equipment and to reconcile some of the often divergent views of the biochemist and the engineer.

The theoretical aspects of drying and end-product quality are covered first and this is followed by a discussion on the advantages and disadvantages of each drier type with reference, wherever necessary, to the appropriate theoretical aspects. To enable direct comparison between the various driers, a single efficiency factor the 'overall thermal efficiency', has been defined, which is used throughout this review. It should be noted that moisture contents are defined on a wet basis throughout. Some illustrations of the various types of drier are included.

2. THE THEORY OF DRYING AS APPLIED TO COCOA

The process of drying is governed by two important controlling factors as outlined by Marshall (47) and these are:

- the transfer of heat into the bean to provide the energy necessary for the evaporation;
- the movement of the vaporised moisture from some point within the bean to the surrounding drying air.

The rate of drying is determined by whichever of these two processes is the slower (or rate determining) step. Freshly fermented cocoa has considerable free surface moisture and the drying rate during the first few hours depends entirely on the rate at which heat can be transferred to the bean surface. This in turn will be a function of both air flow and temperature. At this stage, and for constant drying air conditions, the drying rate normally remains constant and represents the maximum achieved during the whole drying process. Later, when moisture must be removed from within the bean, heat must be transferred into the bean by conduction from the bean surface to the vicinity of the evaporation. The speed with which the water vapour diffuses back to the surface of the bean will determine the overall drying rate. As this moisture is drawn more and more from the centre of the bean, so the resistance to moisture movement increases and the drying rate progressively decreases. These two distinct phases, the constant rate period and the falling rate period, represent the theoretical basis for the interpretation of the drying of high initial moisture content, granular products such as cocoa beans (10).

Both the constant and the falling rate periods have been observed during the drying of thin beds of freshly fermented cocoa beans. Bravo and McGaw (9) detected a constant rate period during which the moisture content fell to some 43-39%. They further found that the falling rate period consisted of two distinct stages, with a changeover point occurring at a moisture content of approximately 26-20%. Consistent with the theory of drying, they observed that the drying rate during the constant rate period was dependent upon both temperature and air flow, but only temperature dependency was observed during the two falling rate periods. They explained the constant rate period as the removal of superficial moisture and the drying of the testa, the first falling rate period as the removal of moisture lying between the testa and the cotyledon and the second falling rate period as the drying of the cotyledon itself. They noted that each successive stage had a lower drying rate than the previous one. Strictly speaking, these results are valid only for thin beds of 1 or 2 beans depth, where the moisture content of any bean is fully representative of that of the whole bed. Cocoa drying in deeper layers develops a moisture content profile though the depth of the bed and the distinction between the differing drying periods, although still valid on an individual bean basis, is not a true representation of the bed as a whole.

Drying rate profiles for various air-flow rates under typical throughflow drying conditions, with dry weight loadings of 50 to 55 kg/m^2 and air temperature of approximately 60°C are shown in Figure 1 (49). At an air-flow rate of 0.18 m/sec, the drying rate curve exhibited the expected constant and falling rate behaviour. At 0.03 m/sec which is a rate similar to the one normally used for platform drying, the drying rates were low, falling off during the early part of drying before rising to a peak later. At a nominal 0.01 m/sec, which is typical of natural convection drying (49), the form of the curve was similar to that for platform drying, but the rates were lower throughout. If the 0.18 m/sec curve in Figure 1 is taken to represent typical constant and falling rate phenomena as in standard drying rate theory, then its intersection with the lower air flow rate curves will indicate the onset of falling rate conditions. This intersection represents the point at which the value of the applied air-flow ceases to have an effect upon the drying. The intersection occurs at some 23% moisture content for platform drier

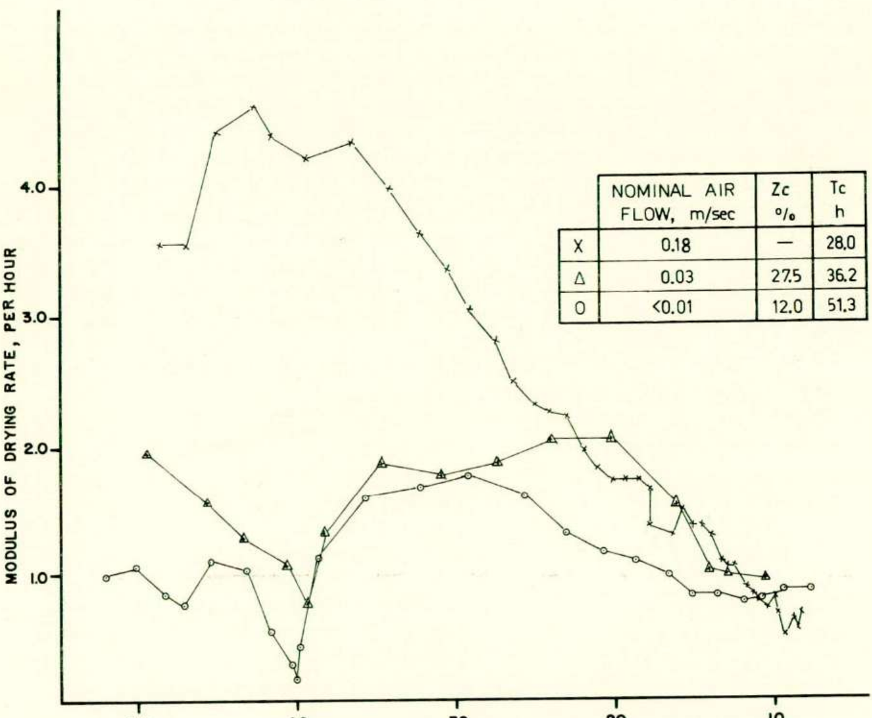

Figure 1: Drying rate profiles for throughflow drying in deep beds at three air flow rates where Tc is the drying time from 50% to 7% m.c. and Zc is the overall drying efficiency over the period Tc. (See Section 5 for further details).

conditions and 11% for the natural convection drier. The air-flow rates typically used for cocoa drying are therefore substantially lower than those at which the standard cocoa drying theory applies.

There is evidence to show that the low initial drying rates demonstrated in Figure 1 are mainly due to condensation within the bean bed (51). Air enters at the base of the cocoa bed and begins to extract moisture from the successive layers of beans during its passage through the crop. As the air rises, its temperature is reduced. If the bed is too deep or the air-flow too low, saturation of the air will occur before it escapes from the cocoa and then heat loss to the upper layers of crop will cause condensation of moisture extracted from the lower layers. In-bed condensation will be reduced as the cocoa becomes skin-dry and this accounts for the rise in the drying rate observed in Figure 1 below 40% m.c. The maximum depth to which cocoa should be loaded on any drier depends upon the drier's capacity to generate a flow of air. A forced convection drier can dry beds of greater depth than can a natural convection drier. Both will handle much higher loadings than a sun drying platform. For a given throughput, therefore, a forced convection drier can be smaller than a natural convection drier and a sun drying platform will have to be very large. Both air-flow rate and bed depth should be determined so as to just preclude condensation, though a large safety margin should be allowed. The reduction in efficiency with reduced air flow in condensation conditions can be seen from Figure 1. The overall increase in drying rate associated with the higher air flow should also be noted.

A compromise is necessary when choosing between drying speed and drying efficiency, but it is hard to make this decision because of the lack of reliable data from carefully controlled experiments using deep beds of cocoa. Shelton (68) carried out such a study and concluded that maximum drying efficiency, but not overall efficiency, was obtained at the maximum bed-depth tested (0.254 m), at the lowest air flow tested (0.051 m/sec) and at moderate air temperatures (60-66°C). Jacquet et al (36) also investigated deep bed drying (between 0.1 and 0.28 m) and presented values of the overall mass transfer co-efficient for the constant and falling rate periods.

The physical nature of cocoa changes significantly during the drying process. Its density falls from some 700 kg/m^3 to 480 kg/m^3 (32) which represents an effective reduction in bed depth of 24%. The static pressure necessary to force air through the bed also decreases significantly. For example, at a bed loading of 55.9 kg dry beans per m^2 and an air flow of 0.07 m/sec, the necessary static pressure developed beneath the cocoa will fall from some 15 to 5 N/m^2, while the cocoa is being dried to 35% m.c. (51). Below this the static pressure remains almost constant, though it can vary substantially when the drying beans are mixed. It is unlikely that such variations in resistance to air flow will have a dramatic effect on a well designed forced convection unit, but natural convection systems are likely to be more seriously affected.

2.1. Heat Transfer

Of the two rate controlling factors just outlined only heat transfer is controllable by the drier designer. It can be affected by convection, radiation, conduction or by any combination of the three. Driers employing a variety of these methods will now be discussed. The dominant transfer mechanism which is adopted will determine the homogeniety of temperature/

moisture content distribution throughout the bed and the ease with which bean temperature can be controlled. The former will largely determine the maximum production per unit area of a given drier and the frequency with which mixing of the beans is required, while the latter will be partly responsible for end product quality (see Section 3.4).

2.1.1. Drying by Convective Heat Transfer

When a stream of hot air flows over, or more usually through, a bed of cocoa, heat is transferred by convection. Heat transfer is from the air to the cocoa and so the beans can never reach a temperature higher than that of the air itself. Air temperature is relatively easy to measure (a simple thermometer will suffice) and so the control of the drying process is simple. The extent to which the bean temperature approaches that of the drying air depends upon the level of bean moisture and the bean heat transfer co-efficient. During the initial stages of drying, when free moisture exists on the outer surface of the beans (i.e. in the constant rate period), the bean temperature cannot rise above the wet bulb temperature of the drying air. During this period a high drying air temperature can be used in safety to increase the rate of drying, but as soon as skin dry conditions are reached, the bean temperature will begin to rise towards the dry bulb temperature of the air and more care is needed in controlling temperature. The extent to which the beans approach the dry bulb temperature depends upon the convective heat transfer co-efficient which is a measure of the resistance to heat transfer created by the layer of air around the beans and is air flow rate dependant (56). The higher the air flow rate, the nearer the bean temperature approaches that of the drying air. Conversely, the lower the air flow, the higher its temperature can be allowed to rise without prejudicing end product quality. Bravo and McGaw (9) used a single bean layer and showed that after 16 hours of drying at an air temperature of 60°C, the bean had a temperature at the centre of the cotyledon of approximately 59°C for an air flow of 0.49 m/sec., but only 56°C for air flow of 0.047 m/sec.

Beans dried on a throughflow drier will require regular mixing at a frequency determined by the air flow rate adopted. The lower the air flow, the more frequent should be the mixing. Mixing not only prevents the beans sticking together, but also effectively distributes sensible heat throughout the bed thus reducing the risk of condensation.

2.1.2. Drying by Conduction and Radiant Heat Transfer

When cocoa is placed in contact with, or subject to, radiation from a hot surface, the surfaces of the exposed beans are preferentially heated. Some of this heat will be conducted into the bean to effect the drying and some will be lost to the surrounding air by natural convection. The air temperature in such cases must always be lower than, and hence a poor indicator of, bean temperature. Conduction and radiation driers are difficult to control and overheating of the beans can be a serious problem. In the case of radiation driers, the location of a thermometer must be such as to receive the same radiation as that incident upon the beans themselves. In the case of drying by conduction, the thermometer should be welded or glued to the surface through which the beans receive the heat. In neither case can the result be completely satisfactory. There is no substantial air flow through the bean mass, except for the small natural convection component, and this results in localised drying which means that frequent, if not continuous, mixing is necessary.

2.2. Multi-stage Drying

It is evident from the information presented in Section 2 that deep bed cocoa drying is essentially a two-stage process and it is no surprise therefore that many attempts have been made to design driers to benefit from this behaviour. These designs have had the following objectives and design features:

(a) Increased drier throughput or efficiency by: pre-drying in shallow beds and later passing to a deep bed unit; or by reducing temperature and air flow rate at some point in the process; or by re-circulation of the spent drying air.

(b) Improved product appearance by removing the cocoa to a mechanical polisher/drier for some part of the drying period.

(c) Improved handling properties by drying initially on a mechanically agitated unit and later, when the beans become prone to breakage, removing to a static bed.

Increased capital and handling costs are to be expected from a system of multi-stage drying and the resultant benefits must obviously exceed these if the method is to be cost effective. Most frequently designers have tried reducing temperature and air flow, but this is the most difficult to apply due to the problem of determining the critical moisture content at which the air flow rate dependency of the drying ceases to be effective.

Another process which can be considered as a pre-drying is the activity known as 'washing'. Wet cocoa beans have a significant level of glutinous surface moisture and during washing this is removed and replaced, to some extent, with free water which can more easily be removed. In addition to physically reducing total bean moisture content, limited observations have indicated that the washing of the bean also facilitates the subsequent removal of residual moisture (G.A.R. Wood, private communication). Although not yet proven, it seems likely that this is due to the fact that the removal of solid matter in the pulp eliminates a potential barrier to moisture movement across the testa. The reduction of shell weight by washing will sometimes be compensated for by the payment of a premium by the buyer, but in principal it is not recommended on economic grounds.

2.3. Interrupted Drying

Several workers have taken advantage of a multi-stage drying system to introduce interruption or rest periods which are claimed to increase end-product quality and/or system efficiency. There is no experimental proof that either of these benefits actually accrue so there seems no reason why cocoa should not be dried in a single step. The arguments in favour of rest periods, where drying efficiency is concerned, are that the 'tempering period allows the moisture inside the beans to move towards the outside and helps in preventing hardening of the outer casing of the bean' (11). Case hardening of the bean testa has often been discussed, but has never been experimentally studied and would not normally be a problem at the temperatures used for cocoa drying. Any moisture movement towards the outside of the bean which occurs during resting does so at the expense of a loss in sensible heat. Moisture might be easily removed on re-starting the drying, but before any further moisture can be drawn from the centre of the bean, all of the lost sensible heat must be replaced. The only case where 'resting' might be beneficial is when no subsequent re-heating is necessary at the very end of the drying. An experienced operator can halt the heat input to the beans at slightly above the required end-product moisture content and allow the residual heat to complete the process. 'Resting' also increases the capital cost, because of the lower drier throughput and would increase handling costs if the beans are in fact removed from the drier for the purpose.

3. DRYING AND END PRODUCT QUALITY

The factors considered indicative of good drying in 1937 by Knapp (38) are:

(a) beans having good storage properties

(b) crisp, plump beans with shell neither broken nor fragile;

(c) well oxidised interior, i.e. adequate brown colour with low bitterness or astringency;

(d) good flavour without excessive acidity or hammy/smoky flavours.

These factors are just as important today.

3.1. Storage and Mechanical Strength Requirements

Beans must be dried to less than 8% moisture content (38) in order to prevent mould formation during storage. In practice, end-point moisture content usually lies in the range 6 to 7%.

The need for the beans to remain unbroken is obvious, but artificial drying systems are likely to result in more damaged beans (73) than occur in sun drying systems. The thick beds adopted in artificial systems necessitate increased mixing, but also make this mixing more difficult. Higher temperatures attained by the beans during artificial drying probably result in more brittle shells, especially during the final stages of the process. De Vos (75), drying at high temperatures of up to 90°C, recommended that dried beans be left overnight on the drier at depths of not more than 5 cm to allow the re-absorption of moisture by the testa to strengthen it.

Various attempts have been made over the years to mechanise the mixing process. Any such process must develop large forces to mix the wet beans, but at the same time handle dry beans sufficiently gently to avoid damage. Few schemes have been able to combine these requirements and most have been abandoned. Even the comparatively popular rotary type drier can cause appreciable damage under certain circumstances (53, 69). Mechanically mixed circular platform type driers have been tested several times though only in its most recent form does this type of unit give promise of sufficiently low breakage as described in Section 5.2.3.

Shrivelling or wrinkling of the beans is another physical feature which is reportedly caused by drying too rapidly (35, 73) as has the physical collapse of the bean (38). Roelofsen (63), however, has proposed that these two features are inter-related and both due to insufficient fermentation, leaving the testa impermeable to the passage of air. He suggests that contraction of the cotyledon during subsequent drying causes its collapse which in turn draws in the testa, resulting in the wrinkling. Howat et al (33) showed that wrinkling of the testa is not an automatic consequence of high temperature in an experiment where cocoa was dried at temperatures of 80°C to produce a wrinkle-free end product, only slightly more brittle than beans dried in the sun.

3.2. Oxidation During Drying

The oxidation of tannins by the polyphenoloxidase enzymes has been shown to account for both the development of the characteristic chocolate brown colour and for the reduction in end-product bitterness and astringency (24). Although elaborate attempts have been made over the years to ensure the complete oxidation of the beans during drying (20, 69) it is now accepted that a percentage of partly brown, partly purple beans are necessary to give the best chocolate flavour and up to 50% partly brown/partly purple beans is now regarded as acceptable (5).

Much work has been carried out to define the conditions for maximum activity of polyphenoloxidase. There is a general lack of agreement between these results due, perhaps, to a failure to control simultaneously all of the factors upon which the enzyme activity depends namely, temperature, pH and moisture content. Early workers experienced difficulty in determining the temperature range of optimum polyphenoloxidase activity, with values having been quoted variously in the range of 42-60°C (38, 66, 69). In more recent work Quesnel et al (59) found the activity of polyphenoloxidase, extracted from fermented beans, to be in fact only weakly temperature dependent with a slight peak at 35°C. The fact that polyphenoloxidase is rapidly destroyed at 70-75°C has been shown by a number of workers (23, 38, 66). Although there is agreement that the activity of polyphenoloxidase falls off with increased acidity, the optimum pH level is less well defined, being quoted variously as 7 (63), 6 (59), 5 (79) and anywhere in the range of 7-10 (38). However, as will be seen in the following section, cotyledon pH values vary only slightly, if at all, during drying and as such do not represent a significant parameter in determining the oxidation rate.

The oxidation process begins during the last day or two of fermentation with oxygen being drawn initially from the oxygen dissolved in the water which is between the cotyledon and testa of the bean (58). It is the browning of this liquid which indicates the onset of oxidation (63). The gradual evaporation of this water (from 40-20% m.c.) facilitates the access of gaseous oxygen to the cotyledon surface and, as a result, the rate of the oxidation process is accelerated (58). The maximum oxidation rate is achieved at 20% m.c., a figure which agrees with the observation of Bravo and McGaw (9) that, at 23% m.c. the space between the testa and cotyledon and most of the passages within the nib are free of liquid moisture. This allows gaseous oxygen to penetrate to the very centre of the bean, resulting in a more thorough oxidation. On the other hand, however, Roelofsen (63) suggests that shrinkage of the cotyledon would be sufficient to constrict these passages and so browning would only be caused by oxygen derived earlier by the very much slower process of liquid phase diffusion. Below 20% m.c. the lack of water begins to impede the activity of the enzyme, although at 10% m.c. some activity still remains (14, 38).

3.3. Off-Flavour Development

3.3.1. Acidity

During fermentation, a range of both volatile and non-volatile organic acids is produced (44, 76). These make important contributions to the end-product flavour and if an imbalance in the concentrations of the various acids occurs, an off-flavour can result giving rise to tastes described as 'acid', 'insipid', 'fruity', etc. The prominent acid formed is acetic acid which, being volatile, is lost in substantial amounts by evaporation during drying (18). Small quantities are lost both during storage (16, 79) and during the chocolate manufacturing stage (15, 64). Residual acetic acid can still sometimes be found in chocolate after completion of processing and it gives it a 'fruity' flavour (57). The causes of the other acid related off-flavours (namely 'acid', 'sour', etc.) are still not yet fully understood.

The effect of the drying process upon the cotyledon acidity (as defined by pH) was investigated by Howat et al (33) who, during a sequence of 11 tests, on a throughflow tray or cabinet type drier at 80°C, showed that the average post-fermentation pH of 4.8 did not change during artificial drying. Sun drying control samples showed a higher pH of 5.2. The nature of the acid responsible for this increase was not investigated, but was later taken to be volatile acetic acid due to the presence of characteristic 'fruity' off-flavours which were detected only in chocolate made up from the artificially dried cocoa. The volatile nature of this acid at the manufacturing stage was shown by the ability to remove the off-flavour by an aeration/mixing process known as 'conching' (15).

The work of Howat et al (33) was carried out in Africa where acidity is not a serious problem. This is not the case in Malaysia and Carr et al (12), carried out experiments both in Ghana and Malaysia and found no reproducible variation in cotyledon pH or in acetic or lactic acid concentrations during sun drying. It was concluded that the large amount of acetic acid lost from the cocoa during drying is derived entirely from the exterior of the bean.

To some extent this doubt about the effects of drying upon cotyledon acidity is supported by the lack of a proven explanation for the high acid levels in artificially dried cocoa. It has been suggested that rapid high temperature drying does not allow sufficient time for the volatilization of the acetic acid (60) or that heat damage to the testa renders it impermeable to the passage of the acid (20). Cocoa from several areas of the world, notably the Far East and South America, suffers from acidity which cannot be removed by conching and so attention has been recently directed towards the effects of the non-volatile acids (12, 13). The higher dissociation constants of the small chain, volatile and non-volatile carboxylic acids mean that they are, even in very small concentrations, more detrimental to end-product flavour than would be the case with similar amounts of acetic acid (41).

3.3.2. Smoke and other Off-flavours

The prevention of 'smoke' and 'hammy' off-flavours is also made difficult because doubt still exists as to their causes. The 'smoky' flavour attributed to cocoa from the State of Bahia in Brazil is due to direct smoke contamination, either from cooking fires (80) or, more frequently, from old or badly operated wood fired artificial driers (3). The direct uptake of the water soluble components of the smoke is the cause of the contamination (8) and thus the final stage of drying and on-farm storage are low risk periods in terms of the development of smoky off-flavours. The solution to the smoke problem is one of mechanical engineering and rural extension and as such should not be difficult to solve. A much more serious situation would arise if smoke-like flavouring compounds were found to be products of fermentation. 'Hammy' off-flavour is similar to that of smoke and the two are often confused. Cooking fumes have been blamed for this defect, but it is likely to be a fermentation problem. For instance ham-like flavours could be due to small quantities of butyric acid, formed when cocoa is over-fermented (37, 38).

It is often feared that off-flavours might also be picked up from diesel exhaust fumes. This has resulted in great reservations concerning the use of direct fired diesel heaters. However, work carried out by Cadbury Schweppes Limited in conjunction with Shell Petroleum (Australia) has shown that the exposure of cocoa to diesel fumes from such a burner, even when made to operate at below optimum conditions, does not result in any detectable off-flavour (G.A.R. Wood, Private Communication).

3.4. Drying Temperature and End Product Quality

It is evident from the foregoing that there is perhaps a correlation between high temperature drying and low end-product quality. However, available literature shows that very little definitive work has been carried out to determine the limiting temperatures of the many component processes, both physical and chemical, which are part of the drying operation. Quality might be affected by high temperatures due to temperature damage effects, such as enzyme inactivation or case hardening of the testa. Quality might also be affected by rate effects such that the drying rate is preferentially raised to such a point that insufficient time is allowed for the other rate controlled processes such as oxidation or acid diffusion and evaporation. Drying rate is the important factor and, although often considered to be solely temperature dependent, does in fact depend upon a sequence of factors, including the heat exchange mechanism, bed depth, air flow rate and mixing frequency. When considering quality, the adopted value of each of these parameters should be quoted.

From the limited, and, in some cases, empirical, information available and quoted already, it seems that the bean temperature should not be allowed to exceed 65°C until adequate oxidation has taken place, that is to say, until the beans have reached some moisture content between 23 and 10%, nor should the air temperature rise above 80°C if an excessive acid flavour is to be safely avoided. In spite of the obvious fear of reduced end-product quality it is surprising how few workers have managed to produce cocoa of totally unacceptable flavour merely by virtue of excessively high drying temperatures. De Vos (76), working in Suriname, devised a scoring scheme by which he compared cocoa dried under different conditions using washed beans. He considered not only the appearance of the beans by assessing colour and wrinkling, but also the flavour of the end-product chocolate. The drying system employed was a two stage process with the first stage in a rotary unit and the second in a tunnel drier. The most interesting fact about De Vos' optimum drying temperature combination (90°C to 37% moisture content, followed by 70°C) was that it produced better chocolate than that obtained from both higher and lower temperature combinations (99/99°C down to 50/50°C). Furthermore, end-product flavour was found to be preferentially sensitive to variations in second stage drying. By setting thermometers within the bean mass, approximations of the bean temperature were obtained. Drying at 90°C and 70°C respectively, it was found that the beans did not reach temperatures of more than 54°C during the first stage and 66°C at the end of the second stage. Drying washed beans in two stages at temperatures of 90°C and 70°C respectively took from 11.0-12.4 hours.

Wilbaux (78) found that drying at two temperature levels gave the best results. Using titratable acidity as his quality criterion he proposed 20 hour drying in 10 cm beds at an air temperature of 90° C with continuous mixing, following by finishing at 45-50° C in beds of 15-20 cm. Couprie (16) studied a two stage process using a Samoan drier with and without pre-drying for two days in the sun. Temperatures and air flows were not quoted, but chemical and organoleptic tests for astringency and acidity showed the two drying techniques to be comparable, though both produced an end-product of inferior quality compared to the wholly sun-dried control sample.

Haynes (32), working in Malaysia with a small platform drier (of $0.19m^2$) operating at 65.6°C, produced cocoa which gave chocolate of acceptable flavour. Neither the cocoa loading nor the drying air flow were specified, though the latter must have been high (i.e. of the order of 0.2 m/sec) in order to dry in the specified period of 12 hours. A larger platform ($3.3m^2$), operating at from 64-72°C with an air flow of 0.18 m/sec, a drier loading of 29.5 kg. dry cocoa/m^2 and a temperature probably in excess of 65°C enabled the cocoa to be dried in 14 hours, but produced an end-product chocolate with an unacceptable acid taste. It seems probable that the beans used came from different fermentations and insufficient data on other aspects prevents us drawing firm conclusions.

Jacquet et al (36), in a well controlled sequence of 12 tests on a laboratory scale, investigated the throughflow drying of cocoa in beds of depths between 10 and 28 cm. Drying air temperatures of 65-111°C were used and kept constant during any run. High air flows were applied (0.37-0.94 m/sec) and the bean temperature can be assumed to have approximated closely to that of the drying air for some time before the end of the process, which took between 13 and 19 hours. Sun dried control samples were used and the difference between the quality of the artificial and naturally dried end-products for the various runs were subjected to statistical analysis. This analysis showed a high correlation between increased drying temperatures and both astringency and acidity of the end product chocolate on the one hand and bean pH, volatile acid and total acid on the other. Cocoa dried at temperatures above 65-70°C proved to have an unacceptable flavour.

4. NATURAL DRYING IN THE SUN

Natural drying uses the radiant heat of the sun to warm the surface of the exposed cocoa bean. The air in contact with these beans is then itself warmed by convection, its vapour pressure is increased and the drying mechanism initiated. The removal of the moisture laden air is carried out by wind with a contribution from the natural convection currents set up above the cocoa as a result of the convective heating of the adjacent air. Sun drying suffers from all of the drawbacks of radiation drying. These are the need for frequent mixing, low production per unit area of drying floor and possible superheating of the upper layer of beans.

4.1. Simple Natural Drying

Sun drying has been used for drying cocoa for many years on both smallholdings and large plantations. One of the simplest applications of sun drying is by the West African smallholder, notably in Ghana (65) who uses a platform of bamboo mats (See Plate 1). The concrete platform has been used

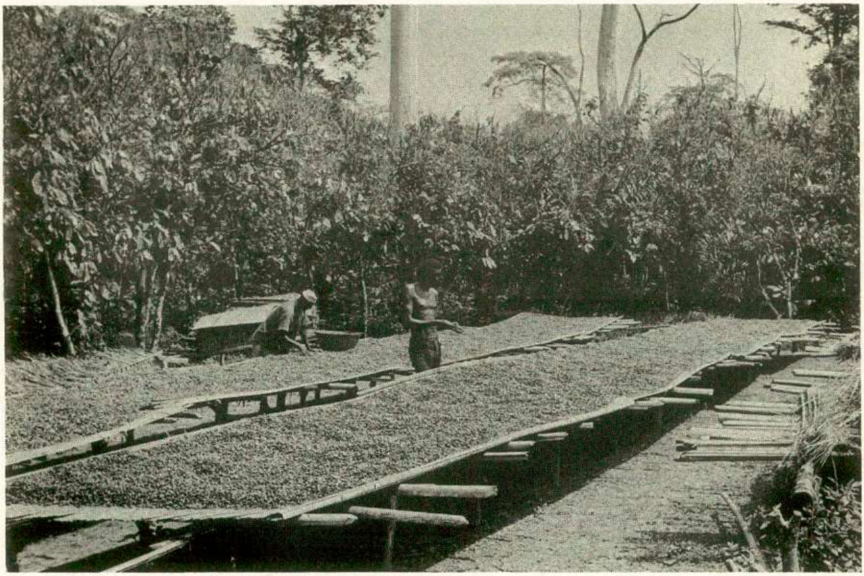

Plate 1 Cocoa beans drying on bamboo mats in Ghana.

for many years in northern South America, parts of the Far East and on a smaller scale in Nigeria (38, 55). A common problem with both of these methods is the lack of protection of the beans during rainy periods. Small areas can be strewn with palm fronds to give cover from a light shower, but during heavier rain drying mats have to be rolled up and stored indoors (65). Cocoa on a concrete platform can be protected by laying corrugated iron sheets or PVC sheets over the beans (83) or by heaping and covering with canvas (73) (See Plate 2). During wet weather prolonged storage of drying cocoa in rolled matting or in heaps will inevitably cause a reduction in quality (69). Concrete floors have the additional drawback that they are attacked by acetic acid and may cause overheating of the beans (31, 55). The crumbling of the concrete floor by acid attack can lead to the contamination of the beans with grit and mixing dried beans on the roughened, uneven surface can increase bean breakage. This can be avoided if the crop is laid on mats. If the whole of a concrete floor is not in use, full advantage of the incident sunlight can be made by periodically sliding mats onto a recently warmed area and allowing the beans to be warmed both from above and below.

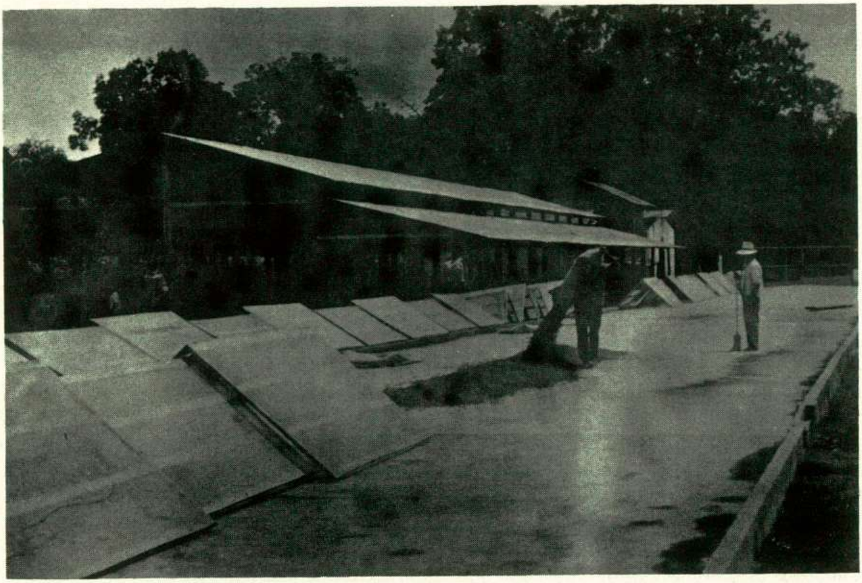

Plate 2 Drying floor or 'tendal' in Ecuador. Concrete floor with covers of polythene sheet on frames for use in event of rain.

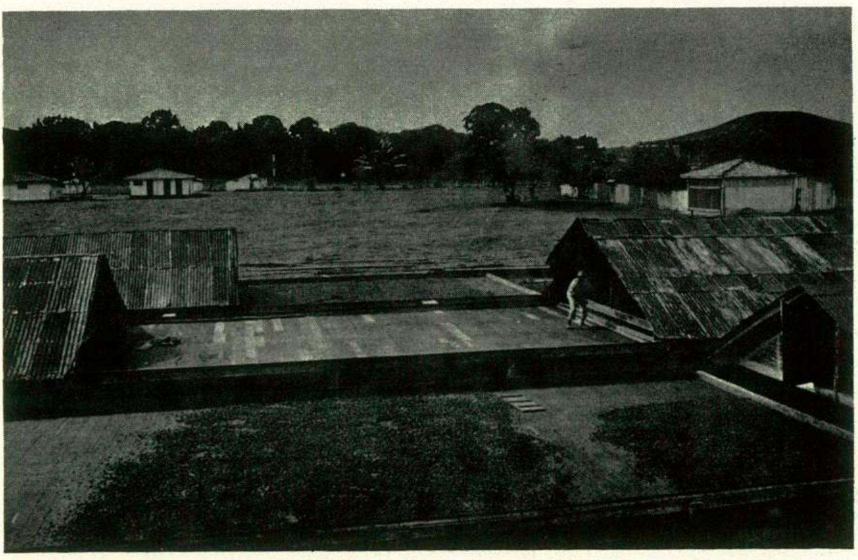

Plate 3 Barçaca with wooden floor and sliding roof on rails in Brazil.

Many schemes have been devised to rapidly cover drying cocoa. A roof of corrugated iron on rails can be rolled over the platform or the platform itself can be mounted on rails and be pushed quickly into a fixed house. The former method is used in the West Indies, notably Trinidad (the Boucan) and in Bahia (the Barçaca). The sliding floor method has been developed to include several levels of platforms which can be retracted one above the other into a single building for protection. All driers of these types have wooden floors (see Plate 3). The only disadvantage of wooden floors is that mould spores can be harboured in the cracks between planks (35).

Barçacas should be loaded with cocoa to depths of only a few beans and certainly with layers of no more than 5 cm depths. The following description of barçaca operation is largely due to Hudson (35), though it is representative of barçaca operation to this day (71). The cocoa should be turned (with a wooden rake) as often as possible during the first day or two. A common practice during this period is to rake the beans into ridges from time to time to allow the wooden platform to dry out. All foreign matter should be picked out of the beans during the first day. When a significant amount of mould appears or when an end-product of finer appearance is required the beans can be 'danced'. In this procedure cocoa with a moisture content of about 10% is heaped and a small amount of water is poured onto the beans which are then trodden (or 'danced') with bare feet to remove surface contamination. Three to four days of good sun are then required to complete the drying. It is unlikely that dancing actually destroys surface mould or that it improves the bean storage properties (46). Overheating of the beans on a sun drying platform seems an unlikely occurrence but the closing of the barçaca or boucan roof during the hours of the midday sun has often been advocated. (35, 71). No experimental evidence is available to prove that there are any advantages to compensate for the increased drying time which becomes necessary. A thermometer caked in dry cocoa mucilage located on a barcaca can reach temperatures in excess of 55°C and maintain this level for several hours but this seems too low to cause any detrimental effects to the drying beans. The drying capacity of a barçaca is low in relation to the capital investment needed and its productivity can vary tremendously depending on the weather conditions. In sunny conditions 18 kg of dry beans can be produced per square metre of drying floor and drying could be completed in about 7 days (71, 83). In rainy conditions drying times of up to 22 days may be necessary (28) and drier loading must be reduced by as much as half (L.M. Sobral private communication).

4.2. Enhanced Direct Sun Drying

One of the major drawbacks of merely exposing the beans to direct solar radiation is that full use is not being made of the available energy. A part of the incident radiation is reflected from the beans and the wind probably removes a greater proportion by convection. Solar cabinets of various designs have been developed to minimise these losses. These systems cover the beans with a transparent material such as PVC, glass or fibre glass. Some prevent reflective heat losses but all allow the beans to be enclosed in a volume – a solar cabinet, through which the air flow can be controlled and optimised. The advantages of the solar cabinet have been known for many years (40), but little work has been done to adapt it to the drying of cocoa.

Richard (61, 62) described a simple drier suitable for the smaller farmer, consisting of a small platform of bamboo (4.9 by 1.62m) bounded by wooden edges. This was covered with PVC sheeting which could be removed to allow access for the necessary daily mixing of the beans. The drier was pivoted about its mid-point so that the optimum angle to the sun could be maintained throughout the day (hence the name 'rocking drier' coined by Richard). Air throughflow was by inlets at the bottom and exit vents at the top and the convection of air was aided by matt-black areas (one seventh that of the platform) at each end of the drier which were not loaded with cocoa. Full drying data were not presented, but in good weather some 22.5 kg of dry cocoa could be produced per square metre, though this would be reduced to 10-12.5 kg in unfavourable conditions. It was claimed that this drier reduced normal sun drying times by two days in adverse weather conditions, as compared to the traditional sun drying platform. This was probably because drying continued during rainy weather, whereas the beans would have been covered with an impermeable material on a traditional sun drying platform. The drying rate is not improved in periods of good sun. The cocoa produced in these types of driers has been compared with the normal sun-dried product and no significant difference was found (74).

Ghosh (26) described a large glass-roofed drier housing two perforated platforms each of 12.0 by 1.76 m, divided by a central access aisle. Air inlets were located above and below the cocoa and air exit was by means of a ridge vent. Drying time of one day less than the normal for sun drying was claimed, but drier loadings were not quoted. Loading would need to have been approximately 27 kg/m^2 to compare with a barçaca of the same ground area and such loadings are quite impracticable.

5. ARTIFICIAL DRYING SYSTEMS

Although the larger part of the world's cocoa is successfully dried by direct exposure to the sun, many cocoa growing regions exist in areas where rain during the harvest prevents the use of sun drying and in such regions artificial drying is essential. In reviewing the many schemes which have been developed in various countries some points should be noted. Flow of the drying air is considered in this review to be the air approach velocity in m^3/m^2 drying floor/sec or m/sec, while cocoa bed depth is defined here as kilograms of dry cocoa/m^2 of drying floor. Allowance must be made for the difference between air and bean temperatures arising from the various heat exchange mechanisms which can be employed. The three important criteria which must be considered when assessing an artificial drying scheme are the end product quality, the thermal efficiency of the process and the energy cost.

The ever increasing cost of energy has stimulated debate on the operating costs of driers and to allow comparison between drying schemes, a factor to be known as 'overall drying efficiency' factor will be used. This is defined as 'that proportion of the energy liberated at the combustion stage which is actually used for the evaporation of moisture with the remaining proportion representing lost heat'. It is calculated as:

$$Z = \frac{WL}{FC}$$

where Z is the overall drying efficiency factor, W is the weight of water evaporated (kg), L is latent heat of evaporation of water (2.256×10^6 J/kg), F is the quantity of fuel used (kg or m^3) and C is the net calorific value of fuel used at 25°C.

Z allows for combustion, heat exchange and drying efficiencies, but does not include the mechanical energy consumed in driving a fan, though this usually represents only a very small proportion of the total energy requirement — just over 2% based upon the figures of Allison and Kenton (1) using a platform drier, an oil fired heat exchanger and fan. For direct heating the heat exchange is totally efficient and with electrical heating neither combustion nor heat exchange losses need to be considered. In both these cases the overall thermal efficiency values will be higher than for equivalent drying with indirect heating.

This measure of efficiency — the overall thermal efficiency factor (Z) assumes that resistance to moisture movement from the beans is uniform for all conditions. This is strictly true only when considering drying between fixed terminal moisture contents and therefore in some cases a corrected value Zc may be quoted which considers only the energy used between moisture contents of 50% and 7%. Where the terminal moisture contents differ significantly from these values, i.e. for washed beans or when two stage drying is being considered, particular care must be exercised. In general Z will be higher during the early part of drying period than later, when falling rate drying conditions apply.

5.1. Artificial Driers — Natural Convection

Natural convection or flue type driers usually consist of a wood fired furnace from which combustion gases flow through a horizontal heater pipe before passing to a chimney. D'Oliveiri (19) writing in 1903 described a system once common in the West Indies, in which a horizontal heating tube was centrally located near the floor of a building and was lined on either side by trays on which cocoa was placed. It is now more normal for the heating tube to be set into a plenum chamber with the beans placed above it on a single perforated drying floor or platform. General operating characteristics of the more common types of natural convection drier types are outlined in Table 1.

The heat transfer mechanisms in natural convection driers are complex. A drier of this type has been studied by McDonald et al (48) and this work shows that natural convection from the heater tube (i.e. the mechanism which generates the drying air flow) accounts for only 20-30% of the total transferred heat. The thermal currents thus produced are only strong enough to penetrate thin layers of beans and, consequently, large drying floor areas are needed. The majority of heat is transferred by radiation, much of which is lost to the floors and walls of the drier. Only the radiant heat incident on the drying floor itself is utilised either in raising the temperature of the drying air which passes through it or by heating the lower layer of beans by conduction. The low drying air flow and the conductive heat transfer component mean that the lowermost layer of beans become preferentially dried and therefore the crop must be thoroughly and frequently mixed, especially during the early part of the drying. In practice this means that a man should be in almost continual attendance when such a drier is in use. The high proportion of radiant heat transfer also causes faster drying of the

TABLE 1: OPERATING CHARACTERISTICS OF NATURAL CONVECTION COCOA DRIERS

Drier Type	Area of Platform m^2	Specific Dry Weight Loading kg/m^2	Temperature °C	Air Flow in Cocoa m/sec	Drying Time h	Overall Thermal Efficiency Z%	Source
MARTIN	105	24.2	–	–	20	–	(72)
SAMOAN	11.1	23.8	60-80	–	40-44	9	(4)
TUBULAR (Traditional)	36	37.5	60 43	0.0-0.015 –	36.4 70	15.8 16.3	(49)
TUBULAR (Modified)	36	37.5	64 59	– –	36.9 42.6	15.1 26.6	(48)
INFRA-RED	–	33-45	45-90	–	40	13.8-20.5	(27)

cocoa immediately above the heat exchange tube. The risk of non-uniform drying can be reduced or overcome by increasing the height of the plenum chamber or by more frequent mixing, the choice depending upon the relative availabilities of capital and labour.

5.1.1. The Martin Drier

These units have 'U' shaped heating tubes which allow very large drying floor areas to be covered by a single furnace. Urquhart (72) described how, with a 105 m^2 unit and at a production of 24.2 kg/m^2, a drying time of as little as 20 hours could be achieved. As can be seen from Table 1, this is so much lower than drying times quoted for other similar units that some doubt must exist about its accuracy. It is possible that this figure refers to pre-dried cocoa. Our information suggests that there are no examples of this drier still in use.

5.1.2. The Samoan Drier

This is a smaller and simpler version of the Martin drier and was developed as a low investment installation for the small farmer (4). The construction is of locally available materials, with the once-through heating tube being made of discarded oil drums. There is no furnace or grate as such and wood is burnt directly in the first section of the heater tube (See Plate 4).

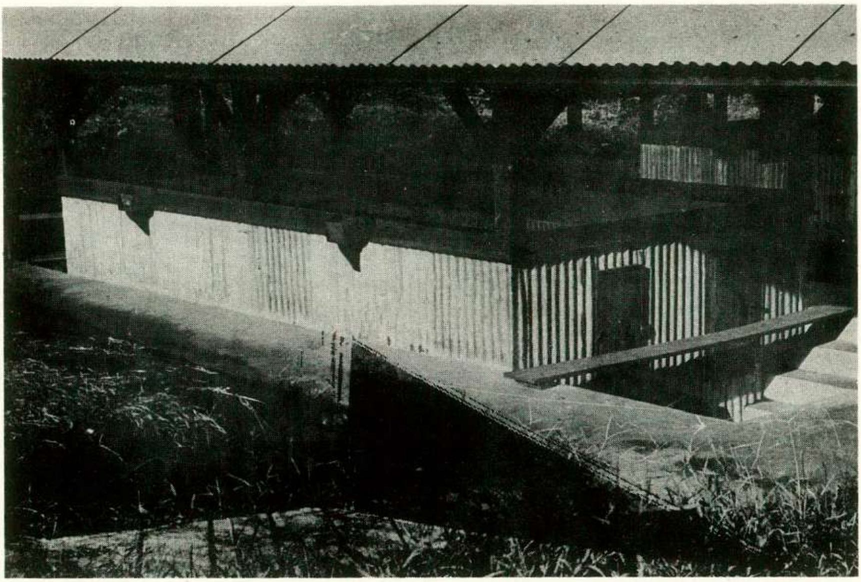

Plate 4 **Samoan driers in Sabah showing heater tube at the bottom of steps. Heater tube is made of discarded oil drums welded together.**

The walls of the oil drums burn through rapidly and must be replaced regularly if smoke contamination is to be avoided. Drying floors of 11.1 m^2 are typical and at a production of 23.8 kg/m^2 a drying time of 40-44 hours is possible (72). At air temperatures of 60-80°C a wood consumption of approximately 15 kg per kg of dried beans has been quoted (4). This fuel consumption represents a low overall thermal efficiency and is probably due to low combustion efficiency.

5.1.3. The Secador Tubular

In Bahia, artificial drying is invariably carried out on a 'secador tubular'. This is a large and expensive building of brick construction with a drying platform of 25-36 m^2 and a plenum chamber height of between 2.5 and 3.0m, housing a single mild steel heating tube (70) (See Figure 2). The performance of such a drier has been studied (48, 49) and, contrary to expectations, the rate of drying is initially very low. At about 40% moisture content, the rate begins to increase, reaching a maximum in the range 30-20% moisture, before falling off in the normal way (see Section 2.0). Only in this last period does the drying rate approach that of forced convection drying at the same moisture content. There are two possible explanations for the behaviour; either shrinkage of the beans during the period when moisture content is reduced from 40-20% results in a decrease in resistance to drying air flows or air flow condensation within the bean mass during the early part of drying effectively holds back the drying rate. Laboratory tests have shown that although a sharp fall in air flow resistance occurs during the period to 35% moisture content, the dominant factor is condensation (49). This effect can be seen from Figure 1. While frequent mixing can help alleviate this, it is clear that the capacity of a secador tubular to generate a flow of air is insufficient for the loadings often applied (see Table 1). The common practice of drying in the sun for 2 days to skin dry the beans, is the best practical solution. The installation of a fan is also a possibility but this has not been fully studied as yet.

The efficiency of the secador tubular is seriously affected by the speed and direction of the ambient wind as the heated air is sucked from the leeward side of the plenum chamber in conditions of medium to high wind. This behaviour must be partly responsible for the reputation of non-uniform drying which is widely attributed to this type of drier. Decreasing the height of the plenum chamber from 3.5 to 2.1 metres increased the non-uniformity of drying with no compensating increase in thermal efficiency and therefore cannot be recommended. Smoke contamination is a danger with any wood-fired drier and Bahian cocoa has a reputation for its off-flavours (see section 3.3.2). The regulation of the combustion air flow on a secador tubular is by a single damper located at the base of the chimney. After experimentation the furnace was found to operate most efficiently with this damper almost totally closed. This leads to almost continuous back-flow of smoke from the furnace door and from any badly seated tube flanges and a large proportion of this smoke passes through the bed of drying cocoa. The relocation of the combustion air flow regulator or damper at the entrance to the furnace ash box effectively puts the whole furnace/heat exchange unit under suction for all combustion air flow rates and almost eliminates the risk of smoke conttamination from this cause.

In its traditional form the secador tubular, for all its immense capital investment, has a performance only slightly better than that of the simple Samoan drier (see Table 1). Improvements, mainly to the furnace, can increase combustion efficiency and have resulted (when operated at 15 kg/hr

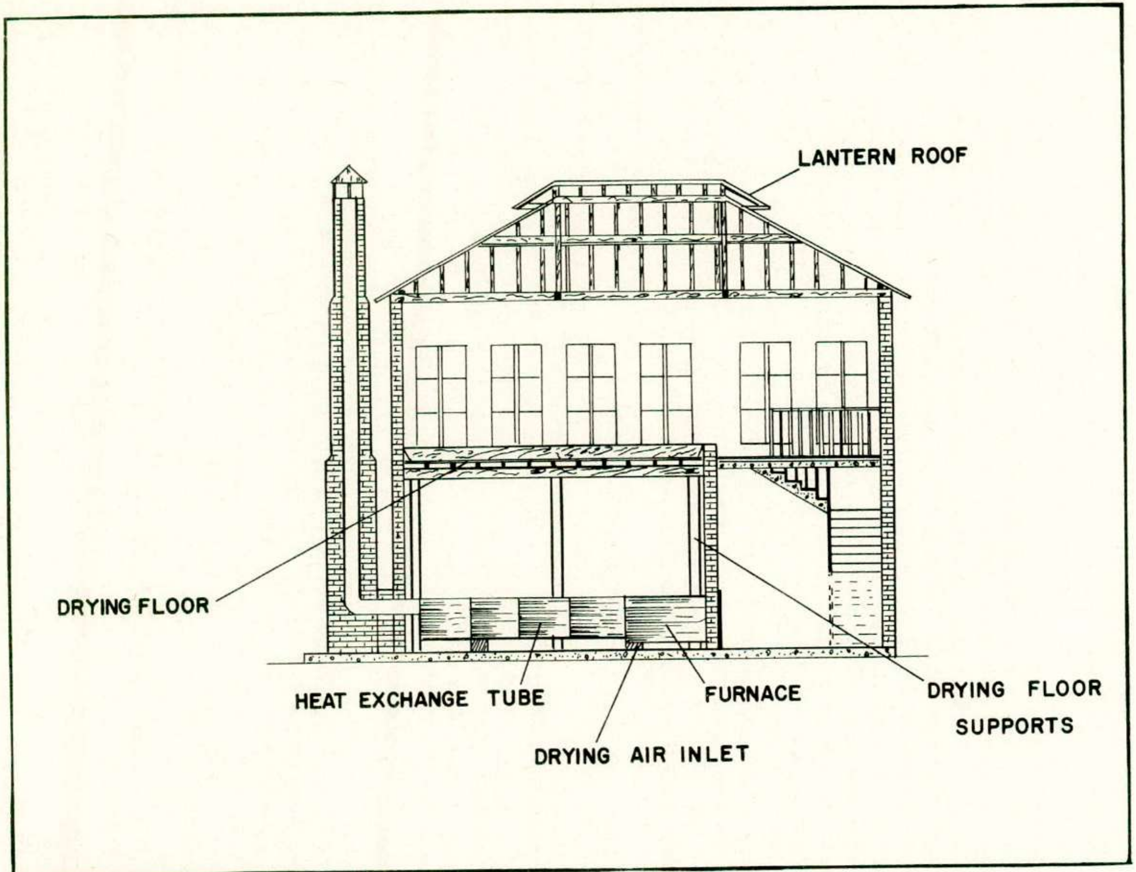

Figure 2: Line drawing of Secador Tubular Natural Convection Artificial Drier widely used in Brazil.

of firewood) in overall thermal efficiencies approaching those obtained by some workers for forced convection drying (49). Ideally wood for this drier should have a moisture content below 20% and to achieve this should be stored under cover for 6 months after felling before use. The performance of the drier, modified or otherwise, increases dramatically if seasoned, dry wood is used.

5.1.4. The Infra-Red Drier

As an alternative to wood-fired natural convection drying, Ghosh (27) described a system for Brazil in which small infra-red gas burners were located below a perforated drying platform in a plenum chamber 1.2 m in height. At a production of between 33-45 kg/m^2, a drying time of less than 40 hours was claimed. One burner for every two square metres of drying floor was recommended and each burner was estimated to consume 0.45 kg/hr of domestic gas (60% butane, 40% propane). Heat transfer from the infra-red plate is almost completely by radiation which results in lower drying air flows and a tendency for preferential drying of the lower layers of beans. Thorough mixing is even more necessary than with the secador tubular and because of this, it is likely that only the lowest figure in Ghosh's quoted range of drier loadings would be practical unless the beans have been pre-dried. An advantage of using a system employing almost exclusively radiant heat transfer is that the air is heated at the level of the drying floor and not of the level of the heater plate. Any suction by wind effects would have to cause a reversal of the air flow back through the cocoa before any heated air would be lost from the system and thus the direction of prevailing wind is unimportant in respect of overall thermal efficiency. An advantage of the incandescent infra-red heater over other types of gas heater, is that it is unlikely to be blown out by draughts. This is important as attempts by the senior author to increase drying air flow by the introduction of simple gas jets (to yield an increased proportion of convective heat transfer) failed, because such burners were extinguished by draughts. By distributing the infra-red burners over the area of the plenum floor, a lower plenum chamber is possible than for the secador tubular, which reduces construction costs. The height of the plenum chamber for this drier is determined by the degree of dis-uniformity of the drying cocoa which can be accepted. Static pressure development is not a factor. Overall drying efficiencies of this drier are similar to the traditional secador tubular (see Table 1). The major drawbacks with this drier type are the dependency on a petroleum derivative as the energy source and the problem of transporting the heavy gas cylinders to the farm. It seems likely that these two considerations will prevent its widespread use.

5.1.5. Sun Aided Natural Convection Driers

One of the earliest attempts at combining natural and artificial drying involved the conversion of a traditional sun drying platform in Trinidad (22). Holes were drilled in the drying floor, the area beneath enclosed a system of pipes through which cycled a thermosyphon of hot water from a wood-fired furnace. At a temperature of 46° C, 9.1 kg/m^2 of cocoa could be produced with a drying time of approximately 60 hours. Although the performance of the unit was subsequently improved by the use of steam as the heating medium (31), this type of drier has not found widespread application.

Rather than modifying existing sun drying platforms to operate with supplementary natural convection, it has been more common to build natural convection or infra-red driers with sliding roofs so as to take advantage of the sun's drying capacity (17, 67, 70, 83). The large drying floors and shallow bed depths associated with such driers make them particularly suited to sun-aided operation. In periods of low production, they can be conveniently worked as a barçaca and then as production increases, artificial drying is used. However, although flexibility is increased substantially the throughput of an already over-worked natural convection drier is not likely to be significantly increased by supplementary direct isolation. A significant increase can only be achieved by an increase in drying air flow, that is to say by the adoption of forced aeration. Once a fan needs to be added to the artificial/sun drying combination, then consideration should rather be given to a fixed roof, deep bed drier, which is more economic in terms of both capital and operating costs. Such a unit is known as a platform drier (82).

5.2. Artificial Driers – Forced Convection

The flexibility and higher thermal efficiency of forced convection driers have been known for many years. D'Oliveiri (19) as early as 1903 described the installation of a fan into a simple cross flow drying house in Trinidad while Hubbard, working in India, has shown that the application of a fan plus electrical heating to a Samoan drier can result in an overall thermal efficiency of 26.7% (G.A.R. Wood, private communication) as compared to 9% for normal operation. In addition to the adaptation of existing natural convection driers, a number of custom built forced-convection type driers have been developed, the most important of which are now described.

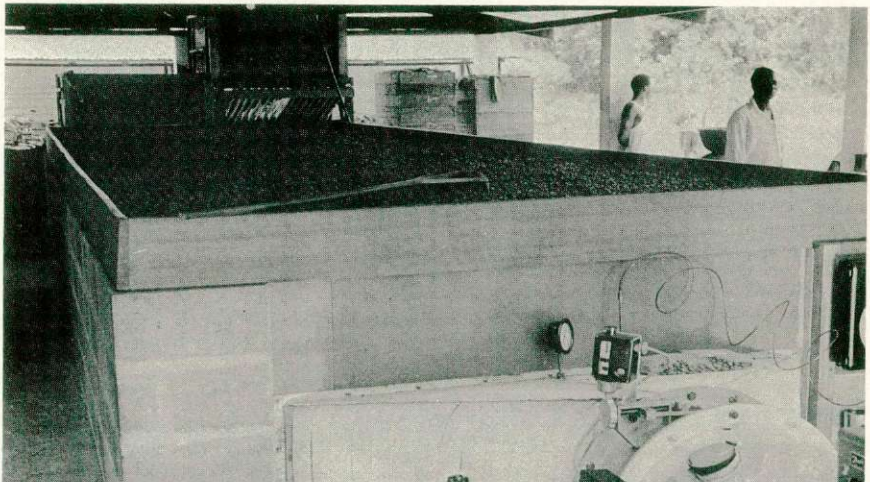

Plate 5 Airwoods heat exchanges and platform drier in Cameroun.

5.2.1. Forced-Convection Platform Driers

The platform drier is a low investment, versatile installation that was first applied to cocoa in the late nineteen-fifties (See Plate 5). The American Drying Systems Company (2) advertised a drier which they termed a 'sheen table'. Five sizes of drier were described with daily cocoa productions in the range 340 to 4100 kg at loadings of between 25 and 37 kg/m^2. The drying sequence recommended was the loading of cocoa to a depth of 0.13 m and drying for 3 hours at 66°C, probably to achieve skin dry conditions. The bed depth was then increased by heaping the beans onto only half of the drier area and the drying was completed within a further 24 hours at air temperatures of 71°C. Mixing was carried out at half hourly intervals throughout.

Gray and Hadley (29) described a range of similar driers called 'tunnel trays'. Their recommended operation included 'resting' periods (see Section 2.2). With a loading of 48.4 kg/m^2, air flows of 0.15 m/sec and air temperatures of between 46 and 54°C, drying within 3 days was claimed, though presumably half of this time consisted of rest periods. Mixing was carried out every half hour.

The first detailed study of platform drier performance for cocoa was carried out by Wood (82) who investigated the operation of a 7.0 by 3.0m platform with a plenum duct height of 1.0 m (See Table 2). For the two production levels tested (29.9 and 42.7 kg/m^2) it was concluded that system efficiency was maximised at the lowest tested flow (0.043 m/sec) and the deepest bed (0.127m) and in this there was agreement with the results of Shelton (68). Shelton recommended an operating temperature of 60°C, but Wood recommended 80°C. At this latter temperature drying times were 24 hours as compared with 29 hours for operations at 70°C and the variation in fuel consumption between the two different temperatures was negligible. Reduction of the drying air flow after several hours drying resulted in a considerable rise in drying efficiency and overall thermal efficiency. The greatest economy in fuel was shown if airflow was reduced after drying for 6.0 hours. In spite of the use of a funnel type expansion duct at the plenum chamber inlet, air flow distribution problems were encountered. These were solved by means of a hessian screen located at the entrance to the plenum duct to decelerate the incoming air and thus aid static pressure development, though this must cause a slight reduction in total available energy.

McDonald and Freire (50) carried out four tests on a gas fired drier of 10.0 by 2.0 m with a plenum duct height of 0.8 m. With an airflow rate of 0.03 m/sec and a production level of approximately 48 kg/m^2 an overall thermal efficiency of 27% was obtained and this was independent of the drying air temperature over the range considered (63.0-74.5°C). This was in agreement with Wood's results, though the recorded drying times of between 36 and 44 hours are considerably longer probably because a lower air flow rate was employed. Instantaneous drying efficiency (defined as the ratio of the moisture uptake capacity of the air entering the cocoa to that of the spent air leaving the bed) was initially high and remained constant until a bean moisture content of 23% was reached, after which it decreased. Although these measured efficiencies did not reach 100% during the initial period, the long period at constant efficiency before the breakpoint, supports the suggestion that condensation could be taking place within the upper part of the cocoa bed.

TABLE 2: OPERATING CHARACTERISTICS OF FORCED CONVECTION PLATFORM TYPE DRIERS

Drying Air Recirculation	Area of Platform m^2	Specific Dry Weight Loading kg/m^2	Temperature °C	Air Flow in Cocoa m/sec	Drying Time h	Overall Thermal Efficiency Z%	Source
NO	3.3	29.6	64-72	0.183	14	21.1	(32)
NO	11.8	42.7	70-80	0.046-0.102	20-28	18.5-29.9	(82)
NO	–	–	75	–	22	40	(39)
NO	18	46-49.5	63-75	0.03	36-43	27	(50)
YES	20.8	27.5-51.7	45-75	0.123	20-23	25.4-46.3	(1)
YES	18	44-46	59-71	0.06	28.4-37	25.4-35.2	(50)

Haynes (32) carried out an incomplete sequence of tests on a platform of $3.3m^2$ at approximately 70°C and with a production level of 29.5 kg/m^2 using electrical heating. Very fast drying was obtained (14 hours) due to the high air flow rate adopted (0.18 m/sec). At such air flow rates, overall thermal efficiency values of much less than the 21% obtained would have been expected had not electric heating been used. (See section 5.0).

Kroutil (39) presented operating data for a platform of unspecified dimensions, but capable of producing 0.81 tonnes of dried beans in 22 hours. An indirect diesel air heater was employed and operating at 75°C, the quoted oil consumption is equivalent to an overall thermal efficiency of some 40%. This is high for a non-recycle type operation.

The performance of a 6.0 by 4.0m platform operated at low temperatures and high air flow rates was investigated by Newton (52). Air movement was by a large axial fan coupled directly to the output shaft of a 30 kw diesel motor. This fan draws air over the engine, cooling it and being itself warmed. Such units are used widely for the aeration and drying of grains (43). The results obtained by Newton are presented in Table 3 and the very high air flows, which are considerably higher than is normal for platform type drying should be noted. The overall thermal efficiency values in this work have been calculated on the engine fuel consumption and are therefore not directly comparable with values calculated for other investigations. It can be seen from Table 3 that increased drier loading gives lower air flows, higher temperatures and increased efficiency. The drying time passes through a minimum value of 60.5 hours at a loading of approximately 100 kg/m^2. Mixing would be difficult at this bed depth which is twice the recommended maximum of Wood (82). At higher loadings the drying was so slow as to risk danger of fungal contamination. In a subsequent trial Newton (54) tested a much larger drying floor of $74.3m^2$ with a view to measuring overall thermal efficiency at a greatly reduced drying air flow. The efficiency was significantly improved (see Table 3), but only at the expense of much increased drying times and off-flavours developed as a result of the slow drying. It was concluded that a fully flexible drying installation would require back-up heat in the form of a diesel air heater. An alternative system has been subsequently proposed (42) with a deep bed below an open tray. The beans are skin dried on this upper tray with whatever mixing is required and are then passed to the lower compartment for finishing, it being assumed that further mixing is not necessary. So far no information on the operation of such a system is available.

Another system which allows for the different behaviour during the constant and falling rate periods is described by Anselmi et al (6, 7). The most recent version of this installation (known as the Barico drier) has three drying floors; a shallow open bed of $37.2m^2$, and two closed containers each of $18.6m^2$. It has a wood fired furnace with a single large diameter heat exchange tube similar to the design used in the Samoan and secador tubular driers. This heat exchanger is used in conjunction with a fan capable of delivering 0.38 m/sec to the open bed or 0.76 m/sec to the containers. The operational sequence is to load the wet beans onto the open bed called the 'skin-drying platform' and to dry, with mixing, for 24 hours until the beans are skin dry. The cocoa is then moved to one of the containers where the bed depth is twice that previously utilised. Drying is completed in a further 48 hours. At any one stage the drier has one container of nearly dry beans,

TABLE 3: A REWORKING OF NEWTON'S RESULTS – DEEP BED, HIGH AIRFLOW WASTE HEAT DRYER

Run Number	Drier Area	Specific dry weight loading	Temperature Rise above Ambient	Air Flow in Cocoa*	Drying Time	Oil Consumed per tonne dry beans**	Overall Thermal Efficiency
	m^2	kg/m^2	°C	m/sec	h	m^3/tonne	Z%
9	20.1	41.30	2.5	–	99.5	0.810	8.5
10	20.1	61.61	3.6	0.78	89	0.609	11.2
6	20.1	96.02	4.1	0.66	60.5	0.355	19.2
4	20.1	134.16	4.4	0.56	94.25	0.287	23.8
8	20.1	141.04	6.4	0.40	88.23	0.282	24.2
3	20.1	250.70	10.2	0.27	139.5	0.238	30.2
–	74.3	75.21	4.1	0.177	132.75	0.160	42.8

* Estimate based upon manufacturers data and the specified temperature rise.

** Corrected to 6% m.c.

Source: (52) and (54)

the other container with cocoa of intermediate moisture content and the open bed filled with recently loaded cocoa. The drying air is blown successively through each of the cocoa beds in this sequence. This batch counter current type operation which allows the air to pass through the driest beans first and the wettest last should lead to highly efficient operation. Very little data has been presented with which to estimate the overall thermal efficiency of this system. Drying is apparently carried out at 50-60°C in the containers and at 40-50°C on the skin drying platform. The quoted fuel consumption of 'about half a ton of firewood' per ton of beans indicates an overall thermal efficiency of approximately 38.5%. Even allowing for the advantages to be gained from the depth of the bed used (effectively equal to the combined depth of the three layers of cocoa through which the air passes) this efficiency level seems high for the quoted air flow rates.

5.2.2. Platform Drying with Recirculation of the Drying Air

Recirculation of the spent drying air can be used as a means to increase overall thermal efficiency. In a companion work to that of Wood (82), Allison and Kenton (1) tested a similar, but larger drier with recirculation. A scheme was devised whereby the proportion of recycled air was increased throughout the drying period, during which time the drying air temperature rose to 70°C. The fan used had a free air delivery equivalent of 0.12 m/sec in the cocoa and production levels from 27.5-51.7 kg/m^2 were tested. Overall thermal efficiency values from between 25.4-46.3% and drying times between 20 and 23 hours were recorded.

Maravalhas (45) also studied recirculation and devised an operational scheme which resulted in a claimed fuel consumption equivalent to an overall thermal efficiency of approximately 40% at air temperatures rising to 80°C during the process. McDonald and Freire (50) used the same drier and the same operational sequence and obtained overall thermal efficiency values of between 24 and 40%. Similar drying rate curves as those for non-recirculation were obtained. Although it is clear that improved fuel economy can be achieved by the controlled application of recirculation of the drying air, in neither of the two cases described above was it proved that the proposed operation represented the optimum. A full assessment would be required to take account of both the increased capital cost and operational complexity which are inherent in the use of recirculation.

5.2.3. The Mechanically Mixed Circular Platform Drier

As mentioned in Section 3.1, there has been little success in the application of mechanical mixing to deep bed throughflow drying units. A frequent configuration is a circular platform or kiln with a pivoted shaft at the centre which has attached beams radiating from it just above the level of the cocoa. These beams support agitators projecting into the cocoa and when the unit is rotated about the central pivot, these agitators pass through the cocoa to mix it.

The earliest form of this drier, known as the Hoadley Kiln drier, was described by Hart (31) as consisting of a 10m diameter drying floor with 6 plough type agitators on each of 4 wooden support beams. Drying air flow was by means of a centrifugal fan. A wood fired heater permitted temperatures of up to 66°C and with loadings of 11.5-14.3 kg/m^2, drying could be completed in 30-36 hours. It should be noted that in spite of mechanical mixing, the loadings achieved were not particularly high. The idea of the circular drier was tried again by Buxo and Felipes (11) who described a unit which they termed the 'Activator' dryer which was a 4.5m^2 circular platform with plough type agitators on four rotating beams. Electrical heaters were used giving initial drying air temperatures in the range 49-54°C rising to 65°C later when recirculation was applied. The speed of rotation of the beams was not quoted, but mixing was inadequate in the early stages such that the layer of cocoa in contact with the drying floor was not moved at all and the beans in this layer became cemented together. Bean breakage was noted at later stages in the drying process. To overcome these problems a three stage drying process was developed. The beans were pre-dried to 35% (representing skin dry conditions) on a 3.9m^2 platform drier and then dried to 14% on the mechanically mixed unit before drying was completed on a platform drier. Some 580 kg of dry beans were produced in an overall period of 26-28 hours. It is evident that as a means of mechanical mixing the Activator unit was a failure and its retention in the proposed drying sequence must have been entirely for its capacity for polishing the beans. In fact later reference to this type of unit describes it as a polisher (77).

Gray and Hadley (29) describe a system almost identical to that of Buxo and Felipes (11) except that diesel was used as the energy source. The drying was at slightly higher temperatures than those adopted by Buxo and Felipes, and several rest periods were incorporated resulting in an overall drying time of 72 hours. Fuel consumption figures equivalent to an overall thermal efficiency of some 34% were quoted. In both cases it seems debatable whether the increased capital and operating costs compensate for a system whose only advantage is that of producing a polished end product.

The major problem with the Activator drier was the design of the plough type agitators. They tended to only separate the beans and not to lift and truly mix them, furthermore they could not be located sufficiently close to the floor of the drier without causing breakage to the lowest layer of beans every time they moved. A new version of this drier type, known as the Unidrier, has been developed in Malaysia (G.A.R. Wood, private communication). Instead of plough type agitators, the Unidrier has strips of polypropylene sheet inclined downwards and located near to the floor of the drier. As these rotate they tend to lift the beans away from the bottom of the bed giving true mixing without the danger of breakage. Instead of being driven through the central support shaft, the mixer beams are fixed to a large cog (the size of the drier outside diameter) to which the drive is applied (see Plate 6). There are three sizes of Unidrier, the largest of which is reportedly in operation at some 29 installations and is claimed to handle loadings of 171.2 kg/m^2. At such collosal bed depths 5 tonnes of dry beans are said to be produced in some 40-44 hours on a drier of 29.2m^2 (manufacturers data). Overall thermal efficiencies claimed for this drier when operated with an indirect diesel burner are 21.9-37.5%, rising to 32.8-52.5% with a direct fired unit. At the quoted bed depths these seem realistic figures.

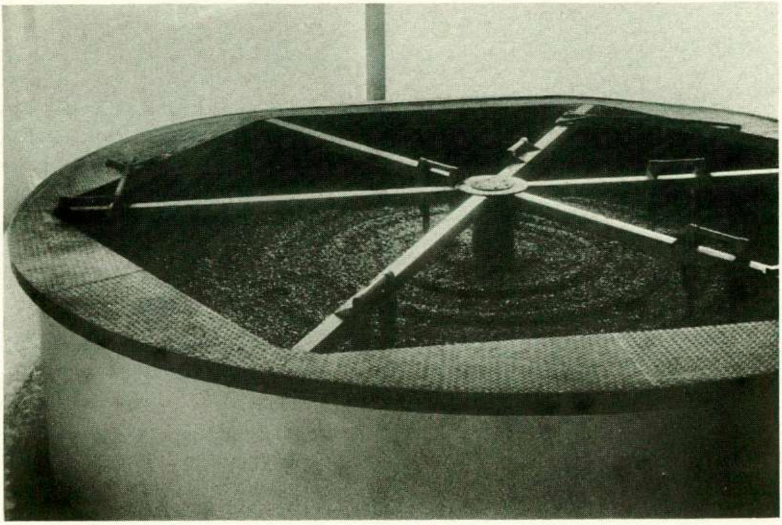

Plate 6 Unidrier (internal diameter 6.1m, capacity 5 tonnes) in use in Indonesia.

5.2.4. The Rotary Drier

The rotary drier is the oldest mechanical cocoa drier having been first patented in 1865 (31). The Gordon drier, for instance, has been in production since before 1900 and has been widely used throughout the world. Many other designs have been developed over the last century and several manufacturing companies still produce proprietary designs of a rotary drier (21). The rotary drier consists of two concentric, perforated horizontal cylinders of steel or wood. The inner cylinder acts as a plenum chamber distributing the heated drying air through the cocoa which is loaded into the annulus between the two cylinders (see Plate 7). When in operation the whole unit rotates very slowly giving a tumbling motion to the beans which prevents them sticking together at the initial stages and later gives a polishing effect, resulting in cocoa equal in appearance to the danced, sun-dried product. This drier can only be considered for larger plantations as it has a capacity in the range of 1.5-3.25 tonnes of dry beans (67, 72).

The comparatively low cross-sectional area of the plenum duct prevents good static pressure development and so airflow distribution problems are almost inevitable in driers of this design. In an attempt to ensure that sufficient drying air is available along the full length of larger driers, air inlets at both ends of the plenum duct have been tried (53). An auxiliary tube within the plenum duct to project a proportion of the drying air into the region of low air flow at its blind end has also been added (25). Nozzles have sometimes been fitted to the plenum duct (53) or a duct of star shaped cross-section can be used (25, 67) to improve the distribution of air within the bean mass.

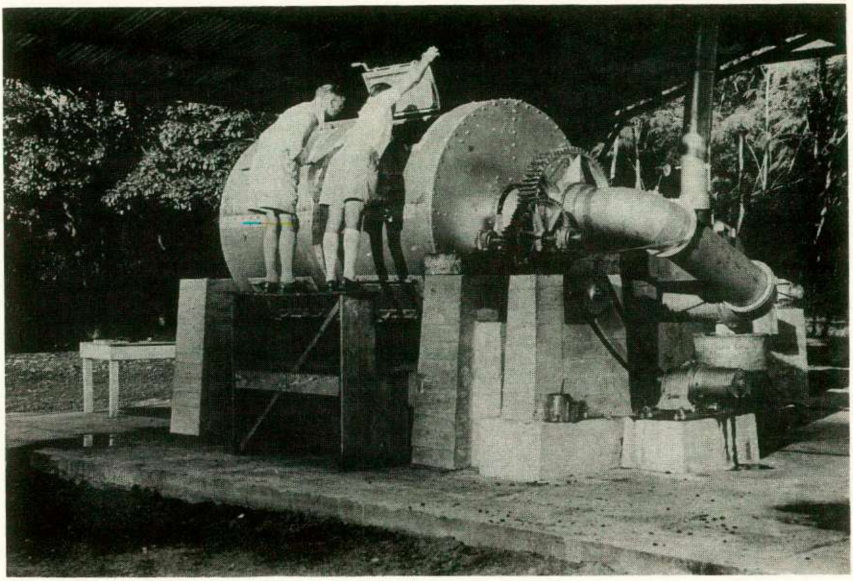

Plate 7 Rotary drier in Papua New Guinea.

A major complication of using a rotary drier for complete drying of cocoa is the effect of shrinkage of the beans during drying (see Section 2.0). This shrinkage reduces the level of the cocoa in the drier and as the beans are made to fall further, the mixing becomes ever more vigorous, eventually causing breakage. Furthermore, this shrinkage reduces the depth of cocoa in the upper part of the container and drying air passes preferentially in that direction to the detriment of drying over the major part of the drier circumference. For driers fitted with air distribution nozzles or star-shaped plenum ducts, shrinkage can expose these outlets and drying will cease altogether. The most usual way to avoid the shrinkage problem is to pre-dry in the sun and for many years this has been the accepted manner of using rotary units (31), but even so, significant breakage can occur if insufficient cocoa is loaded. Flights or baffles have sometimes been added but these have been found by some workers – notably Newton (53) – to be detrimental as they increased breakage of beans. High rotational speeds during the final stages of drying were also shown by Newton (53) to induce breakage and 0.25 rpm was regarded as the ideal. Salz (67) reported that drying of beans direct from the fermentation box with 4-6 hours operation at 4 rpm followed by 0.25 rpm until beans were dry, was a successful method. Another method of avoiding shrinkage and thus breakage, when drying direct from the fermentation box is to have a two compartment drier in which the cocoa can be transferred from one compartment to the other to maintain the level of drying beans (25). The transfer is ideally made in one move after 24 hours of operation and the air flow to the second compartment is shut off.

To allow their use during non-peak conditions rotary driers are often constructed with several compartments which can be operated independently, this obviating the need for a full load (21). However, they still remain comparatively inflexible. If insufficient cocoa is available and the drier is underloaded, breakage of the beans will result, while overloading of the drier will effectively prevent the mixing action and result in condensation and low overall thermal efficiency. Newton (53) found that the operation of a Bentall type rotary drier with perforations of 0.46 cm in both cylinders using freshly fermented beans quickly resulted in rapid clogging of the perforations. He concluded for this reason that a drier with these perforations was only suitable for pre-dried cocoa, though clogging could be avoided by using larger holes and he recommended diameters of 0.77-0.92 cm. However, Freire and McDonald (25) operated with holes of only 0.5 cm, drying cocoa direct from the fermentation box with no sign of clogging. De Vos (75) avoided clogging by washing the beans prior to drying and used a rotary unit with 0.8 by 0.8 cm perforations, operating at 10 rpm to skin dry the cocoa to eliminate the need for manual mixing over the period when this is most difficult.

Assuming the level of the cocoa to be adequately maintained and the mixing action to be effective, rotary driers should be extremely efficient. The bean bed depth is that of the radius of the cylinder, which can be as large as 0.9m and at such depths high overall thermal efficiencies should be possible, provided a sufficiently large air flow is applied to prevent condensation in the outer layers of beans. Only two authors give data on the overall thermal efficiency of rotary driers. Newton (53), working with an installation 2.4m long by 1.8m diameter produced up to 2.59 tonnes of dry beans in 48 hours of intermittent operation (representing approximately 20 hours of burner operation) after having pre-dried in the sun for 2 days to approximately 40% moisture. The overall thermal efficiency obtained varied from 11.2-26.3% with some indication that the higher loadings yielded the better efficiencies. Freire and McDonald (25) dried completely in a rotary drier with two compartments maintaining the level in the large compartment with cocoa from the small section. A wood fired furnace was used and when operating at 30 kg wood per hour, was capable of producing some 1.22 m^3/sec of air at 59°C (representing a combustion/heat exchange efficiency of approximately 40%). This enabled loads of approximately 1 tonne to be produced with a unit 2.0 m long by 1.7 m diameter rotating throughout at 0.25 rpm. Drying times of between 31.5 and 66 hours of continuous operation at 60°C resulted in overall thermal efficiencies of between 5.5 and 14.6% only. These values for overall thermal efficiency are low when compared with platform type driers and are especially unfavourable after considering the substantially higher capital cost of the rotary drier.

5.2.5. The Tunnel Drier

Tunnel driers consist of a long room into which a sequence of trollies with trays loaded with cocoa can be rolled. Once loaded, the drier is closed and sealed and heated air is blown from one end to the other flowing over the cocoa. The trolley nearest the drying air inlet is removed when the cocoa is dry and the remaining trollies are moved up making room for a trolley of wet cocoa at the opposite end. This is a semi-batch process with movement of the cocoa in countercurrent to that of the air. Shulte im Hofe (69) described the operation of tunnel driers in Fernando Po (now Equatorial Guinea) before the First World War. Heating was by a wood-fired furnace with a horizontal flue which ran the length of the tunnel. An interesting air flow system was employed with a water turbine driven fan and a spent drying air exit similar to a chimney which was intended as an aid to ventilation. Complete dryirg in two days was claimed. De Vos (75) used a tunnel drier for final drying only, having pre-dried the beans to 37% moisture on a rotary unit. Operating at 70°C with recirculation of the spent drying air and at a loading of 7 kg per 0.71 m^2, tray drying could be completed in between 8 and 11 hours. Overall thermal efficiencies have been derived and are 32% for the whole drying process using washed beans and 21% for the tunnel drying stage only.

5.2.6. Solar Forced Convection Driers

The energy crisis has resulted in ever increasing interest in the development of forced convection solar energy collectors, for heating air for crop drying, though such units have yet to be successfully applied to cocoa drying. The major problem of cocoa drying is that harvest often occurs during the rainy season. Solar collectors are at their least efficient during rain and the dependency of their performance on the vagaries of the weather makes them unsuitable for widespread use in an industrialised processing sequence of high value perishable cash crops such as cocoa. The most likely use of solar collectors will be as pre-heaters to existing forced convection installations to reduce operating costs (34).

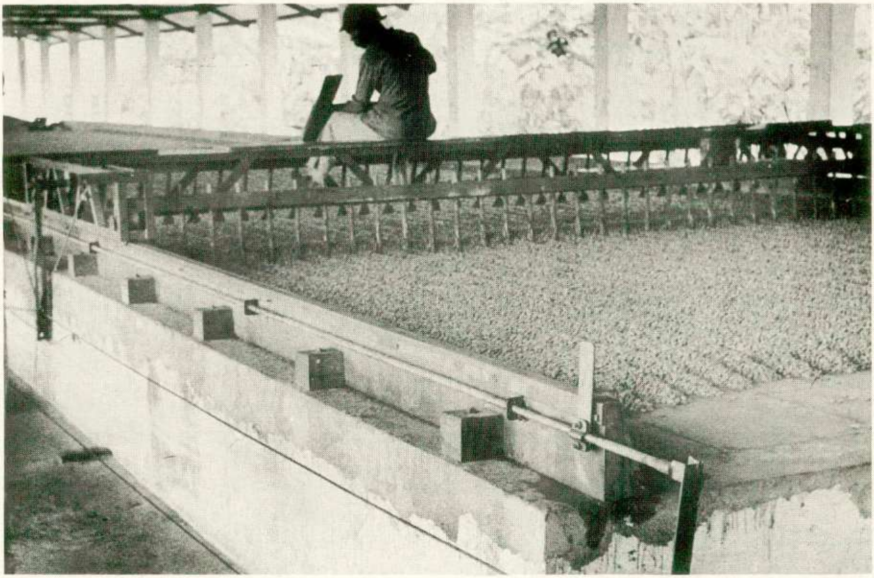

Plate 8 Conduction drier with slate bed in Equatorial Guinea.

5.3. Conduction Driers

All the natural convection driers described in section 5.1 relied to some extent on a conduction mechanism to transfer radiant heat received by the drying floor to the beans. Conduction driers have an unperforated solid floor under which the hot combustion gases pass and, as the name implies, heat transfer is entirely by conduction. The moisture released during drying is dispersed by wind or by natural convection above the beans. Driers of this type have been employed in Fernando Po (81) and San Tome (37) where slate has been used for the drying floor (see Plate 8). Drying is entirely confined to the lower bean layers and so shallow bed depths and continuous mixing are essential which inevitably means low production per unit area of drying floor and high man-power requirements. In this respect there are considerable similarities to barçaca drying. The production of 1 tonne of dry beans on a drier of 15.2 by 3.7m, with a loading of 18.1 kg/m^2 can be achieved in 3 to 4 days, but at a cost of 20 man days of labour (81). This labour cost can be reduced by mechanical mixing which has been successfully applied to this type of drier because it uses a shallow bed on a smooth drying floor. Continuous maintenance of the slate bed is necessary to avoid the formation of cracks through which smoke would inevitably pass and contaminate the crop. This type of drier is not in widespread use today.

6. SOME REFLECTIONS ON FUTURE RESEARCH ON COCOA DRYING TO HELP THE GROWER

The problems associated with cocoa drying can be considered under two headings – the quality of the end-product and the cost of the operation. With increasing energy costs, it is not surprising that operational efficiency represents the farmer's greatest preoccupation, especially in those areas with frequent rain during the harvest period. The solution (insofar as a solution is possible) lies in the correct choice of both drier type and energy source. In many cases too little thought goes into the selection of the drier and tradition often plays the dominant role. The wide range of operational efficiencies quoted in this review highlights the difficulty and emphasises the need for reliable information to enable selection and design of the most appropriate drier.

The choice of energy source has recently become of greater interest. At first sight the idea of enhanced solar drying would seem to have attractions in terms of operational economy, but it is unlikely to have a short term impact in those areas where the problems are the greatest – in the regions of high rainfall. In such areas an infrastructure of artificial driers already exists and the fuel source, in the majority of cases, is wood. The resources of wood are becoming rapidly exhausted and the future for this system of drying depends on the planting of wood fuel trees, either on farms or in strategically located centres. Such a programme should be initiated now, while a reserve of naturally occurring wood fuel still remains.

Research interest in end-product quality currently centres on the reduction of acidity which is, traditionally, a fermentation problem. Recent interest in forced ventilation of the fermentation stage points the way to future work in the cocoa processing field, with the engineer expanding his interests to embrace fermentation and the biochemist, studying drying. In this way the divergent views that have been apparent over recent years may be reconciled, with the elimination of the distinction between fermentation and drying – the two perhaps being known collectively once more as curing.

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Cocoa Abstracts

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Coconut intercropped with cocoa – BARRANT, C.I. Coconut Industry Board, Kingston, Jamaica – *Philippine Journal of Coconut Studies (Philippines)* v. 3(4) p 29-34 Dec 1978.

Three years after planting Malayan Dwarf coconuts at a density of 276 palms per ha. cacao was interplanted in single rows in the middle of the coconut interrows, at densities of 553, 830 and 1107 trees per ha. Five years later coconuts alone and coconut interplanted with highest densities of cacao produced 3.40 tonnes of copra per ha. at the lowest density of cacao interplanting 3.60 tonnes of copra per ha. whereas wet cacao yields increased with densities and were 580, 753 and 1019 kg per ha respectively. Indications are that the cacao at maximum production should increase the net return from the land by at least 50%.

Armillaria on cacao in Sao Tomé – RISHBETH J. University of Cambridge, Cambridge, U.K. – *Tropical Agriculture (Trinidad and Tobago)* v.57(2) p.155-165: Apr. 1980.

Sources of inoculum of Armillaria mellea causing a root disease in cacao are indicated. The fungus can spread up to 5 m/year in high rainfall areas. Mortality can be up to 9% but is usually much lower. Suitably situated trenches generally prevented further spread of the disease in cacao. Other possible control measures are indicated.

Resistance of clonal cocoa in Papua New Guinea to bark canker caused by Phytophthora palmivora (Butl. (Butl. – PRIOR, C; SITAPAI, E. University of Papua New Guinea, Port Moresby, Papua New Guinea – *Tropical Agriculture (Trinidad and Tobago)* v.57(2) p.167-169: Apr. 1980.

Sixteen clones of Trinitario cocoa were assessed twice for resistance to Phytophthora palmivora bark canker during 1977. Agreement between the two rankings based on these two assessments was statistically significant. The clones showed a very wide range in resistance.

(Productive capacity of the vertisols utilized for cacao in the "Recôncavo Bahiano") Capacidad productiva de los vertisols utilizados con cacao en Recôncavo de Bahia – SILVA, L.F. DA; PINHO, A.F.S. Divisão de Geociências, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil – *Revista Theobroma (Brazil)* v.9(1) p.3-12; Jan. 1979.

Under greenhouse conditions cacao seedlings grown on vertisols were superior to those grown on the, for cacao highly suitable, alfisols. In the field, however, results on vertisols were disappointing. This apparent contradiction may be explained by problems of soil management and temporary poor aeration, but also scarcity of pollinating insects.

(Microbiological activity in cocoa soils influenced by shade and fertilizers) Atividade microbiana em solos de cacaual sob a influência do sombreamento e adubação, – SANTOS, O.M. Divisão de Botânica. Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil – *Revista Theobroma (Brazil)* v.9(1) p.13-23; Jan. 1979.

Soil microbial activity in cacao soils as affected by shade and/or fertilizers was measured by means of CO_2 evolution and cellulose decomposition, at night and by day and at various depths. Soil respiration was higher at night than by day; cellulose decomposition was highest in the upper zones and related with a decline in nitrogen content in the subsoil, and unfertilized shaded plots showed the highest microbial activity.

Fermentation and organoleptic quality of cacao as affected by partial removal of pulp juices from the beans prior to curing – LOPEZ, A.S. Divisão de Bioengenharia, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil – *Revista Theobroma (Brazil)* v.9(1) p.25-37; Jan. 1979.

The partial removal of juice from the pulp of cacao beans has a negative effect on the quality of the chocolate probably because of the variations in the fermentation process which it introduces.

Ivory Coast continues to expand cocoa production – DULL, R.E.T. (Prep) Foreign Agricultural Service, USDA, Washington, D.C. USA – *Foreign Agriculture Circular (USA)* USDA-FCB 1-80, 6 p, Jan. 1980.

This paper gives a general description of the cacao industry in Ivory Coast where 863,000 ha were planted with this crop in 1977 of which 526,000 ha were in production, yielding 312,000 t in 1978/79.

The effect of soil moisture and of N, P and K on incidence of infection of cacao seedlings inoculated with Verticillium dahliae. – EMECHEBE, A.M. Plant Pathology Section, Ahmadu Bello Univ. Samaru, Zaria, Nigeria – *Plant and Soil (Netherlands)* v.54(1) p.143-147. 1980.

Incidence of infection of cacao was studied with plants grown in potted soil or in sand supplemented by nutrient solution. Incidence of infection increased with increase in soil moisture up to 60-70% saturation but it was not affected by the frequency of watering potted soil. Levels of N, P and K did not influence the incidence of infection of cacao by V.dahliae.

August 1980

Rat damage to agricultural crops – WILLIAMS, J.M. Research Div., Ministry of Agriculture and Fisheries, Christchurch, New Zealand – *Advisory Leaflet (SPC) South Pacific Commission (SPC) Noumea (New Caledonia)* no. 11, 6p 1979.

Three species of rat live in the Pacific Islands. The Polynesian rat (Rattus exulans), the roof or ship rat (Rattus rattus) and the Norway rat (Rattus norvegicus). All 3 species cause agricultural damage but the more extensive distribution of R.exulans and R.rattus results in these 2 being responsible for most crop damage in coconuts (Cocos nucifera), in cacao (Theobroma cacao) and some other crops, assessment of damage and control measures are discussed.

Nematodes associated with cacao: a review – SOSAMMA, V.K., KOSHY, P.K., SUNDARARAJU, P. Nematology Lab., Central Plantation Crops Research Inst , Kayangulam, Kerals, India – *Technical Document – Plant Protection Committee for the South East Asia and Pacific Region* (FAO) no.123 14 p 197?

A list of nematodes associated with cocoa and supporting references is presented.

The International Cocoa Market. Interview with U.K. HACKMAN, Executive Secretary of the ICCO, PIPER, I. – *Courier (EEC)* no. 61, p.72-74. May 1980.

In this interview the executive secretary of the International Cocoa Organisation explains why in his views the International Cocoa Agreement have remained largely unoperative.

The International Cocoa Organisation – ANON – *Courier (EEC)* No. 61, p.75; May 1980.

The article describes the establishment and operations of the International Cocoa Organisation.

The prospects for production and consumption 1980-1985 – ANON. – *Courier (EEC)* no. 61, p.80-81; May 1980.

World cocoa production in 1985 is estimated to be 1,872,000 tonnes (1978/1979: 1.5 m tonnes). World cocoa bean grindings are presumed to be a function of price levels and real income growth in consuming countries, and to be between 1,603,000 and 1,796,000 tonnes in 1985.

The economic importance of the cocoa tree in the ACP states and the different varieties grown – LIABEUF, J. – *Courier (EEC)* no. 61, p.86-87; May 1980.

This article briefly reviews the planting material (Criollo, Amazonian Forastero and Trinitario) used in the main cocoa producing countries in Africa, the Caribbean and the Pacific (– ACP).

Principal diseases of the cocoa tree – MULLER, R.A. ORSTOM, Paris, France – *Courier (EEC)* no. 61, p.87-89; May 1980.

This article gives a brief description of the most important diseases of cocoa, i.e. root rot (Basidiomycetes sp.), tracheomycosis (Calonectria rigiduscula, Verticillium dahliae), witches' broom disease (Marasmius perniciosus), swollen shoot (viral disease), monilia and black pod (Phytophthora palmivora).

Cocoa tree pests in ACP countries – LAVABRE, E.M. Institut Français du Café et du Cacao (IFCC), Paris, France – *Courier (EEC)* no. 61, p.90-91; May 1980.

This paper lists the most important cocoa pests and describes how chemical control was sometimes successful and sometimes a failure for which tree resistance and pest management may become an answer.

Cocoa production in five ACP states – ANON – *Courier (EEC)* no. 61, p.95-97; May 1980.

This paper summarises the findings of a study by the International Cocoa Organisation on the production of cocoa in Cameroon, Ghana, Ivory Coast, Nigeria and Papua New Guinea.

Branch formation in cocoa (Theobroma cacao L., Sterculiaceae) – WHEAT, D. Harvard Univ., Cambridge, Massachusetts, USA – *Turrialba (IICA)* v.29(4) p.275-284; Oct. 1979.

The 2 buds present in the leaf axils of cacao have different morphogenetic potential, but the distribution between 2 types of buds is not the source of the axis differentiation of the plant. A description is presented of the formation of orthotropic and plagiotropic branches. The distinction between plagiotropic and orthotropic branches is not due to their origin from different types of buds, nor to their origin by syllepsis or prolepsis.

Bidding for cocoa power – ANON – *West Africa (UK)* no. 3267, p.385, 387; 3 Mar 1980.

The chances of the success of Ivory Coast's withdrawal from the international cacao market are considered in the light of the storage problem as related to quality deterioration, the expansion of the Brazilian cacao industry, and the development of the cacao industry in Ivory Coast.

(Mechanisation of post-harvest treatment of cacao) Méchanisation du traitement après-récolte du cacao – FOMBELLE, C. de SECEMIA, Senlis, France – *Afrique Agriculture (France)* no. 56, p.42-44; 1 Apr 1980.

The cacao (Theobroma cacao) grower usually cleans the cacao beans from adherent slime by a local fermenting process, followed by drying of the beans. During this fermentation process the germ is killed. After fermentation the water content of the beans is 55-60% and must be reduced to 7.5% by drying in the sun. Since 1970, SATMACI (Company for Agricultural Mechanization in Ivory Coast) has developed units for mechanized fermentation and drying with a capacity of 1000-5000 t beans a year. A description of these units is given.

Record world cocoa bean harvest expected in 1979/80 – DULL, R.E.T. Foreign Agricultural Service, UDA, Washington, DC, USA – *Foreign Agriculture Circular. Cocoa (USA), USDA* – FCB 2-80, 22 p; Feb. 1980.

World cacao bean production (Theobroma cacao) for the 1979/80 (October-September) season is expected to approximate a record of 1.6 million tons, more than 7% greater than the preceding outturn. More favourable growing conditions in Ghana, Nigeria and Cameroon, together with new plantings coming into bearing in Brazil, Ivory Coast and Malaysia, are largely responsible for this bumper crop. Production data of major producers like Ghana (300,000 t), Ivory Coast (320-330,000 t), Brazil (exceeding 314,000 t), Ecuador (88,000 t) and Malaysia (30,000 t) are reviewed. Figures on imports of major customers like USA and USSR are discussed. Various tables on production of cacao beans in specified countries during the period 1974/1980, cacao bean grindings by specified countries and US trade in cacao beans and products during 1978 and 1979 are presented.

(Artificial drying of cocoa beans) Le séchage artificiel des fèves de cacao – JACQUET, M.; VINCENT, J.C.; HAHN, J.; LOTODE, R. Institut Français de Café et du Cacao (IFCC), Montpellier, France – *Café Cacao Thé (France)* v.24 (1) p.43-56; Jan. 1980.

In this study cacao (Theobroma cacao) bean drying curves were plotted under different artificial conditions. The properties of such beans were then compared with those of similar beans subjected to solar drying. It appeared that, in order to compare reasonably well with solar dried beans, artificial drying should maintain a temperature of 65 to 70C with a moderate air-flow of 0.4 to 0.5 m/s, to avoid 'caking' or 'crusting'.

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