EXPERIMENTAL EVALUATION OF MECHANICAL DEHYDRATION OF NIGERIAN COCOA BEANS

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SUMMARY
A serious problem encountered in commercial cocoa-bean processing is the mouldiness and sprouting which often occur during the "fermentation-sun drying" stages, especially during the rainy season (May-October). An alternative processing technique which employs a forced ventilation, and electrically heated, drying oven has been evaluated, and found suitable for eliminating the sun-drying problem. Several experimental studies and organoleptic tests, using "processed seeds" "unprocessed seeds" and "pod-fermented seeds" (as described in this report) have demonstrated the feasibility of producing acceptable commercial cocoa beans by this technique, at a temperature of about 50^{o}C. Total dehydration period. at 50^{o}C, was about 60 hours, and this could be further reduced to about 7 to 8 hours at higher temperatures (75° to 85°C). However the quality of the products produced at the higher temperatures is somewhat lower than that of 50^{0}C. The results indicate a need for further investigation of the fermentation process. dehydration at lower temperatures than 50°C, and the quantitative analysis of the theobromine content of the finished product. The conclusion was that the technique is a feasible proposition which deserves the further investigation and a cost-benefit analysis based on pilot-plant trials.

INTRODUCTION
In the Imo and Anambra States (ECS) of Nigeria, and perhaps elsewhere, a major problem encountered in commercial cocoa-seed processing is the loss of a large quantity of the product, through rejection by the Marketing Board, if the seeds have either sprouted or grown mouldy. The Marketing Board is a Federal Government establishment which is responsible for purchasing agricultural products from farmers, and for exporting them to foreign customers. Quite often an entire harvest is lost through this problem. Where the affected product is rejected outright, the farmer suffers considerable economic loss, to the tune of ₦450 per ton.

The problem arises mainly because the farmers depend entirely on fermentation and sun-drying of the seeds. Usually the fermentation process is improperly controlled, and in the rainy season (May to October) sun drying is virtually unreliable. The farmers are then forced by the wet weather to protect the already fermented and very damp seeds until the sun shines. During this period of protection (or drying in the shade), the seeds might develop moulds and many could germinate.

In view of the economic importance, to Nigeria of commercial cocoa-seeds, it was considered necessary to investigate the problem, and to attempt a solution which is based on any known technological advances. For instance, artificial drying of agricultural products, in ovens and such devices, is a well known practice in the temperate countries of the industrialised world. Thus, it would appear that artificial drying is the answer to the problem of unreliable sun shine. This technique has never been tried by cocoa farmers presumably because of the general absence of both rural electrification and mechanisation of the processing techniques. However, the picture is changing rapidly, with industrial development. Consequently, in this project several laboratory experiments have been carried out to evaluate the feasibility of producing acceptable commercial cocoa-beans, using an electrically heated oven which is assisted by a ventilator and a fan. The technique has been termed "mechanical dehydration" and this paper reports the laboratory studies and the results obtained.

Description of the Cocoa: (Theobroma Cacao L.) The cocoa fruits, or cocoa pods, used in the laboratory experiments were harvested from an orchard at Uzuakoli (a village in the Bende Division of the Imo State). A mature cocoa pod is about 15 to 20 cm. long, green in colour, and has the shape of a pointed vegetable marrow. It is attached directly to the trunk of its tree, and when ripe for harvest is either completely orange in colour or orange with streaks of green.

A cocoa pod contains about 40 to 50 seeds which are closely packed together and attached to a central fibrous stalk in the pod. Each individual seed is flattened-ovoid in shape and about 5 to 8 mm thick. Each seed has a shell about 1 mm thick which is covered by a succulent, extremely moist, colourless, mucilaginous pulp. This succulent pulp has a sweet taste.

The shell protects the edible kernel which consists mainly of two irregularly folded deep purple-coloured cotyledons. In the fresh and raw state, the cotyledons have an unbearably astringent and bitter taste; but when the seeds are fermented and dried, they taste mildly bitter with the characteristic chocolate flavour. The cotyledons can then be easily separated into small angular fragments.

Conventional Method of Processing by Farmers:
The processing technique adopted by cocoa farmers will be described briefly because of the part it played in the choice of a mechanical dehydration method:- The harvested cocoa pods are first broken open, then the seeds are separated and packed into air-tight, double-layer jute bags or boxes, in which they undergo a process of fermentation. After two to three days the bags are opened and the seeds stirred around with a

wooden batten, considerable heat and steam being generated thereby. (The author has measured a temperature of about 48°C inside the fermentation bags, during a demonstration of the process by a farmer).

Following the stirring operation, the seeds are repacked into the bags for a further period of four days' fermentation. Then they are spread out in the sun to dry, the succulent, mucilaginous pulp coating the shell of the seeds and thereby adding to its apparent thickness. With continuous dry and sunny weather it takes from six to ten days (depending on the intensity of the sun) to dry the seeds satisfactorily. If there are no mouldy or sprouted seed at this stage the dried product is then regarded as "Grade 1" commercial cocoa seeds, and could fetch the maximum market price. The kernel acquires a deep chocolate colour or chocolate brown.

With adverse weather (rainy season) and the improperly controlled fermentation, the seeds could sprout and grow mouldy. Then the dried product is classified as "grade II or III", depending on the degree of mouldiness and amount of sprouting. These grades are less valuable than grade I, and may be rejected outright by the cocoa Marketing Board.

Choice of Mechanical Dehydration Technique:
The work of previous investigators, and the observation of high temperature in the fermenting seeds, have thrown some light on the function of the fermentation process. It is well known that the kernel and the shell of cocoa seeds contain the alkaloid theobromine, which is responsible for the astringent and bitter taste of the raw kernel. The theobromine is toxic when present in quantities of about 2.0 gm. The kernel also contains traces of caffeine, of a volatile oil, and about half its weight of solid fat. Wadsworth (1) reported that the theobromine is brought into the shell from the kernel by the "heating" that occurs during the fermentation process. Thus, it would appear that one of the functions of the fermentation is to generate enough heat to drive the theobromine and other volatile matter from the kernel:- leaving the cotyledons with the mildly bitter taste and the characteristic flavour.

Woodman (2) confirmed the poisonous effects of theobromine: he reported that cocoa shells fed to some livestock killed the' animals by theobromine poisoning. Holmes (3) found that cocoa "residues" after extraction of the fat by a solvent, contained 2.6 to 3.2% of theobromine, Considering these findings, it would appear that any alternative process to the conventional fermentation must be such that enough heat is generated to drive the theobromine from the kernels, leaving the cotyledons with the same taste and flavour as the conventionally fermented products.

The answer to the problem of mouldiness lies in mechanical drying rather than sun-drying, since the latter is unreliable in the wet season. Consequent upon this reasoning, it was decided to employ an oven for the dehydration of the cocoa-seeds, thus eliminating sun-drying. Furthermore, if the temperature of the oven could be suitably controlled, it might be possible to select a temperature (or range of temperatures) at which the heat developed would be enough to drive off the theobromine and other objectionable matter from the kernel to the shell, leaving the cotyledons with the same properties as those of conventionally fermented seeds. In this way, the single oven could be used to achieve the same objective as with the conventional fermentation and sun drying. A laboratory electrical oven was therefore chosen for the studies.

Description of the Oven:
The oven was an electrically heated, forced ventilation, laboratory type. The internal dimensions were 61cm high, 51cm. wide and 46 cm. deep, with basket shelves. The door had a double glazed window, 25 cm. x 25 cm fitted to it for observing the condition of the oven contents.

The oven temperature was controlled by a direct reading solid state compensat (electronic controller) . An independent safety thermostat was also fitted to the oven to provide additional security of the oven content; and in the event of failure of the electronic controller,' the safety thermostat took over the maintainence of the oven temperature the take over being shown by an indicator lamp.

An adjustable ventilator in the top centre of the oven, when opened, allowed air to be drawn in by a fan mounted at the rear of the oven. The ventilator incorporated a clip to which a mercury- in-glass thermometer was placed A sheathed heating element surrounded the fan, and was shielded from the internal space of the oven by a baffle. The air which was drawn in from the ventilator flowed through the oven, and was recalculated to the top and bottom of the internal space by the fan. The fan convection gave a ventilation rate of 2000 litres per hour.

EXPERIMENTAL

Sample Treatment
It was considered that the presence of the succulent mucilaginous pulp would retard the rate of mass diffusivity of moisture and the volatile matter from the kernel, when the beans are placed in the hot oven. Besides, more heat-energy would be required to first dry the very moist pulp before the radiative and convective heat permeated into the kernel to initiate the mass diffusivity. Consequently, for a number of samples of the cocoa-beans, the succulent pulp was scraped off mechanically using fibre-brush and thoroughly washed with water. The clean beans then consisted merely of the shell and the kernel inside, the water on the shell being wiped off by means of sheets of blotting paper and tea-cloth. The samples were labelled "Processed Seeds".

In order to evaluate the influence of the succulent pulp on "drying time" etc. another group of samples was used in the experiments without the mechanical removal of the pulp. The samples were labelled "Unprocessed Seeds". A third group of samples was labelled "Pod-Fermented Seeds": a number of harvested pods was left on the laboratory bench for eight days during which time the seeds (in the .pods) underwent some fermentation. After this period, the pods were merely broken open and the seeds extracted and used in the experiment. It was observed that the pulp became mildly damp instead of very moist after, the dormant period of eight days in the pod. This treatment was an attempt to simulate the case where harvested pods might be left for some days before being broken open for dehydration. The 8-days were considered necessary because the conventional fermentation by cocoa farmers lasted about eight days.

Dehydration Procedure:

For the very first experiment within 24-hours of harvesting, the cocoa pods were broken open and the beans extracted, and treated as described earlier to obtain "processed seeds". After about 2 to 3 hours of the sample treatment batches of seeds whose initial weights (wet basis) had been pre-determined were spread, one seed-layer deep in wire-mesh drying trays of 12 cm x 20 cm. each. These initial weights were recorded as Wo(gramme).Each tray was then placed (on one of the basket shelves in the electrical oven which was previously set and controlled at a temperature of 50°C. with the fan convection adjusted to give a ventilation rate of 2000 litres per hour.

This oven temperature was selected because it approximated to that measured in the conventional fermentation process used by cocoa farmers. As drying progressed, the trays were removed periodically from the oven and the beans weighed, their weights being recorded as W_t (i.e. weight at time. t). In the early stages of drying the weights of the beans were determined every 30-min. but as the drying rate decreased the time between weightings was increased to 1-hour. Drying was continued until the beans stopped losing weight. For the initial experiment at 50°C, it took 2 to 2½ days to attain the constant weight of the drying beans.

The experiment was repeated at higher temperatures, up to a maximum of 85°C, and using various initial weights, W_o of samples of the "processed seeds" "Unprocessed seeds" and the "pod-fermental seeds". At the higher drying temperatures, it took from 6½ to 8 hours, (depending on sample treatment) for the beans to stop losing weight; thus a considerable saving in drying time was achieved.

For comparison, a sample of commercial "grade 1" cocoa beans was obtained from the cocoa farmer in whose orchards the experimental pods were harvested. The sample was taken' as "standard" against which a "test-panel" carried out an organoleptic evaluation of the flavour and taste of the experimental products. Samples of the experimental products and the "standard" were arbitrarily selected, shelled and given to a group of six people. They were asked to taste these, one after the other, and then rate the samples as astringent and very bitter, or bitter, or mildly bitter; with comments on other flavosrs and characteristics. The interest here was to relate any differences between the "standard" and the experimental samples to changes in the various types of 'sample treatment used, dehydration temperature, and theobromine effect on bitterness. Finally samples of the experimental beans were given .to the cocoa Marketing Board, Umuahia, to assess customer acceptability.

ANALYSIS OF RESULTS

Organoleptic Quality

The group's general reaction to all of the samples was very favourable. All kernels were said to possess mildly bitter taste. However, three members of the panel identified the standard sample as having a slightly more pleasant and characteristic flavour, followed by the pod-fermented seeds which were dehydrated at 50°C. The third sample selected in order of preference, was those dehydrated also at 50°C (processed and un-processed). The flavour of other samples (dehydrated above 50°C), though good, was said to linger longer in the mouth, those subjected to 85°C dehydration temperature being described as having a "toast" aroma.

Furthermore, the cotyledons of the standard samples were said to be of deeper chocolate colour than the experimental beans whose colour varied from light purple (at 85°C) to light chocolate brown (at 50°C) for the pod-fermented and others. However, all the mechanically dehydrated samples sent to the Marketing Board were described as "Super" grade 1 cocoa beans. The physical appearance of the unshelled experimental beans was said to be superior to the conventional grade I beans (see Fig.1).

Drying Curves:

The typical drying curves (weight vs time) for four samples at different dehydration temperatures are shown in Figure 2, and those for pod-fermented samples in Figure 3. The initial weight, Woo of each sample was confirmed by first plotting the weight, W_t. obtained at time, t, during the early part of the dehydration, and extrapolating back to t=0. The value, w_o found in this manner agreed very well with that obtained by direct weighing of the wet sample. The dry weight, w_f, of a sample was taken as the-weight at which the sample stopped losing weight during the oven dehydration experiment. For all samples studied, the dry weight was achieved within 6½ to 8 hours, except those at 50° where the dry weight took 2 to 2.5 days to attain.

To compare the effect of temperature on the amount of moisture and volatile matter lost by each sample it was necessary to compute the expression, $\frac{w_o - w_f}{w_o}$ (expressed as a percentage). The comparison and the variation of this expression with drying time are shown in Figure 4. The slope of the drying curve, within two hours of placing the samples in the oven, gave the initial "dehydration rate" (gm/hr.); and the difference between W_o and the dry weight w_f was taken as the "dehydrated Moisture" (expressed as percentage of W_o). All these parameters are collected together in Table I. showing the "dehydration properties" of the samples.

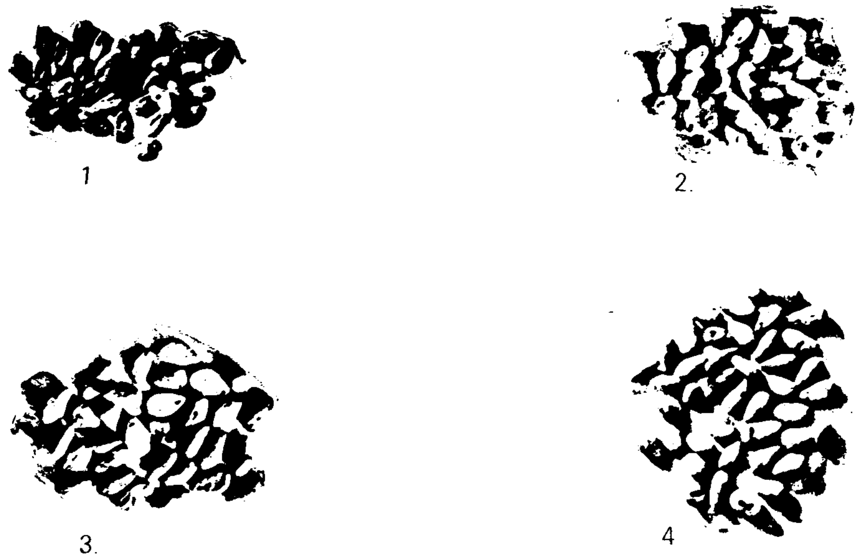

FIG. I: PHYSICAL APPEARANCE OF COCOA BEANS

1 — "Standard" grade I
2 — "Unprocessed" beans
3 — Pod—fermented beans
4 — "Processed" beans

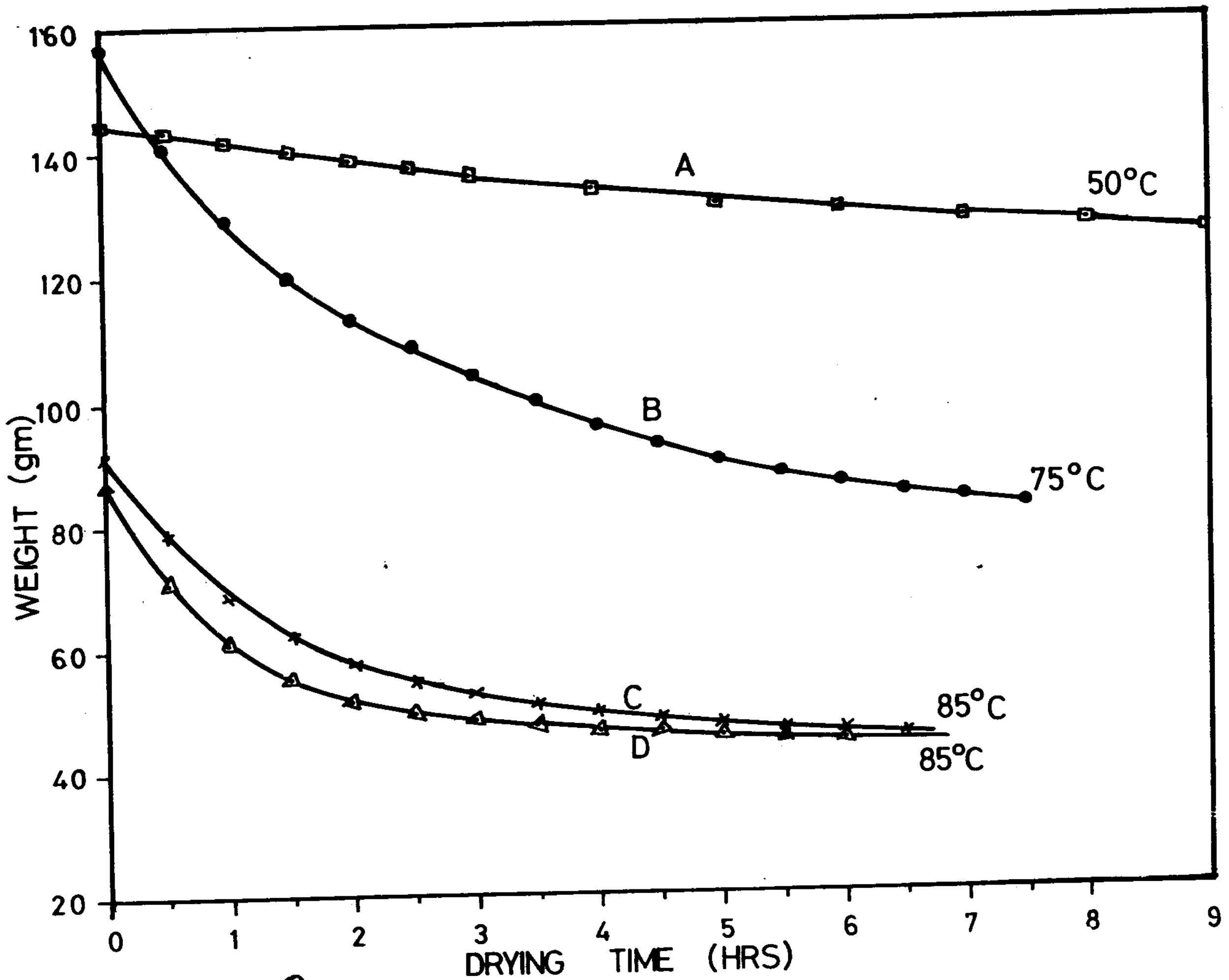

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FIG. I: DRYING CURVE AT VARIOUS TEMPERATURES

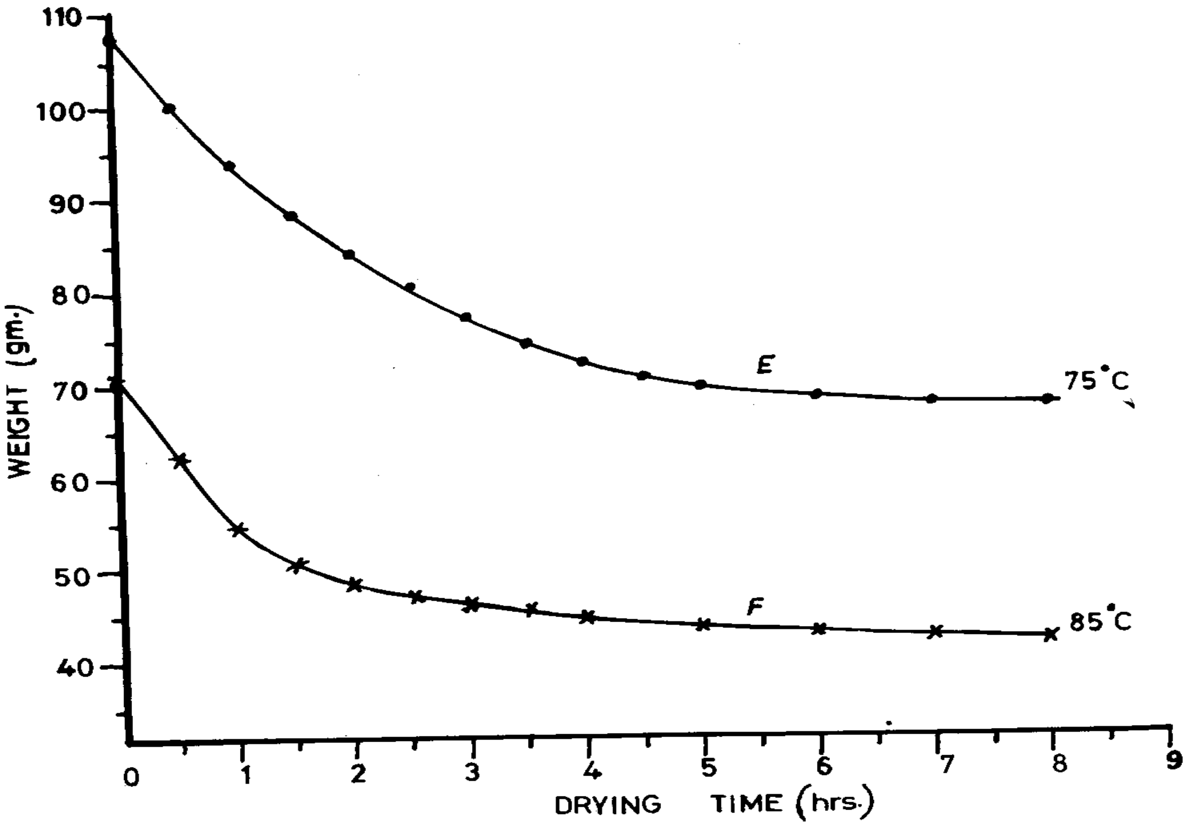

FIG. 3: DRYING CURVE FOR POD-FERMENTED SEEDS.

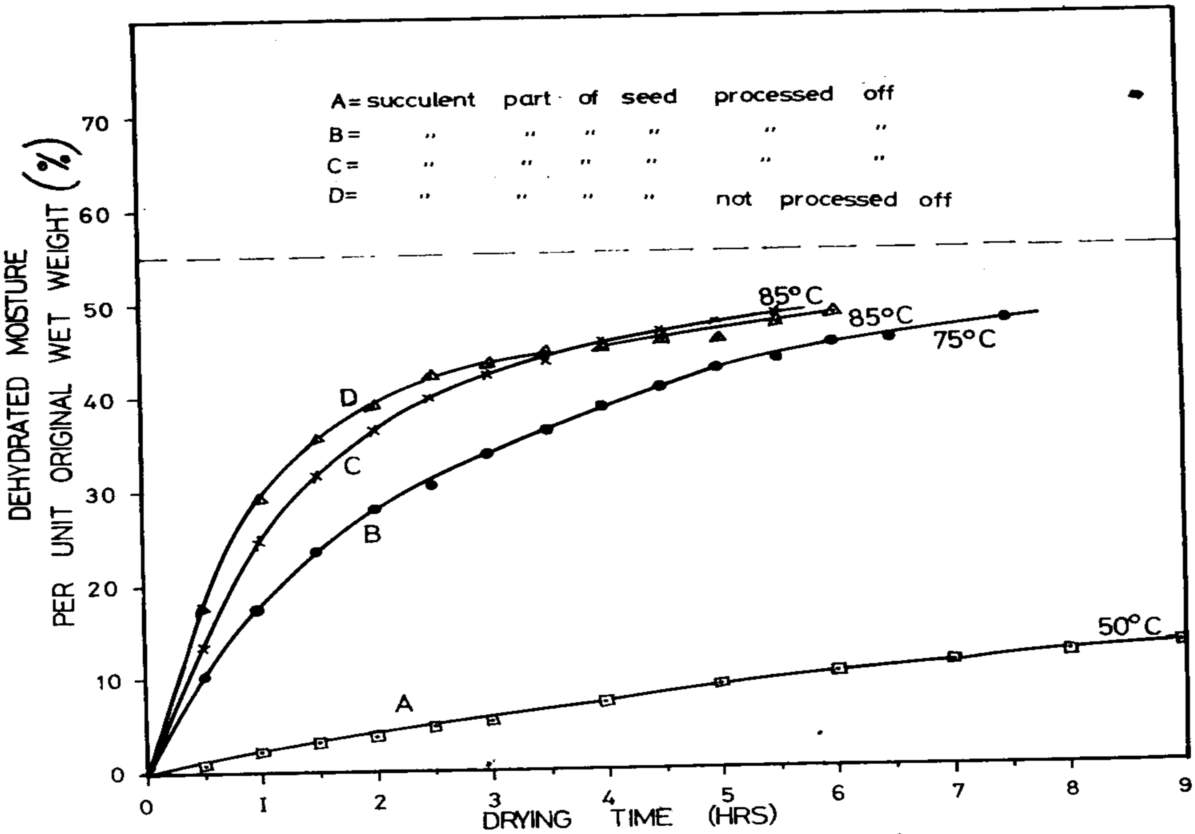

FIG. 4: COMPARISON OF MOISTURE RATIO, $MR = (W_0 - W_T / W_0) \times 100\%$

SAMPLE CODE	SAMPLE CONDITION	OVEN TEMP. (°C)	INITIAL WEIGHT W_0 (gm)	DRY WEIGHT (gm)	D_f (%)	INITIAL DEHYDRATION RATE (gm/hr.)	DEHYDRATED MOISTURE (%) WET BASIS	DRYING TIME (hrs.)
A_1	Processed	50	145.0	120.0	82.8	3.04	17.2	60
A_2	Unprocessed	50	140.1	113.1	80.7	9.3	19.3	60
B	Processed	75	157.2	83.2	53.0	29.1	47.0	7.5
C	Processed	85	91.5	46.2	51.5	23.8	49.5	6.5
D	Unprocessed	85	86.4	44.5	56.5	29.5	43.5	6.5
G	Unprocessed: 4–days Pod Fermentation	50	86.6	73.6	85.0	3.7	15.0	63.5
E	Unprocessed: 8–days Pod Fermentation	75	107.5	67.8	63.2	13.1	36.8	8.0
F	Unprocessed: 4–days Pod Fermentation	85	71.2	42.5	59.7	17.6	40.3	8.0

TABLE I: DEHYDRATED PROPERTIES OF COCOA BEANS

DISCUSSION AND CONCLUSION

From the comments of the test-panel, and the Marketing Board, it would appear that acceptable commercial cocoa beans could be produced by the mechanical dehydration technique. However, the fact that at 50°C dehydration the "pod-fermented" samples had the nearest qualities to those of the "standard" suggests that some fermentation is necessary for optimum results.

Furthermore, from "column 6" of Table 1 it may be seen that the dry weight of the cocoa beans (expressed as a percentage of the initial wet weight) was highest at the dehydration temperature of 50°C, for the "processed", "unprocessed", and the "pod-fermented" beans (i.e. Sample codes A1, A2 and G). At higher temperatures (above 50°C), the dry weight (%) was very much reduced. Since the cocoa beans are sold by weight, it follows that the farmer stands to lose if the dehydration, temperature is high. It may also be seen that the highest dry weight (85 %) was obtained for sample G. Thus it appears, from the trend in column 6, that both fermentation and low dehydration temperature are necessary. Probably, the percentage of the dry weight could be further increased if the temperature of the pod-fermented beans was lower than 50°C. This assumption was not investigated because the supply of cocoa pods was insufficient when the trend was observed.

The percentage dehydrated moisture (column 8 of Table I) could be used to calculate the dry weight to be expected from a given initial wet weight of harvested cocoa 'beans, for a chosen dehydration temperature. For instance if a farmer harvests ten tons of raw cocoa beans and decides to dehydrate them at 50°C after 4-days pod fermentation (i.e. sample G. Table I), then he could estimate that 15 percent of this weight would be dehydrated moisture. Thus the expected dry weight would be 8.5 tons, (using the expression $\frac{w_o - w_f}{w_o}$=15 %). Therefore he could budget for his expected revenue. It may be seen also that the dehydrated moisture increased with increasing temperature and as would be expected it was more for the unprocessed seeds than for the "processed" seeds, using the same dehydration temperature. However, in this regard sample code "D" appears spurious, with a dehydrated moisture of 43.5 % instead of a higher value than 49.5%.

The drying curves (figs 3 & 4) show that about the first 2½ hours of the dehydration period were used mainly in drying the external moisture on the beans (i.e. moisture on the shell. and in the succulent pulp if unprocessed). Thereafter the diffusivity of the moisture and other volatile matter in the kernels began to predominate, at a slower rate than the external moisture. Eventually, the total drying time both for the "processed" and "unprocessed" beans became virtually the same (6½ -7½ hours) at 75^0-85^0C. Thus it appears that very little is achieved by first "processing" the fresh beans. The same phenomena were obtained with the unprocessed, pod fermented beans (Fig. III), except that the total drying time increased to about 8-hours. At the lower temperature of 50^0C, the total drying time was about 60 hours. Since the initial dehydration rate (column 7, Table I) is higher at high temperatures, during the first 2½ hours of drying, it might be possible to reduce the total drying time by first starting off with a high oven temperature for about 2½ hours, and then reducing it to about 50°C. In this way, the external moisture would be got rid of rapidly, and the lower temperature could then affect the kernel moisture. The plots in Figs. II and III are curved initially and approach straight lines at the later stages of dehydration, thus indicating a diffusion process for the internal moisture.

Since Nigerian cocoa pods are harvested twice a year, both in the wet and dry seasons, this evaluation has shown that mechanical dehydration is a feasible proposition which is applicable in all seasons. However, there is need for further study, along two lines of approach, before the commercial utilisation of the technique can be advocated. Firstly, there is need to establish how best to control the fermentation process for optimum-quality beans, the lowest dehydration temperature (or range of temperatures) for the highest percentage of dry-weight recovery, and the quantitative analysis of the theobromine content of the resultant finished product. Secondly, there is need to evaluate the economic advantages of the technique over the conventional processing methods. This might involve the use of pilot plants the ovens of which may be fired by solid fuel (coal), or electricity or liquid fuel (oil). Thus, running costs can be compared. The first of these further studies is now in progress, and the results will be published in due course.

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