

Some Quality Characteristics of Solar-Dried Cocoa Beans in St Lucia

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Abstract: A field comparison of solar drying and open-air sun-drying of cocoa (*Theobroma cocoa* L) beans was carried out in St Lucia. Four methods of drying (indirect solar drier, direct solar drier, open air/perforated steel surface and open air/non-perforated wooden surface) were examined at three loading rates: 13.7, 26.9 and 40.4 kg m⁻². Beans from the open air had a higher incidence of external mould and poorer external appearance, though differences were minor. Beans dried at the lower rate of 13 kg m⁻² showed the best colour, but the highest titratable acidity. Conversely, beans dried at the higher loading rate of 40.4 kg m⁻² showed significantly lower titratable acidity, but poorer colour. Differences in cut-test score, colour, pH and titratable acidity between the open air and closed driers were small or not significant. While not significant, the indirect drier did show the highest cut-test score and the direct drier the poorest. Beans from the indirect drier were darker and more purple, while those from the direct drier were lighter coloured and less purple. The beans from the direct drier, dried to 6% moisture (WB) were, though not significantly so, more brittle and higher in titratable acidity than those from either the open air or indirect drier. Overall the beans from the indirect drier showed the highest quality and those from the direct drier the poorest. Whether the modest improvement of the indirect drier over the open air driers is sufficient to warrant investment in such a drier is unclear. © 1998 SCI.

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INTRODUCTION

The challenge of cocoa drying has been one of using available sources of energy efficiently to reduce moisture to safe storage levels, while producing beans of acceptable quality. Sun-drying, if done properly, produces the best quality beans (Crespo 1985). This method however is inefficient and produces beans of inconsistent quality when drying conditions are unfavourable, and under

conditions in St Lucia where a large number of small farms make a significant contribution to output.

A large number of reports have referred to the high acidity and poor flavour development of artificially dried beans compared to sun-dried beans with similar levels of fermentation (Shelton 1967; Jinap *et al* 1994). Quesnel and Jugmohunsingh (1970) examined the effect of high temperature on browning reactions during cocoa processing. They concluded that these flavour development reactions are enzymatic and are inhibited at drying temperatures beyond 60°C. Furthermore, it appears that rapid moisture loss inhibits the enzymatic breakdown of acids (Liau 1978). Acidity of cocoa liquor, as measured by pH, has been correlated to acidity

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scores obtained from parallel taste tests (Baigrie and Rumbelow 1987).

Artificially dried beans are described as brittle and are said to lack lustre (Urquhart 1961) due to the high drying temperatures. The broken beans which result present problems during roasting (Urquhart 1961) and in storage are more liable to be attacked by insect pests (Wadsworth 1955).

Jinap *et al* (1994) found beans air blown for 72 h and subsequently dried in an oven at 60°C were of comparable quality to sun-dried beans. Both of these were of better quality than beans oven dried at 60°C. Low-cost solar drying has the potential of enhancing drying rate without causing problems associated with drying at high temperatures.

The drying efficiency of solar and sun-dried cocoa beans was investigated. A direct and an indirect solar drier were both equipped with perforated steel trays while open-air sun-drying was carried out on perforated steel and solid wooden trays. Beans were dried at loading rates of 13.5, 26.9 and 40.4 kg m⁻². Quality assessments were made to determine whether there were any associated improvements or deterioration in quality. Mouldiness, acidity, brittleness and internal colour were assessed and are reported. The performance of the driers was reported by Bonaparte (1996).

EXPERIMENTAL

The beans were of a mixed variety and were supplied, after fermentation, by Union Vale Estates located on the west coast of the island. The beans were fermented over 8 days in deep wooden boxes measuring 66 cm × 91.5 cm × 122 cm and turned by transferring to adjacent boxes. These transfers, and hence mixing of the beans, were done on the second and fourth day, and every 24 h subsequently to the end of fermentation. By then the beans were about 48% moisture (WB).

Four drying units were constructed for this study. Two of these units were cabinet-type solar driers and the other two for open-air sun-drying. They were all built with a 50 mm × 50 mm wooden frame and plywood, using local labour.

One solar drier was indirectly heated by a flat plate collector with the cocoa drying beans completely sheltered from the sun's rays. The 1.355 m × 0.705 m × 1.66 m drying chamber was comprised of two shelves, one above the other, each holding two adjacent trays (0.6 × 0.6 m each). The top of this chamber was fitted with a wind-assisted ventilator. The collector measured 1.955 m × 1.195 m × 0.23 m with a fibre-glass glazing on the top and along the sides. The glazing was a shatterproof, glass-fibre-reinforced polymer (Sun-Lite® HP, Solar Components Corporation, Manchester, UK). Manufacturers claim 85–90%

solar transmission, including most of the infrared and visible region, excellent UV resistance and less than 10% loss of transmissivity in 15–20 years. Temperature of the collector surface as measured by a thermocouple was too unreliable for efficiency calculations to be made.

The absorber was a 1.09 m × 1.905 m black-painted, flat sheet galvanised steel, fastened to the floor of the collector which was tilted at an angle of 20°. The ratio of absorber surface to drier cross-sectional area, important in maximising performance, was not specifically studied in designing the drier. The size of the collector and the angle of inclination were not selected on the basis of potential heat requirement, but rather with respect to the cost of sheet metal, an important consideration for the small farmer. The base of the collector was insulated with fibreglass foam (*R* value = 6.5). Ambient air entered the collector through a 12.5 m square mesh and rose to enter the 405 m high plenum beneath the first shelf by natural convection.

The second unit was a direct drier with cocoa beans exposed to the sun's rays. It was comprised of a single level chamber with a fibreglass glazing roof tilted at an angle of 20°. Two movable drying trays formed the bottom of the drier and completed the drying chamber. While there were no ventilation holes, irregularities in construction allowed for some small (1–2 mm) gaps between the lid and the frame. Trays used in the driers had perforated steel bases, allowing some ventilation through the tray itself.

The third and fourth units, used for open-air sun-drying, were comprised of the same frame as the direct drier in terms of size and elevation, but with open top and sides. The frame allowed covering of the beans in bad weather and at night. Two types of drying trays were both built of a wooden frame measuring 0.6 m × 0.6 m × 0.1 m, with perforated stainless-steel and non-perforated wood bases. The latter simulated traditional farm conditions where beans are dried on wooden platforms or wooden trays.

Seven batches of fermented beans were dried by four methods (Table 1) and three loading rates: 13.5, 26.9 and 40.4 kg m². Trays of beans were exposed to sunlight from about 7 am to 5 pm daily and all trays were hand stirred about every 3 h. Drying of each batch was continued for 6–12 days.

Physical quality assessment

A modified cut-test known as the Cut Test Score method (Shamsuddin and Dimick 1986; Ilangantileke *et al* 1991) was used in this study. One hundred beans were cut lengthwise to expose maximum cotyledon surface and the colour assessed as fully brown, 3/4 brown, half purple/half brown, 3/4 purple, fully purple, or slaty. Scores of 6, 5, 4, 3, 2 and 1 were allotted to the

TABLE 1

Cut-test score, colour comparison, pH and titratable acidity of cocoa beans dried in different solar driers at different loading rates

Factor	Cut-test score	Hunter colour measurement			pH	Titratable acidity (meq(NaOH) per 100 g)
		L	a	b		
<i>Solar drier</i>						
Indirect	590.3a ^a	32.05c	15.65a	14.33b	4.81a	22.38a
Direct	576.8a	33.93a	14.64c	14.66ab	4.78a	23.03a
Open air, solid bottom	580.3a	33.06b	14.97b	15.14a	4.89a	20.72a
Open air, perforated steel bottom	579.6a	32.25c	14.91bc	13.56c	4.90a	21.58a
<i>Loading rate (kg m⁻²)</i>						
13.5	— ^b	31.29b	14.91b	13.77b	4.62a	23.31a
26.9	—	33.81a	15.30a	15.32a	4.78a	23.05a
40.4	—	33.37a	14.90b	14.17b	5.10a	18.59b

^a For drier type and for loading rate, values sharing a letter columnwise are not significantly different ($\alpha = 0.01$) based on Duncan's multiple range test.

^b Not measured.

respective colour categories. The number of beans in each category was multiplied by the category score to obtain the cut-test score for the particular drying treatment. The cut-test scores indicated the level of browning of the beans and the degree of fermentation. During the cut-test, which was done in normal daylight, the beans were checked for internal moulding and insect infestation.

In addition, Hunter *L-a-b* colour values (Hunter 1948) of the ground beans were measured with a Minolta CR-300 tristimulus colorimeter (8 mm aperture) as suggested by Francis (1991). The values of *L* (lightness; 0 = black, 100 = white), *a* (green = -100 to red = +100) and *b* (blue = -100 to yellow = +100) create a colourspace in which any colour can be described. Preliminary results indicated that samples of 20–25 beans adequately represented the average *L-a-b* values of a batch of beans from this experiment.

The instrument was calibrated using a standard white tile and nibs from eight beans within the range of colours present. For the comparisons, each of 30 beans from a random sample was shelled, grounded and passed through no 48 sieve. The *L-a-b* colour was measured with illuminant C as the light source. Colour measurement for two batches of beans from each drying method was used for the comparisons. Bleached beans were excluded from both the cut-test and colour meter assessment.

A subjective visual assessment was made of the external mouldiness of the beans.

Crushing strength indicated whether beans dried at the higher temperature of the solar dried were more susceptible to being crushed than beans dried under ambient conditions. The beans were tested at final moisture content. The bean samples from each method of

drying were taken randomly. From those samples, beans between 22 mm and 24 mm in length were taken. Beans were compressed at the natural moisture level of (6%). In addition, beans from the driers were rewetted to 8% moisture (WB) and at 16% (WB) to determine whether moisture levels made significant difference.

The compression tests were carried out using an Instron Universal Testing Machine modified model 5402. The beans were compressed along the long axis until the shell cracked. When the bean shell breaks under loading, the cotyledon falls apart.

Chemical assessments

Chemical assessment was restricted to the determination of pH and titratable acidity. About 100 beans were shelled and the nibs were finely ground. Ten grams of ground nibs were immediately blended in 100 ml of distilled water for about 2 min. The blended liquid was made up to 200 ml in a flask and stirred every 5 min for at least half an hour. The suspension was then filtered under vacuum through Whatman no 4 filter paper. Three 25 ml aliquots were used for pH determination. On those same samples the titratable acidity was assessed against 0.01 M sodium hydroxide solution and titrated to pH of 8 (Jinap *et al* 1994) using a Fisher Accumet® Selective Ion Analyzer model pH meter. The above procedure was performed in duplicate. The chemical analyses were conducted after all drying was completed.

The pH and titratable acidity data were analysed using the SAS® statistical package. Visual colour by the cut-test score and the shell strength of the beans were analysed using a simple comparison of means as

beans were lumped together for assessment according to drying method. Depth of loading was not considered. The colorimetric measurements were analysed by simple comparison of means.

RESULTS

External appearance

The external appearance of beans dried in the solar driers was excellent compared to that dried in the open sun. Beans dried in the solar driers had few signs of external moulding. At 13.7 kg m^{-2} there was no discernible difference in the external appearance of beans dried by the four methods and no signs of external mould. At 26.9 kg m^{-2} there were no obvious differences between beans from the two solar driers. At the two higher loading rates, 26.9 kg m^{-2} and 40.4 kg m^{-2} , differences between the two sun-drying treatments were variable from one run to the next. Overall, the level of moulding in the experiment was very low and beans from the indirect drier did not require polishing for mould removal. The sun-dried beans, especially those dried on the wooden surface, would have benefited more from polishing.

Surface moulding is a function of very high humidity and low air movement. Fitting the indirect drier with a ventilator resulted in obvious decline in visible surface mould in trial runs. The trays with perforated bases produced beans with less surface moulds compared to solid surfaces under similar drying conditions at high loads.

Internal colour and cut-test

Mean cut-test scores for the drying methods ranged from 576.8 to 590.3 (Table 1). These scores indicate a high proportion of fully brown beans in the samples from all the drying treatments. The cut-test score revealed no statistical differences amongst the drying methods (Table 1). However, the indirect drier showed the highest score and the direct drier the lowest.

Shamsuddin and Dimick (1986) used the cut-test score to assess the degree of fermentation and hence the flavour potential of the beans. Thus, the very high test score observed is a reflection of the high degree of fermentation attributed to the long period (8 days) of fermentation.

The beans showed no signs of insect infestation or insect damage, and negligible levels of internal moulding. The few beans with signs of internal mould indicated an association with pre-fermentation defects and their mouldiness may have occurred before drying. Hence, the rates of drying were sufficiently rapid to prevent internal moulding. Beans from the indirect drier

and open-air perforated steel bottom driers were the lightest, and those from the direct drier the darkest (Table 1). Beans with high (lightest) *L*-values were also low in both the desirable purple and brown pigments. The beans from the direct drier showed the lowest *a* (least red) value and was among the highest *b* (least blue) values, thus having the least of the desirable purple pigments. The indirect drier, on the other hand, had the highest *a* value and a slightly lower, though not significantly so, *b* value. Purple pigments were more obvious and increasingly masked the brown pigments as *b* values decreased below 10 on the colour meter.

With regards to loading rate, the beans from the 13.5 kg m^{-2} loading rate were significantly darker than those from the two higher loading rates (Table 1). This loading rate showed a low *a* value and the lowest *b* value. Thus overall, the lower loading rate resulted in higher quality in terms of colour (high *L*, low *b*), although the *a* value was not highest.

Compression tests

For all drying methods, there were differences in the energy to yield due to variation in moisture content. At 6% moisture, beans were relatively brittle and both shells and nibs yield relatively early compared to beans at a higher moisture content (Table 2). At 8% and 16.1% moisture (WB) there is some deformation of the nib before the shell yields, while the drier beans at 6% (WB) undergo brittle fracture. The energy to yield was statistically higher at 8% and 16.1%, compared to 6%. Thus, the ability of the beans to withstand loading increases with moisture content at least at the moisture levels examined in this experiment.

The energy levels at which the cocoa bean shells break were statistically similar for the different drying methods, though those from the direct drier tended to be weaker (Table 2). Capacity to withstand loading was

TABLE 2
Comparison of energy (J) requirements for bean failure under compression^a

Drier	Bean moisture content (WB)		
	6%	8%	16%
Open air, combined	0.1272a	0.775	NA
Direct	0.0713a	0.785	NA
Indirect	0.1459aB	0.584A	0.785A

^a For beans with 6% moisture content, values sharing a lower case letter are not significantly different ($\alpha = 0.05$) based on Duncan's multiple range test. For beans dried in the indirect dryer, values sharing an upper case letter are not significantly different ($\alpha = 0.01$) based on Duncan's multiple range test.

related to moisture content rather than methods of drying. Below 6% moisture (WB), beans were brittle and the shells cracked relatively early upon application of force. Thus, leaving beans in the drier after they have been reduced to safe moisture levels, a practice which is very likely in a small farmer context, may result in increased brittleness.

Titrateable acidity and pH

The pH of dried beans ranged from 4.6 to 5.6, but showed no significant differences ($\alpha = 0.05$) with either drier type or loading rates. pH values above 5.0, however, were recorded for the treatments in a single drying run only. In general, beans dried by the solar and sun-drying methods were acidic by commercial standards and had a distinct acidic odour during the cut-test.

Titrateable acidity (TA) varied from 20.4 to 26.9 meq(NaOH) per 100 g of ground nibs at the lowest loading rate and 17.98 to 29.09 meq per 100 g at 26.7 kg m⁻² loading rate. At 40.4 kg m⁻² loading rate, titrateable acidity varied from 12.6 to 25.53 meq per 100 g of ground nibs. Drying methods showed no significant differences in titrateable acidity but differences due to higher loading rates existed. There were no differences between 13.7 and 26.9 kg m⁻², but across drying methods, loading rates of 40.4 kg m⁻² gave statistically lower levels of titrated acids than the lower loads examined (Table 1).

High loading rates were expected to slow down drying especially in the early stages and therefore allowed the pH to rise. Shade, and hence slow initial drying rate, has been shown to produce beans of higher pH when compared to more rapid drying methods (Jinap *et al* 1994). The higher loading rates used may not have significantly slowed the initial drying to allow any appreciable increases in the pH of the nibs.

Acidity of beans is influenced by several factors and fermentation method is known to be crucial. Fermentation in large boxes has been shown to produce more acid beans than either heap or tray fermentation (Meyer *et al* 1989). Thus, in the context of the sun and solar-drying treatments used in the experiment, pre-drying factors rather than the actual drying technology may be responsible for the low pH of the nibs.

Titrateable acidity is a better measure of the total acids in cocoa liquor than pH, and both parameters have been correlated with taste scores or flavour acidity (Chong *et al* 1978; Duncan *et al* 1989). The fact that the pH is not significant, while the TA is significant is not very clear. Jinap and Dimick (1990) found a -0.91 correlation coefficient relating titrateable acidity and pH of samples. High loading rates have the potential to slow down the initial rate of drying in the bean mass and therefore allow a longer period for the loss of acids

either enzymatically (Liau 1980) or physically (Jinap *et al* 1994). Under the variability inherent in field conditions one cannot isolate the exact cause.

CONCLUSIONS

There was little difference in cut-test score, colour, pH and titrateable acidity between the open air and closed driers. Though not statistically significant, the indirect drier showed the highest test score and the direct drier the poorest. The indirect drier had a darker and more purple bean colour, while the direct drier was the contrary. The beans from the direct drier, dried to 6% moisture (WB) were, though not significantly so, more brittle and higher in titrateable acidity than those from either the open-air or indirect drier. Thus, overall the beans from the indirect drier showed the highest quality and those from the direct drier the poorest. Whether the modest improvement of the indirect drier over the open-air driers is sufficient to warrant investment in such a drier is unclear.

With respect to loading rate, beans dried at the lower rate of 13 kg m⁻² showed the best colour, but the highest titrateable acidity. Conversely, beans dried at the higher loading rate of 40.4 kg m⁻² showed significantly lower titrateable acidity, but poorer colour.

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