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Technical and Economic Parameters for the Adoption of Solar Drying Systems on Small Farms

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Solar cabinet dryers appear suitable for use by small Caribbean farmers, many with farms less than 1 ha in size. Perishable products like sorrel, hot peppers, sweet potatoes and mango slices may be dried for safe storage. In a solar cabinet dryer of the multi-rack design, an overall drying efficiency of 25% can be expected. Crops can be dried in thin layers with loading densities of less than 5 kg/m², in two days of fair weather. For the small farmers, with holdings ranging from 0.125 to 1 ha, and with 50% of their annual crop yield dried, dryers with cover areas ranging approximately from 3.8 m² to 30.8 m² respectively, will be adequate for a crop like sorrel. The minimum estimated cost of such dryers would correspondingly increase from US$75 to US$600.

Keywords: Drying, solar, efficiency, cost.

A major problem faced by farmers producing crops which are seasonal and perishable, is the adverse effect on farm income as a result of seasonal gluts. Drying of such commodities so as to facilitate storage, processing, marketing and utilisation provides an opportunity for stabilising and even increasing farm income. Traditional open sun drying of perishables such as ginger, sorrel, hot pepper, coconut and shrimp is extensively practiced in the Caribbean, though on a limited scale, and usually by small farmers with surpluses from the fresh market trade. Sun drying, from an economic viewpoint, is attractive to the small farmer, as it requires a negligible investment in capital. However, open sun drying methods have a number of disadvantages including:

1. A dependency upon fair weather, with minimal rainfall requiring extra handling.
2. Excessive handling of the crop during the normal drying cycle.
3. A reduction in crop quality due to contamination with dust, dirt, etc.
4. Crop losses due to handling and open drying.

For small Caribbean farmers, many with farm sizes of less than 1 ha, an alternative approach to open sun drying is the use of a simple solar dryer, described as the cabinet dryer (Lawand, 1966). In such a direct, passive solar dryer, the crop to be dried is placed in a thin layer in the cabinet which has a transparent cover. Heat is generated by the absorption of solar radiation by the crop, as well as by the internal surfaces of the dryer chamber. This heat evaporates the moisture in the crop and expands the air in the cabinet, thus creating a natural air flow through the crop bed and removing evaporated moisture.

There are other types of passive solar dryers (Szulmayer, 1971; Headley and Singh, 1979), but direct dryers of the cabinet type permit the shortest and fastest operation, although crop quality may not be the best (Lof, 1962). The cabinet dryer, with its simplicity in design and construction therefore appears to be an attractive option for the small farmer. However, the initial cost of such a dryer must be an important consideration for the farmer, with a negligible investment, when compared to the traditional open sun drying.

SOLAR CABINET DRYER PERFORMANCE

Description

A solar cabinet dryer was designed, built and tested at the University of the West Indies, St. Augustine, Trinidad. It was built as a multi-rack unit to facilitate easy handling of the produce to be dried, and to facilitate improved dryer performance as discussed by Sandhu et al. (1979).

In Figure 1, a pictorial drawing of the assembled dryer shows the essential functional features and major dimensions. The transparent glass cover was 1.67 m², inclined at 10° to the horizontal, and faced south. The side and end panels which supported the glass cover were made from 2 cm thick wooden planks. There were 5 cm × 86 cm openings (with protective wire mesh screens) for air movement on the front and rear end panels. The base of the dryer was comprised of a flat galvanised sheet screwed onto the wooden sides, with 4 cm thick "Styrotex" insulation below the metal sheet. Four trays, each 34 cm × 85 cm, made with a wooden frame and a wire mesh base, could be inserted into the dryer through slits in the side panels. The trays were supported by wooden runners in the dryer. All internal surfaces of the dryer were painted with a flat, black paint.

Testing

Sorrel, sweet potatoes, green mangoes and hot peppers were dried in the solar dryer. In the case of sorrel, seeds were manually removed prior to drying. The sweet potatoes were washed, diced into 1 cm cubes, and treated with a potassium metabisulphite solution. The green mangoes were cut into 0.5 - 1.5 cm thick slices, and blanched in boiling water before drying. Hot peppers were cut into two sections before drying.

All crops were spread in a thin layer on the drying trays, averaging 1.07 kg, 1.70 kg., 1.35 kg and 1.3 kg in weight per tray of sorrel, hot pepper, mango slices and sweet potatoes respectively. The initial moisture contents of all the crops were measured by the oven method, and during drying the weight changes in the crops were measured by removing and weighing the trays at 2 - 3 h intervals. Air temperatures within the cabinet dryer were measured initially by thermometers and later by thermocouples.

FIGURE 1. The solar cabinet dryer.

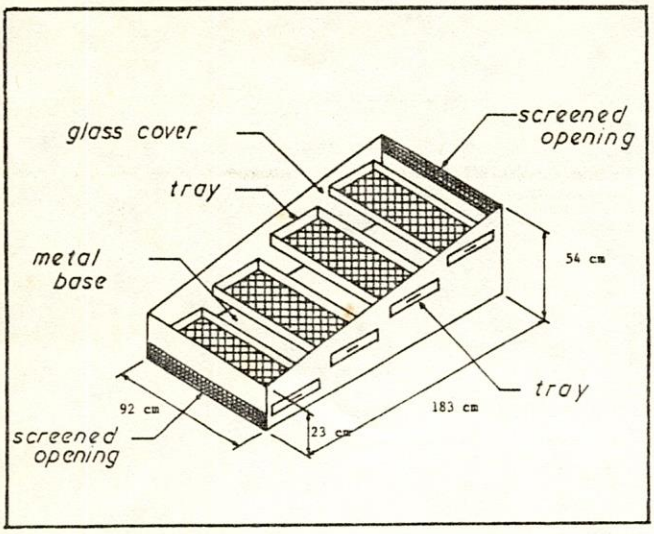
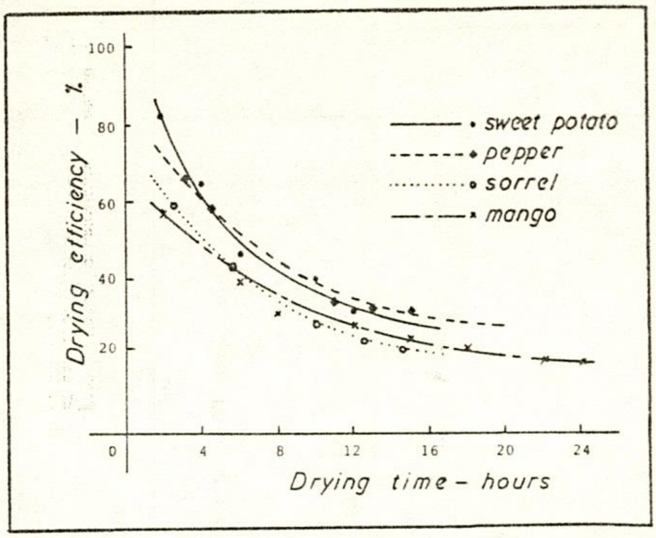


FIGURE 2. Drying efficiency with drying time for various crops.



Performance

Tables 1 and 2 show the changes in moisture content of the crops with the time of day, drying time (sunshine hours), the average temperature in the dryer, and the drying efficiency.

The drying effeciency (η) was calculated from the relationship,

$$\eta = \frac{Q_{eff} \times 100}{Q_{in}} = \frac{27.777 \times W_r \times L}{A \times I \times t} \qquad \text{[EQUATION 1]}$$

where:

Q_{eff} = quantity of heat used in the drying process
Q_{in} = quantity of heat entering the dryer
W_r = crop weight loss (kg)
L = latent heat of vaporisation (KJ/kg)
A = dryer cover area (m^2)
I = solar radiation level (W/m^2)
t = drying time (h).

Solar radiation intensity, I, was estimated from the mean daily solar radiation data of Smith (1967), for Trinidad. An average daily value for the dry months of January to May was estimated at 18.5 $MJ/m^2 \cdot day$ or 428 W/m^2 for 12 hours of the day.

The changes in drying efficiency during the drying cycle and the drying times for the four crops are shown in Figure 2. As drying progresses, and as the rate of drying of the crop decreases in the dryer, drying efficiency also falls. Lawand (1966) and Umarov and Tairov (1982) have reported similar changes in drying efficiency with drying time. Based upon the results given in Tables 1 and 2, average, weighted drying efficiencies for the entire drying cycles can be calculated. These are 25%, 44%, 28% and 37% for mango slices, diced sweet potatoes, de-seeded sorrel and cut hot peppers respectively. It should be noted that the hot peppers were dried to a moisture content of 31%, and with further drying necessary for safe storage, a lower drying efficiency can be expected. The sweet potatoes dried rapidly, principally due to the size reduction, and hence showed the highest drying efficiency. Pande et al. (1981) have reported average drying efficiencies in a solar cabinet dryer for cluster bean pods, chilies and dates, of 19%, 20% and 18% respectively.

TECHNICAL AND ECONOMIC CONSIDERATIONS

Based on Equation [1], a moisture removal rate M ($kg/m^2 \cdot h$), for a solar cabinet dryer may be described and is given by,

$$M = We/At = 36\eta I \times 10^{-3}/L \qquad \text{[EQUATION 2]}$$

For many perishable crops, drying in a solar cabinet dryer can be completed in two full days, as seen in Tables 1 and 2. The dryer installed capacity C_o (kg/batch), can therefore be minimised for the small farmer, and the dryer used throughout the crop duration, if

$$C_o = \frac{2N}{D} \qquad \text{[EQUATION 3]}$$

where

N = quantity of crop to be dried per year (kg),
D = duration of crop harvest (days).

Under these conditions and assuming negligible sensible heating, the transparent cover area S (m^2) required for the cabinet dryer can be evaluated,

$$S = \frac{C_o \times (M_i - M_f)}{M \times t \times (1 - M_f)} \qquad \text{[EQUATION 4]}$$

$$= \frac{(2N)}{(DMt)} \times \frac{(M_i - M_f)}{(1 - M_f)} \qquad \text{[EQUATION 5]}$$

where

M_i = initial moisture content of the crop, decimal wet basis
M_f = final moisture content of the crop, decimal wet basis
t = drying time of 2 days, (24 h).

The initial cost of the dryer X ($) can be given through a linear relationship and is,

$$X = KS \qquad \text{[EQUATION 6]}$$

where

K = cost of dryer per m^2 of cover area ($\$/m^2$).

DISCUSSION

Sorrel, with a yield of 12,000 kg/ha and a harvesting period of 12 weeks, may be used as an example of a crop with potential for solar drying by small farmers. The crop could be dried from an initial moisture content of 90%, to a final moisture content of 15% in 2 days with a cabinet dryer. It can be assumed that 50% of the annual crop will be sold on the fresh market, with the remainder

TABLE 1. The drying of green mango slices and diced sweet potatoes in a solar cabinet dryer.

DAY	TIME	DRYING TIME (hr)	DRYING TEMP. (°C)	MOISTURE CONTENT (%)	DRYING EFFICIENCY (%)
			Mangoes		
1	11.00	0	43	87	-
1	13.00	2	47	83	57
1	15.00	4	48	77	50
1	17.00	6	37	74	39
2	8.00	9	37	68	31
2	11.00	12	55	55	28
2	14.00	15	50	40	25
2	17.00	18	36	29	22
3	9.00	22	60	23	18
3	11.00	24	66	12	17
			Sweet Potatoes		
1	11.00	0	50	67	-
1	13.00	2	53	47	83
1	15.00	4	56	22	65
1	17.00	6	41	13	46
2	8.00	9	47	10	40
2	11.00	12	45	5	31

TABLE 2. The drying of sorrel and hot peppers in a solar cabinet dryer.

DAY	TIME	DRYING TIME (hr)	DRYING TEMP. (°C)	MOISTURE CONTENT (%)	DRYING EFFICIENCY (%)
			Sorrel		
1	10.30	0	51	88	-
1	13.00	2.5	52	80	59
1	16.00	5.5	47	68	43
2	8.30	10.0	37	53	28
2	11.00	12.5	60	32	24
2	13.00	14.5	55	21	22
			Hot Pepper		
1	10.00	0	53	87	-
1	13.00	3.0	57	81	66
1	14.30	4.5	52	77	59
2	9.00	11.0	37	66	34
2	11.00	13.0	49	53	33
2	13.00	15.0	47	31	32

TABLE 3. Solar cabinet drying systems for small farms ranging from 0.125 - 1.0 ha in size.

FARM SIZE (ha)	0.125	0.250	0.500	1.00
Quantity* of crop to be dried per annum, (kg)	750	1500	3000	6000
Dryer batch size, (kg)	17.8	35.7	71.4	142.8
Dryer cover area, (m^2)	3.8	7.7	15.4	30.8
Estimated dryer initial cost, ($US)	75	150	300	600

* Based on an annual yield of 12,000 kg/ha for sorrel and assuming 50% sold on the fresh market

dried. With simple woodframe construction and plastic sheeting, it is felt that the minimum initial cost/m² of dryer area is approximately US$20.00.

With these parameters, for farms ranging in size from 0.125 - 1 ha, the dryer capacity using Equation [3], the dryer cover area using Equation [5] and the dryer initial cost using Equation [6], may all be established. These calculated results are shown in Table 3. For the small Caribbean farmer, these initial costs, although significant, may be acceptable. However, for larger acreages, the initial costs associated with solar drying may be prohibitive, despite benefits of reduced labour requirements and improved crop quality as compared to open sun drying. It should be noted that to obtain rapid drying of perishables, the approximate loading density of the crop in the solar cabinet dryer should be less than 5 kg/m². Higher loading densities will require stirring of the crop in the trays to ensure uniformity in drying and to prevent possible deterioration.

CONCLUSIONS

Perishable crops such as sweet potatoes, sorrel, hot peppers and green mangoes can be safely dried in a simple solar cabinet dryer. With loading densities of less than 5 kg/m² of drying tray area, drying can be completed in two days of fair weather. The drying efficiency is dependent upon the crop characteristics, and as drying proceeds and the drying rate reduces, the drying efficiency correspondingly declines. For the multi-rack cabinet dryer tested, an average drying efficiency of 25% in the complete drying cycle can be expected for crops such as de-seeded sorrel, cut hot peppers and sliced green mangoes.

The simple solar cabinet drying system appears suitable for use by small farmers desirous of drying a portion of their annual crops. Such a system can reduce the labour requirements associated with open sun drying and may also improve the quality of the crop. For the small Caribbean farmers, with farm sizes of 0.125 - 1 ha, the initial costs of such systems are significant, but not prohibitive.

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