Harvesting and Processing

Editors: Edward J. Weber, James H. Cock, Amy Chouinard

Proceedings of a workshop held at Cali, Colombia, 1978
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Proceedings of a workshop held at CIAT, Cali, Colombia, 24–28 April 1978

Editors: Edward J. Weber,1 James H. Cock,2 and Amy Chouinard3

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Cassava Processing for Animal Feed¹

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Abstract. An inclined tray-drying system for cassava chips was developed at CIAT and tested against traditional concrete floor drying in five locations throughout Colombia with varying climatic conditions. The results obtained show that tray drying can double the output per unit area of drying surface compared with concrete drying. In areas where it can be guaranteed not to rain overnight a greater improvement in performance is achieved if drying is started between 1400 and 1700 hours. The loss of moisture at night is greatest where there are high windspeeds. The cost of materials for constructing the trays and their supports is lower than for laying an equivalent area of concrete, but the cost of maintenance and the life of the trays has not yet been determined. The possibility of combining natural drying with solar or artificial drying is discussed with a view to improving the product and to reducing the dependence on weather conditions. A number of options are already available and could be evaluated under practical conditions.

The enormous potential for using cassava as a feed for all types of livestock has recently been recognized (Coursey and Halliday 1974), and a large amount of research has been devoted to defining the optimum levels of dry cassava in animal diets and to modifying the plant’s chemical and physical properties that restrict its use (Nestel and Graham 1977).

At present, countries within the European Economic Community (EEC), where the high price of cereals has stimulated the search for alternatives, are the principal importers of cassava. In future, other industrialized nations, such as Japan, Canada, the United States, and Eastern Europe, may find it economic to use cassava as a feed ingredient (Phillips 1974a), and the producing countries themselves will likely use more cassava for feed as the demand for livestock products increases.

Thailand and Indonesia are the world’s largest exporters of dried cassava, largely in the form of pellets. These countries, together with Malaysia, which produces dry cassava for internal use, have well-established industries that clean, chip, sun dry, and pellet the roots.

In other countries of Asia, Africa, and Latin America, where cassava forms an important part of the staple diet, it is grown principally by small farmers for family consumption or for sale in the local market. It is virtually never dried for animal feed, although the small or large roots that are unsuitable for human consumption are often fed fresh to the household pig. Currently, the yields are often poor, although improved varieties of cassava and better agricultural practices can markedly increase yields (Centro Internacional de Agricultura Tropical 1975; 1976).

Low yields and small agricultural marketing units make it economically unfeasible for the compound feed industry to substitute cassava for other sources of energy, such as maize and rice bran. Capital-intensive processing plants require a constant supply of high-quality raw material. Thus, a processing technology that suits small farmers or small-to-medium industries is needed in cassava-producing countries. In this respect, much can be gained from studying the established industries of Southeast Asia.

¹In the text of this paper all moisture contents are given on a wet basis; on some graphs they are given on a dry basis to emphasize the difference in water content of cassava when comparing drying methods. The moisture content on a wet basis (mcwb) is the grams of water in a 100-g fresh sample: \( \%mcwb = \frac{Mw}{Mw-Md} \times 100 \), where \( Mw \) = weight of water in sample and \( Md \) = weight of dry matter. Fresh cassava has a moisture content of 60–70%, wet basis, which is equivalent to 150–233%, dry basis (\( \%mcdb = \frac{Mw}{Md} \times 100 \)). For safe storage, the moisture must be reduced to 14%, wet basis, or 16% dry basis.
Natural Drying in Southeast Asia

The majority of the cassava processed for animal feed in Southeast Asia is sun dried. The Malaysian and Thai industries are well developed with some processors handling up to 25 t/day of fresh roots. In Indonesia, drying is carried out on a smaller scale by individual farmers. The techniques used in each country are basically the same, differing only in the level of mechanization (Manurung 1974).

A high quality product depends on good management at each stage of processing. Careful harvesting reduces damage to the roots and thus cuts down on deterioration before drying. Although it is unnecessary to peel the roots (as is done in Indonesia), the removal of clinging mud by washing improves both the visual and nutritional quality of the final product. The roots may be cleaned manually in concrete tanks or mechanically in rotary washers depending on the quantity to be processed. Slicing or cutting is then carried out to reduce the size of the roots, which are spread either on concrete floors (Malaysia and Thailand) or on bamboo mats (Indonesia) to dry; the chips are turned from time to time to ensure uniform drying within 2–3 days. For the export market, it has become the custom to pellet the dry cassava. This eliminates dust and gives a uniform product with improved handling properties and an increase in weight-to-volume ratio of 25–40%, which substantially reduces the freight cost.

The greater care taken by Indonesian farmers results in a higher quality product than that produced in Thailand. Thai pellets contain high levels of silica and fibre caused by the drying of unwashed roots together with the adulteration of the chips with fibrous material and sand in the pelleting process; they also suffer from high microbial contamination caused by poor chipping and inefficient drying. The Asian Institute of Technology (AIT) is investigating better chipping

Fig. 1. This is the final arrangement of the supporting frames showing units of four trays with gaps left between them to enable stacking at night or before rain. The horizontal trays, one on top of the other, are covered by corrugated iron or canvas. The pile being raised off the ground on two bamboo posts. The method of supporting the lower edge of the trays on the frame is also shown with a one-third section of the lower bamboo rail cut away.
and drying methods, but existing price differences between good and poor quality products (Muller 1977) offer little incentive for improving practices.

**Tray-Drying System**

Investigations by Roa (1974) at CIAT showed that cassava dries more rapidly when the circulation of air is improved by placing the chips in mesh trays raised off the ground. To take full advantage of the drying power of the wind, the trays should be held vertically. However, in a practical system, the trays are more conveniently held at an angle that does not require expensive innovations to keep the chips from sliding to the bottom of the tray (Fig. 1). Experiments indicate that wooden-framed trays, 0.90 m × 1.70 m × 50 mm, can be propped at an angle 25–30° (300 mm off the ground) without disturbing the chips, although in high winds a smaller angle may be required. The trays, made of plastic mosquito screen and chicken netting, can hold 30 kg of fresh chips.

Trials were carried out to compare concrete and tray drying at CIAT and in four other locations in Colombia, selected for their wide variations in climatic conditions. The results obtained are discussed in this paper with reference to the parameters that affect the drying time.

The quality of sun-dried cassava depends to a great extent on the drying time — the shorter the process, the lower the loss of carbohydrates by fermentation and the lower the level of microbial and dust contamination. The parameters that control the drying time are the geometry (shape and size) of the cassava chips; the chip loading on the drying surface; the climatic conditions of air temperature and humidity, windspeed, and solar radiation; and the fresh moisture content of the cassava. Under natural drying conditions, it is only possible to control the chip geometry and loading, whereas using artificial heat driers, the air temperature and velocity may be optimized to reduce the drying time and provide better quality.

**Chip Shape and Size**

Moisture is removed from cassava by diffusion from within the material and evaporation at the surface. Hence, the rate of drying depends on the chips' surface area and on the rate of removal of saturated air from the surface. This means that the drying time may be shortened by cutting the cassava roots into chips that are sufficiently thin to maximize surface area but retain their structure uniformity to allow the free circulation of air around them. According to Roa (1974), the optimum natural drying characteristics are obtained by cassava chips in the form of neat, uniform, and firm rectangular bars of dimensions $8 \times 8 \times 50$ mm. In practice, this geometry is hard to achieve other than by a hand-operated chipper.

At AIT, chips produced by a Malaysian cutting machine have been compared with chips of regular dimensions and similar size and found to give satisfactory results. Malaysian cutting machines (Fig. 2) reduce the cassava roots to chips approximately 4–8 mm thick and 10–80 mm long, which are smaller and more regular in size than the chips produced by the equivalent Thai machines and consequently dry more rapidly. The corrugated blades, which in Malaysia are hand forged by blacksmiths, could be difficult to make in some countries. A similar blade can be pressed out with a tool developed by the industrial development department of the Tropical Products Institute, London (Best 1978). This type of blade was used successfully for the trials in Colombia.

**Chip Loading**

The number of chips spread out per unit area also affects drying time. In Thailand, cassava is spread on the concrete drying surface at a density of 6.1 kg/m² (10 t/rai), drying in 3 sunny days. In Malaysia, chips are spread at 3.7 kg/m² (250 pikuls/acre) and dry within 1.5 days (Manurung 1974).

The first experimental trials to be carried out in trays were those of Lavigne (1966) in Madagascar. Using chips 6–8 mm thick and 80 mm long, spread at 10–15 kg/m² on horizontal split bamboo trays raised 40 cm above the ground, Lavigne determined that 70 hours of sun were necessary to dry the product. The colour and odour were most acceptable when the 70 hours were distributed over fewer days. Roa (1974) compared concrete floor drying with horizontal and vertical mesh tray drying. Making use of a computer model to interpret his results, he predicted that, to complete drying in 3 days, the following chip densities are permissible: 5–13 kg/m² on concrete, 20–30 kg/m² for horizontal trays, and 30–40 kg/m² for vertically held trays. The advantage of drying in mesh trays has also been illustrated at AIT, where a possible 73% increase in chip production over traditional Thai methods was estimated.

The improved circulation of air obtained in inclined trays permits higher chip-loading rates than on concrete. The optimum thickness of chips
on the tray depends on the windspeed during the initial stages of drying. The author's experience has indicated that 10 kg/m² can be safely used without turning the chips even under very windless conditions (less than 0.5 m/s) and that in areas with higher windspeeds, averaging 2 m/s, 15 kg/m² is acceptable. In climatic conditions similar to those prevailing at CIAT, the output per unit area of drying surface can be more than doubled by the use of inclined trays (Table 1).

These results were substantiated by the trials in four other locations (Table 2).

Output during concrete drying can also be increased through increased loading, but, at higher loading rates, turning is more important and more difficult, especially when the cassava is fresh. The optimum loading probably lies between 5 and 10 kg/m²; in practice, the rate is determined more by feel than by measurement.
Climate

Although the climate is a phenomenon over which there is little or no control, an appreciation of the role that air temperature and relative humidity, windspeed, and solar radiation play in natural drying can lead to a considerable shortening of the drying time and also indicate how drying methods may be further improved.

An examination of the relationship between the equilibrium moisture content of cassava at varying temperature and relative humidities (RH) (Fig. 3) shows that it is theoretically possible to dry cassava down to 25% moisture content, wet basis (mcwb), with air at 90% RH (Roa 1974). Drying progresses steadily if the saturated air is continually removed from the surface of the material through efficient air circulation, or in the case of natural drying, windspeed. As the material dries out, the drying depends more on temperature, which controls the rate of moisture diffusion. To reach 14% mcwb requires an RH of less than 70% at 30 °C; or, more significantly, for the mcwb to drop below 10% at the same temperature requires an RH of less than 50%; these conditions are usually only experienced in the middle of the day. A typical tray drying curve illustrates these points (Fig. 4).

A better use of the climatic conditions can be made if tray drying is started later in the day. At dawn, the strongest winds are experienced between 1500 and 2000 hours. This extra drying power was used to remove large quantities of moisture from cassava chipped at 1700 and left on the drying racks overnight (Fig. 5).

Climate

<table>
<thead>
<tr>
<th>Location</th>
<th>Temp. (°C)</th>
<th>Humidity (%)</th>
<th>Windspeed (m/s)</th>
<th>Solar radiation (cal/cm²/s)</th>
<th>Inclined trays (loaded at 10 kg/m²)</th>
<th>Black concrete (loaded at 5 kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sevilla</td>
<td>31</td>
<td>68</td>
<td>1.0</td>
<td>0.71</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Espinal</td>
<td>30</td>
<td>64</td>
<td>0.9</td>
<td>0.65</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Palmira</td>
<td>26</td>
<td>66</td>
<td>1.2</td>
<td>0.61</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Caicedonia</td>
<td>26</td>
<td>67</td>
<td>0.8</td>
<td>0.58</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>El Darién</td>
<td>24</td>
<td>70</td>
<td>1.9</td>
<td>0.73</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 2. Hours required for drying cassava to 14% mcwb in five different locations (drying between 0800 and 1800, average values for three trials).

<table>
<thead>
<tr>
<th>Location</th>
<th>Temp. (°C)</th>
<th>Humidity (%)</th>
<th>Windspeed (m/s)</th>
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<td>0.73</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 1. Cassava drying on concrete and in trays (CIAT 1976).a

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Chip density (kg/m²)</th>
<th>No. trials</th>
<th>Avg. drying time (h)b</th>
<th>Improvementc</th>
<th>Plain concrete (%)</th>
<th>Black concrete (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain concrete</td>
<td>5</td>
<td>5</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4</td>
<td>19</td>
<td>26</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Black concrete</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>5</td>
<td>17</td>
<td>41</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Horizontal trays</td>
<td>30 cm above ground</td>
<td>5</td>
<td>1</td>
<td>7</td>
<td>71</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7</td>
<td>14</td>
<td>71</td>
<td>43</td>
<td>43</td>
</tr>
<tr>
<td>Inclined trays at 28°</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>100</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>13</td>
<td>11</td>
<td>118</td>
<td>82</td>
<td>82</td>
</tr>
</tbody>
</table>

a Average daytime (0800-1800) climatic conditions: temperature 27°C; relative humidity 59%; windspeed 1.5 m/s; solar radiation 0.71 cal/cm²/s.
b Average drying time in hours between 0800 and 1800; trials started at 0800.
c Improvement in output per unit area of drying surface = (p_d/θ_t - p_o/θ_o)/(p_o/θ_o) × 100 where p_d = density of chips, improved method, kg/m²; p_o = density of chips, original method, kg/m²; θ_t = improved drying time, h; θ_o = original drying time, h.
Fig. 3. Air temperature and relative humidity corresponding to equilibrium moisture content in cassava.

Fig. 4. In this typical drying curve, water loss is rapid to begin with, reaching a maximum at midday and then decreasing. At 1800 hours the moisture content of the cassava is sufficiently low (less than 20%) for water to be absorbed from the air overnight. On the following day, water loss is very slow, requiring 5 hours to complete the drying.

The following day was at its peak. Night drying at CIAT used a total of only 7 daylight hours (1 hour the 1st day and 6 the next), whereas normal drying requires 15 hours of sunlight. Unfortunately, weather conditions are not so favourable everywhere, and the trials at other locations produced less perfect results (Table 3). The findings were that the number of daylight drying hours was at a minimum when cassava was chipped between 1400 and 1700 hours. Table 4 gives the loss of water during the night with the respective climatic conditions, confirming that the windspeed is the controlling factor during the initial stages of drying. Night drying is advantageous if it can be guaranteed not to rain overnight, an assumption that can only be made at certain times of the year.

A significant reduction in the time required for drying on concrete can be obtained by painting or
pigmenting the concrete surface black to increase the absorption of solar radiation (Table 1). Thanh et al. (1976) reported temperatures of up to 6 °C higher on black concrete. The increase in temperature reduces the relative humidity of the air around the chips, a factor that is of particular importance in the later stages of drying. There is a danger that the white cassava dust left behind on the drying floor will reduce the effect of the black surface; during CIAT trials it was necessary to wash the floor regularly. It will be interesting to learn if this has been a problem in the further work carried out by AIT under pilot-scale operation.

Cassava Moisture Content

The moisture content of fresh cassava, which varies according to the variety, age at harvesting, the soil conditions, and the rainfall, normally ranges between 60 and 70%. This variation represents a 30% difference in quantity of fresh cassava needed to produce 1 t of dry chips (2.4 t and 3.2 t respectively). Therefore, the selection of a high dry-matter variety increases the dry yield and reduces the labour requirement per tonne, an important consideration in a labour-intensive process.

Although, in theory, the lower-moisture varieties should dry more quickly than others, in practice, the difference is minimal because the extra water is removed rapidly in the initial stages (Fig. 6). In some ways, this illustrates the inefficiency of natural drying in that only a very small proportion of the available energy is used for drying. If the same cassava were to be dried artificially, both the drying time and cost would be greater for the cassava with a higher moisture content.

The Brazilian heat-drying process of Maquina D’Andrea (Vitti 1966) incorporates a dewatering operation before drying. The chips are hydraul-
cally pressed to remove 25–30% of the water with the result that the drying time and fuel consumption are reduced. An attempt was made in Colombia to adopt this practice using a manually operated batch press with a capacity of 70 kg/batch or 210 kg/h. Extraction of water was satisfactory at about 30% but nothing was gained on subsequent natural drying (Fig. 7). Approximately 6% dry matter (predominantly starch) was removed with the water and, unless recovered through sedimentation, represented a loss of feeding value in the final product. Furthermore, the extra handling required to press the chips increased the labour requirements and overall drying cost.

**Drying Systems: the Choice**

Farmers traditionally use the most economic drying method available to them, whether it be...
spreading the crop in the front yard, on the rooftop, or on the edge of the nearest paved road. The sophistication of the method usually corresponds to the quantity and value of the product. Thus, coffee driers have sliding roofs to protect the crop from rain, and cassava starch is dried in wooden trays raised off the ground to prevent contamination by dust and dirt.

The question is whether the value of dried cassava for animal feed justifies the use of an improved technology, such as inclined tray drying. In Thailand and on farms that have concrete drying patios, the capital has already been invested in the system, and there would be little sense in adopting a new one. However, when starting from scratch, tray drying has advantages that should not be overlooked: the drying area is cut in half; labour input is reduced because the chips seldom need turning and do not have to be respread each day; and the final product contains a lower proportion of fines and dust owing to reduced handling. Any cost comparison of the two systems is location specific, depending on the availability and price of materials. At CIAT, it appeared that the capital cost per unit throughput could be 30% less for tray drying (Best 1978).

Large-scale operations, such as the Thai industries would have to be better organized for tray drying than they are at present. The trays must be loaded with a certain amount of care to ensure uniform drying and must be carried to the drying racks by trolley, cart, etc. The feasibility of the system needs to be tested under real conditions, particularly to evaluate its two major disadvantages — the level of tray maintenance and their useful life.

**Combining Drying Systems**

It appears that the greatest problem in natural drying, whether on concrete or in trays, lies in the reduction of the moisture content from around 35% to a safe storage value below 14%. Although this range represents only 25% of the total water content of the cassava, its removal can occupy up to half the drying time. This problem could be overcome by combining natural drying with the use of either solar-heated air driers or artificial driers to reduce the dependence on the weather and give greater operating flexibility.

There are a variety of solar crop drier designs available from the Brace Research Institute, McGill University, Canada, that might be adapted for partially dry cassava. These designs need to be built and tested under farm conditions to establish their technical and economic feasibility.

Within existing constraints, the most suitable artificial driers are through-circulation batch driers, commonly used on farms for drying grain. They usually have three components — drying bins, which are of simple construction from local materials; fans; and auxiliary heaters, both of which are available in most countries. The running costs of the driers can be appreciably reduced by employing fans that pick up the waste heat from the engine. Depending on the quantity of cassava to be handled, there may be no further source of heat necessary. De Padua (1976) gives a good description of through-circulation driers, explaining the fuel options available (oil, gas, or solid fuel), types of burner, and choice of fan. Under certain circumstances it might be worthwhile considering the use of the cassava stems as a source of solid fuel.

A number of laboratory studies have been carried out to determine the optimum parameters — bed depth, air temperature, and velocity — for through-circulation driers (Chirife and Cachero 1970; Chirife 1971; Webb and Gill 1974). This work was done using uniform chips of fresh cassava and should be substantiated on a pilot scale using machine-cut roots. In this respect, the available cutting machines may require further improvement to produce more uniform chips and reduce the pressure drop across the bed. For bed depths up to 120 mm, the drying time is not increased at speeds greater than 5000 kg/h/m², and scorching of the chips occurs above 84 °C (Chirife and Cachero 1970). The optimum conditions for partially dried cassava are likely to be different, with the possibility of using greater bed depths and a decreased air-flow rate (Webb and Gill 1974).

Lister (Lister Farm Equipment Limited, Dursley, Gloucestershire GL11 4HS), manufacturers of through-circulation farm drying equipment, claim that their moisture extraction unit is suitable for drying cassava. Their double-bin, reversible-flow system uses drying air to a maximum by passing it first through one bin containing partially dry cassava and then through another that is charged with fresh cassava. The basic unit gives outputs of 2–7.5 t/day, depending on the number of additional heaters used; 2 t/day are obtained using only the engine’s heat. This throughput could be substantially increased if a major part of the drying load were removed beforehand by natural drying.

In conclusion, there exist many options for improving the rudimentary methods of cassava drying that could be put into immediate use and evaluated under practical conditions.