CASSAVA PROCESSING AND STORAGE

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Editors: E. V. Araullo, Barry Nestel, and Marilyn Campbell
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Technology of Cassava Chips and Pellets Processing in Indonesia, Malaysia, and Thailand

FIRMAN MANURUNG

Department of Chemical Engineering
University of Malaya, Kuala Lumpur, Malaysia


Abstract At present, the processing methods for the production of cassava chips and pellets in Indonesia, Malaysia, and Thailand involve root cleaning, chipping, sun-drying, and pelletizing.

Whereas in Indonesia the roots are peeled and cut by hand before drying, the practice in Malaysia and Thailand is to feed the unwashed whole roots into chipping machines. For roots harvested from clay soil, the use of root washers, as employed in the cassava starch manufacture, is suggested. The chipping machines as used in Malaysia and Thailand are described. Methods of improving the performance of the chipping machines are suggested.

Sun-drying is carried out by many methods in Indonesia. In Malaysia and Thailand, however, sun-drying is done exclusively on cement drying floors. The overall heat efficiency during sun-drying of cassava chips was estimated to be between 11 and 14% and the main cost of sun-drying was labour. Causes of low-heat efficiency were analyzed and methods of improving sun-drying with respect to chips quality and cost reduction are suggested. The possibility of using artificial heat-drying, a combination of sun- and artificial heat-drying, and a combination of mechanical dewatering and artificial heat-drying are discussed. Static-bed, moving-bed, rotary, fluidized-bed, and pneumatic drying systems are described.

Pelletizing presses as used by the feed-millers in Europe and the USA are used in Thailand and Indonesia for the production of pellets from cassava chips and dried roots. Presses manufactured in Thailand, known as native presses, made up about 75% of the total pelletizing capacity in Thailand and about 20% in Indonesia. The pellet quality is affected by the nature and the percentage of different components in the material to be pressed, the condition of the material (i.e., moisture content, particle size, and temperature) before pressing, and the dimensions and shape of the dies in the pelletizing presses. The effect of each factor on the pellet quality is discussed. In addition to the above factors, the performance of the pelletizing plants is very much dependent on the quality of the dies and rolls. The low quality of products, i.e., soft pellets and high meal percentage, from the native plants was the result of too high moisture content, low quality dies and rolls, incomplete removal of tramp metals, and, in some instances, dismantling of pellet cooler and screen. Methods of improving the performance of both the native and the imported pelletizing plants are suggested.
Cassava is grown in most tropical areas of the world. Its popularity stems from several attributes: it is easily planted and requires little attention; it can stand drought and short periods of flood fairly well and grows on relatively poor soils; and it is high yielding compared to many other crops.

Before World War II, cassava was exported from South East Asia mainly as starch for industrial purposes and food products. Since the end of the war, a variety of cassava products, such as cassava meal, dried roots, chips, and pellets, have been exported for animal feed purposes. The European Economic Community's (EEC) Common Agricultural Policy (CAP), which made grain more expensive for animal feed, caused a sudden surge in cassava exports, since cassava, as a starch source, in...
manuring: cassava processing comparison

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combination with soybean, as a protein source, is an excellent substitute for grain in feed formulations.

Thailand, as the world's largest exporter of cassava chips and pellets, increased her exports from about 3000 metric tons (t) in 1960 to over 1.2 million t in 1972. Indonesia, on the other hand, which is one of the largest producers of cassava roots, could not respond to the demand due to fluctuations in internal consumption. At present, the high cost of production prevents Malaysia from exporting, but cassava has good opportunities in the local feed demand, which is increasing at a rapid rate.

One development that coincides with the increase in the demand for cassava is the introduction of more mechanized handling of the product in bulk during ship unloading, transportation, and storage in Europe. This requires a more uniform-size product, for which pellets were introduced. Another point in favour of pellets is the reduced volume-to-weight ratio, which helps lower shipping cost. Exports from Southeast Asia are now almost exclusively in pellet form.

The demand for cassava in 1980 in the EEC's animal feed market was projected by Phillips (1974) to be 246–634% greater than the 1970 demand. With regard to quality, Mathot (1972) stated that if the products were equal to the pure dried cassava and the pellets contained much less meal, almost three times as much cassava could be used in Holland and the price of the product would increase to approximate the nutritional value.

This paper is an attempt to analyze the problems faced by the industry in its efforts to meet the above demands. Each processing step is analyzed, and possible improvements with regard to quality and reduction in production cost are suggested. From these analyses, areas that need further study are identified.

**Pre-Drying Processing**

Before drying, cassava roots require cleaning to remove adhering soil and sand. For a good quality product the outer skin and the inner peel are sometimes removed. The roots must be reduced in size to facilitate drying, and at present this is done by chipping. Discussion of the processes follows.

**Root Cleaning**

In Malaysia and Thailand the fresh roots arrive in trucks and are dumped into a yard near the chipping machines. No washing of the roots is done. As workers transfer the roots from the dumping yard to the chipping machines, some lumps of mud and soil are shaken off. Despite this, however, silica content of the chips produced in Malaysia is quite high, reaching over 5% in some instances. In Thailand, the maximum silica content of 3% seems to be easily attainable.

Without washing and peeling, the amount of silica in the product is affected by the type of soil as well as the weather conditions. Clay tends to adhere whereas sandy soil separates easily from the outer skin of the roots. Cassava harvested during the rainy season contain a large amount of muddy soil clinging strongly to the skin of the roots. Dry soil, on the other hand, may break away from the skin during handling of the roots.

For roots containing too much soil and relatively high percentages of outer skin, the silica and fibre content of the final product may be reduced by washing the roots before clipping. Root washers (as described by Holleman and Aten 1956), such as those used in starch manufacture, could be used for this purpose. These are troughs with agitating paddles on a horizontal shaft. The rotating paddles push the roots, while they are washed, from one end to the other. Chain conveyors are used to move the roots from the washer outlet to the chipper, or to a holding yard where the washed roots drain.

Installation of any root cleaner would increase the capital outlay of the present chipping and drying plants. Its use, however, may be justified if the level of production is high, say over 25 t/day. This could be practiced in Thailand and Malaysia where large quantities of roots are processed in one plant. In Indonesia, however, where the roots are individually peeled by hand, washing is not necessary.
Chipping

The chipping machine used in Malaysia consists of a rotating circular steel plate (about 12 mm thick and about 100 cm diam) to which six blades are attached. The blade consists of a 1–1.5-mm steel plate that is corrugated at the cutting edge. The front view of the chipper can be seen in Fig. 1 and a close-up of one blade on position in Fig. 2. A sample of newly cut chips is shown in Fig. 3.

Instead of a heavy thick plate as used in Malaysia, the Thai chipper uses a thin circular plate that is cut and formed to produce cutting
elements throughout the surface. The front view of a transportable version of the machine is shown in Fig. 4. The cutting side of the plate, which is normally made out of the cover of a 44-gal oil drum, is shown in Fig. 5. A sample of wet chips is shown in Fig. 6.

Fig. 3. Newly cut chips in Malaysia.

Fig. 4. Front view of a transportable Thai chipping machine.
At present no chipping machine is used in Indonesia. After peeling by hand, the roots are halved along their lengths by knives. The larger roots are quartered and the smaller ones (up to 3 cm diam) are left whole. A sample of dried roots is shown in Fig. 7.

**Fig. 5.** Cutting plate of a Thai chipper.

**Fig. 6.** Thai chips on the drying floor.
The Malaysian chipping machine is quite satisfactory. It is difficult to obtain data for its operating cost but a rough estimate gives US 3–6¢ per 100 kg fresh roots, with labour ranging from 30 to 50% of the cost. The machine produces strips about 6 mm wide and 3–6 mm thick, with a small percentage of fine particles. The length of the strips is dependent on the position of the roots at the time of cutting. Strips up to 25 cm long were observed emerging from the machine but these soon crumbled into much shorter pieces during handling. The blades can be easily replaced and may be modified to produce strips of different cross-section if the need arises.

The chipping machine used in Thailand, although working on the same principle as the Malaysian machines, produces chips of much wider size ranges. Chips up to 3 cm diam were observed. This could be reduced by narrowing the opening in the cutting plate.

The capacities of both the Thai and Malaysian machines could be increased if the feed rate and the pressure of the roots against the cutting blade were made more uniform. This could be achieved by the use of a conveyor, as used in the starch factories in feeding the rasper. Furthermore, if the roots are maintained in the horizontal position when they meet the cutting blade, chips of relatively uniform length could be produced. The increase in pressure of the roots against the cutting blade may be achieved by maintaining a certain column of roots above the cutting level. This will also have the added advantage of minimizing fine particles, which are produced by the cutting blade lightly scraping the roots.

For the same machine, the cost of chipping increases with decreasing size of chips, since more energy (fuel or electricity) is expended in breaking up the same amount of materials. The cost of chipping, however, is much smaller than the cost of drying. It is, therefore, logical that the size and shape of chips be so determined as to give the minimum cost of drying. This is expected to favour smaller chip size.

The small farmers of Indonesia who produce the dried roots will not be in a position to own a chipping machine. One solution to this problem would be for the present buying agents and small traders in dried roots to own drying yards and chipping machines, and buy fresh roots from the farmers instead of dried roots.
roots. Buying roots from the farmers will not be a new venture in Indonesia, as the small starch manufacturers obtained their raw materials this way. In some instances the starch factories buy peeled roots.

Another possibility is for the traders to own small transportable chipping machines with diesel engine drive for renting to the farmers. NISIR in Malaysia has produced models of small chipping machines using 1–2 hp drive. The cutting element is similar to that of the Thai machine but it is positioned horizontally at the bottom of a cylinder. The cutting plate is rotated around a vertical shaft. Two vertical baffles are placed near the cutting plate to prevent the roots from rotating with the plate. One advantage of this method is that the pressure of roots against the cutting blade is maintained.

The introduction of root chipping in Indonesia should improve quality with respect to mould and perhaps bacteria standard plate count. It also should minimize loss due to moulding and insect infestation during storage. Another advantage may be the possibility of extending the drying season rather than concentrating heavily on the driest months of the year (July and August).

Drying

Drying involves the removal of moisture from the solid materials by evaporation. The heat of evaporation of 80°F water ranges from 1049 Btu/lb at 80°F to 1105 Btu/lb at 220°F. The heat necessary to evaporate the moisture from the solid may be slightly higher than that required by pure water.

Although the required heat for drying is not difficult to estimate, the rate of drying, hence the required time for drying, is a great deal more difficult to predict. It will depend largely on the techniques of drying employed as well as on the nature of the solid itself.

Theory of Drying

The first attempt to analyze the drying process was done by Lewis (1921) who studied drying of fibrous materials. This was followed by Sherwood (1929a, b, 1930, 1931), Sherwood and Comings (1932), and Sherwood and Gilliland (1933), who worked on clay, soap, sand, wood, pigment, etc. These studies indicate that when a material that is initially saturated with moisture is dried under constant conditions, the moisture is first removed at a constant drying rate. After the material reaches a certain moisture content known as the "critical moisture content," the drying rate continuously decreases until the equilibrium moisture content is reached at which drying stops.

The constant-rate drying period may be associated with the presence of unbound moisture in the material. Bound moisture is that which is intimately associated with the material, such as water contained within the cells of plant materials. Unbound moisture, on the other hand, is that which adheres loosely to the material, such as water on the outside of sand particles. As long as unbound moisture is present, the moisture will evaporate at a constant rate, with the surface remaining at a constant temperature equal to the wet bulb temperature of the drying gas. In other words, moisture evaporation proceeds as if the surface is of pure water.

The rate of mass transfer from the solid surface is given by \( N = K_f (Y_s - Y) \) where \( Y_s \) and \( Y \) are the humidities at the solid surface and the bulk of the drying gas respectively; and \( K_f \) is the mass transfer coefficient, which increases with temperature and the degree of gas turbulence. For constant gas temperature and humidity, therefore, the rate of drying in the constant-rate period could be increased by increasing the gas velocity or the degree of turbulence in general.

As the moisture evaporates from the surface, this is replaced by moisture being transferred from the interior of the solid. There are two mechanisms proposed to describe the movement of moisture from the interior to the surface. The first theory describes the moisture movement by diffusion. The second theory describes it by capillary suction. The movement of moisture in a layer of granular material or very porous solid may be described with the use of capillary action. For pieces of materials such as soap and wood, the diffusion equation has been employed successfully.
The rate of mass transfer by diffusion in one direction is given by:

$$N = D \frac{\partial c}{\partial z}$$

where $c$ is the moisture concentration in the solid; $z$ is the distance passed by the diffusing component; and $D$ is the diffusivity. The diffusivity depends largely on the nature of the solid and, in general, increases with temperature.

The rate of mass transfer by diffusion from the interior of the solid is normally much lower than that of evaporation of unbound moisture from the surface of the solid. This rate could be increased by increasing the temperature of drying, hence the diffusivity, and by decreasing the size of the solid. This can be seen from the above equation.

The imbalance between the high rate of evaporation from the surface and the low rate of diffusion from the interior results in the depletion of moisture from the surface until some part of the solid becomes exposed to the drying gas. At this point the constant-rate drying ends and the falling-rate period begins.

As drying proceeds the area of dry solid surface increases. This period is known as the unsaturated surface or first falling-rate drying period, and is characterized by an almost linear relationship between the rate of drying and moisture content. The second falling-rate drying period begins when all the solid surface is free of water film and gas–water interface recedes into the interior of the solid. This is characterized by a steeper decrease in the drying rate until the equilibrium moisture content for the whole solid is reached when the drying rate becomes zero.

As the rate of drying decreases, the surface temperature of the solid rises continuously approaching the dry-bulb temperature of the gas. Chirife and Cachero (1970) measured the temperature of 3-mm thick chip surface during drying with an air dry-bulb temperature of 82°C. They found the temperature of the chip surface to be continuously increasing, indicating that the 3-mm thick chips dried wholly within the falling-rate period.

Higher drying temperature will continue to result in the increase of diffusivity, hence the rate of drying, as long as the drying process does not change the nature of the solid. With some materials, however, quick drying may result in shrinkage or hardening on the surface, which render the surface relatively impervious to moisture, thereby decreasing effective diffusivity and hence the rate of drying. This phenomenon is known as “case-hardening,” which many materials show when dried at very high initial rate, such as with the use of high-temperature gas of low humidity. For materials such as these, increasing the humidity of the drying gas may result in a higher overall rate of drying.

Sun-Drying

The common practice in Malaysia and Thailand is to produce the chips early in the morning, from about 0700 to 1000 h. The fresh chips are distributed on the drying floor and then spread out manually with the use of shovels. The spread-out chips are turned over every 1–2 h with the use of rakes.

At the end of the day or during rainy weather the chips are heaped into mounds, which are sheltered under portable roofs made of corrugated iron on wooden frames.

Most chip producers in Malaysia now use small tractors fitted with wooden boards for the distribution and collection of the chips. A tractor is shown pushing a heap of dry chips in Fig. 8. No tractor is used in Thailand, except for hauling the dry products from the floor in some large-size operations.

A small proportion of the chips, particularly the small particles and powder, remain on the drying floor. These are collected by workers with the use of various types of brooms, wooden boards, and wheelbarrows.

In Indonesia, peeled roots are dried by various methods, including being hung on poles or lines on the farm, or spread out on the roof or on woven bamboo mats on the ground.

Since sun-drying is entirely dependent on the weather, the duration of drying and chips quality vary considerably. The time of drying and the chip quality are also dependent on the chip size. In Malaysia, where chips are small, drying is completed to about 15% moisture content in 1.5 days. This would take
about 3 days in Thailand where the chips are larger. In Indonesia, the dried roots still contain about 25% moisture after about 1 wk drying.

**EFFICIENCY OF THE PRESENT SUN-DRYING METHODS**

The fraction of energy that reaches the earth surface depends on the condition of the atmosphere and the angle of incidence. The angle of incidence, in turn, depends on the location on earth (i.e., degree latitude north or south of the equator), the time of the year (winter or summer), and the time of the day. Pillay (1967) measured total radiation in Kuala Lumpur with the use of a Kipp solarimeter. For a typical sunny day, the intensity of radiation changes from 90 Btu/ft² h at 0800 h to 315 Btu/ft² h at 1200 h to 45 Btu/ft² h at 1630 h. The total radiation for a whole day may be obtained by integrating the intensity with respect to time. The daily radiation is fairly constant in the tropic between 2000 and 2500 Btu/ft² day.

Of the total daily radiation an average of 70% can be consistently utilized in solar distillation (Telkes 1953), water heating (Pillay 1967; Hotzel and Woertz 1942), and air heating (Williams et al. 1969). For sun-drying, however, this efficiency can be approached only during the constant-rate drying period or at very high moisture content. Investigations of coffee drying on cement floors (Sivetz and Foote 1963) showed that the heat efficiency decreased from 61% on the first day of drying, when the moisture content was 63.9%, to 0.54% on the 14th of the last day of drying when the moisture content was 9.9%. The depth of coffee layer used was 6 cm. The heat efficiency over the whole period of drying was 13.8%.

In Malaysia, where an average of 250 pikuls (1 pikul = 60 kg) per acre could be dried in 1.5 sunny days, the estimated overall efficiency was 13.5%. In Thailand, with an average of 10 t/rai (1 rai = .4 acre) being dried in 3 sunny days the corresponding efficiency was 11%. In both instances, the roots and chips moisture contents were assumed to be 65 and 18%, respectively.
ENERGY LOSSES DURING SUN-DRYING

Among the energy losses during sun-drying, the following could be the most important.

Incomplete absorption and reradiation to the atmosphere — This is determined by the nature of the materials receiving the radiation, i.e., cassava chips and drying floor. It will be difficult, if not impossible, to change the absorptivity and emissivity of the cassava chips. The absorptivity and emissivity of the drying floor could be changed by surface treatment or with the use of different materials. The increase in absorptivity of the drying floor could be an advantage if the surface is directly hit by the sun’s rays. This means that either a thin layer of relatively coarse chips should be used or smaller chips should be formed into ridges instead of into a uniform layer. This would expose a proportion of the floor surface to the sun. The increase in the amount of heat being absorbed by the drying floor will result in an increase in temperature, which in turn increases heat losses by convection, conduction, and reradiation.

Heat transfer by convection to the atmosphere — This is affected by the wind velocity (i.e., degree of turbulence) and the temperature difference between the air and the material being dried. The increase in the degree of turbulence increases the coefficient of mass transfer from the surface to the air. This mass transfer, however, may be controlling only in the earlier stage of drying. When the material is already partially dried, the diffusion of moisture from the interior of the solid will be controlled. At this stage it may be more advantageous to minimize the degree of turbulence, say, by covering with transparent plastic sheet or glass, thereby minimizing heat loss by convection. This should result in the increase of temperature level of the material, which, in turn, increases the rate of moisture movement from the interior.

Heat transfer by conduction through the drying floor to the ground — Concrete flooring has a relatively high heat conductivity compared to many other materials. The amount of heat loss by conduction through 2.5-cm thick materials is calculated for different drying surface temperatures and a constant ground temperature of 80°F. Conductivities were obtained from Perry et al. (1963). The results are shown in Table 1.

It can be seen that concrete is a relatively good heat conductor. Wood would conserve heat much more effectively than concrete. Air is even better than wood, if it can be maintained perfectly still to prevent convection. This, however, would be difficult to achieve without the aid of some fluffy materials, such as kapok and sawdust.

When it is realized that the amount of radiation reaching the surface is only in the order of 200–300 Btu/ft² h, the above losses may be very substantial.

LABOUR REQUIREMENT

Sun-drying is a very labour-intensive operation. Its economy, therefore, is strongly dependent on the level of wages.

The labour requirement for sun-drying varies depending on the type of facilities used (cement floor, bamboo mat, etc.), the level of mechanization (such as the use of tractors), the frequency of rain during drying, and the drying floor loading.

Malaysia and Thailand use very much the same type of implements and follow more or less the same procedure on the drying floor, except for the extensive use of tractors in Malaysia. One proprietor in Malaysia, processing about 200–250 pikuls a day on a 1-acre floor, employs 16–20 labourers. This includes two labourers working at the chipper for less than half a day. At a labour wage of $5.00 per day, the total labour cost of processing, which is mainly for drying, is about 0.60/pikul or US 40/l00 kg roots, when the chips dry in 1½ days. Another proprietor in Malaysia, processing 300–400 pikuls a day on a 1½-acre drying floor with the use of two tractors, employs 16–20 labourers. This includes two labourers working at the chipper for less than half a day. At a labour wage of $5.00 per day, the total labour cost of processing, which is mainly for drying, is about 0.60/pikul or US 40/l00 kg roots, when the chips dry in 1½ days. Another proprietor in Malaysia, processing 300–400 pikuls a day on a 1½-acre drying floor with the use of two tractors, employs 16 labourers. Each tractor, therefore, replaces six labourers, giving a saving in wages of US $30.00 per day. The cost of operating the tractors is estimated at not more than US $10.00. The data of Beeny (1969) was used to estimate this figure.

One proprietor in northeastern Thailand, with 12 rais of drying floor, employs a total
of 70 workers for chipping and drying. At a loading of 10 t/rai and a wage level of 9 Baht/day, the total labour cost of processing is 1.58 Baht/100 kg (US 8.0/100 kg) fresh roots or 3.94 Baht/100 kg (US 20t/100 kg) chips, when the chips are dried in 3 days. Mathot (1972) estimated the total cost of drying at Chonburi to be around 6.90 Baht/100 kg dried products. When this is compared to the Malaysian condition, it is understandable why there is no need for tractors on the drying floors in Thailand.

The number of workers employed per unit area of drying floor is roughly the same in both Thailand and Malaysia, which is from 35 to 40 workers/ha of drying floor (this includes workers operating the chipping machines).

In Indonesia, labour utilization is difficult to estimate. The practice is distinctly different from those followed in Malaysia and Thailand. This practice also varies widely from one location to another within Indonesia. Harvesting, peeling, cutting, and drying may be carried out by the same person. One estimate for this type of practice in an area in Middle Java gives an output of 100 kg of roots per person per day. No attempt is made to collect the roots during the rainy days in this particular location.

One feature of sun-drying is that it will require approximately the same number of workers per day to handle the same amount of materials whether the drying takes 1, 2, or 3 days. The chips have to be spread out for drying in the morning, turned around periodically and collected late in the afternoon. The same procedure has to be followed the next day and the day after until the chips are dry. Shortening the drying period, for instance by using small chips, should, therefore, result in a proportional reduction of labour requirement.

### Artificial Heat Drying

Efforts to develop artificial heat-drying of cassava chips are understandable if one considers the advantage of this method over sun-drying. Among the important advantages are: reduction in space requirement; reduction in labour requirement; scheduling of the whole operation independent of the weather; better quality control; and little chance of mould growth and bacteria contamination.

The investment in artificial heat-drying facilities together with fuel, power, and maintenance costs must be weighed against the investment in large land and cement drying floors together with the cost of labour. Even if the cost of artificial heat-drying is higher, the benefits of the last three above-mentioned advantages may be overriding.

Whereas the main cost of sun-drying is in labour, the main cost of artificial heat-drying is expected to be in fuel. The economics of artificial heat-drying, therefore, would be heavily affected by the heat efficiency.

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### Table 1: Heat losses by conduction through 2.5-cm thick materials at different surface temperatures.

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity $Btu/ft^2\cdot°F/ft$</th>
<th>Heat loss $Btu/ft^2\cdot h$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>150°F $(65.6°C)$</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.54</td>
<td>453.6</td>
</tr>
<tr>
<td>Water</td>
<td>0.356</td>
<td>299.0</td>
</tr>
<tr>
<td>Dry sand</td>
<td>0.19</td>
<td>159.6</td>
</tr>
<tr>
<td>Wood (pine)</td>
<td>0.087</td>
<td>73.1</td>
</tr>
<tr>
<td>Ashes (wood)</td>
<td>0.041</td>
<td>34.4</td>
</tr>
<tr>
<td>Sawdust</td>
<td>0.032</td>
<td>26.9</td>
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<tr>
<td>Air</td>
<td>0.0153</td>
<td>12.9</td>
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HEAT EFFICIENCY AND ALLOWABLE DRYING TEMPERATURE

The heat efficiency of drying is very much determined by the level of gas temperature used and by the rate of drying. The fraction of heat in the gas that can be utilized for drying increases with increasing gas temperature. The efficiency could range from as low as 10% for batch through-circulation dryers using a gas temperature between 100 and 200°F, to over 60% for continuous dryers with a gas temperature of up to 1500°F.

As mentioned earlier, the rate of mass transfer increases with temperature, assuming that case-hardening does not occur. It is, therefore, advantageous to perform the drying at the highest possible temperature that the cassava will tolerate without deterioration in quality.

Chirife and Cachero (1970) reported that scorching of cassava chips occurs at 84°C and over. The equipment used is a laboratory batch through-circulation dryer where the chips are 3 mm thick, 2 cm wide, and 6-7 cm long. A preliminary test conducted by Toh (1972) shows that scorching, for which browning tint on the surface is taken as the criterium, is not only a function of temperature but it is also dependent on the moisture content and the time during which the cassava is subjected to the temperature. The test involves drying ground cassava in an oven at various temperatures. The result is shown in Table 2.

Table 2. Results of drying ground cassava in an oven at various temperatures.

<table>
<thead>
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<th>Moisture content, %</th>
<th>Oven temperature (°C)</th>
<th>Time before scorching is observed (min)</th>
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<tr>
<td></td>
<td>90°C</td>
<td>110°C</td>
</tr>
<tr>
<td>66.7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>56.5a</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>48.7a</td>
<td>No scorching</td>
<td>24 h</td>
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</tbody>
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aGround cassava was partially dried in a basket centrifuge.

Although scorching appears at a low temperature when the cassava is at a high moisture content, it may be possible to use a very high temperature initially, as the temperature of the cassava chips itself will remain low, i.e., near the wet-bulb temperature of the gas. As the moisture content decreases, accompanied by the surface temperature approaching that of the gas, the temperature of the drying gas must be reduced. If use is made of this fact in a drying system, a reasonably high heat efficiency can be expected.

ARTIFICIAL HEAT-DRYING SYSTEMS

There are a large number of dryers that can be used for cassava products. These may be roughly classified into five groups. A brief discussion of each group and its possibilities for drying chips follows.

Static-bed dryers — All the commercial batch crop dryers, i.e., storage, bin, tray, and through-circulation dryers, that have been used for wheat, rice, coffee, and other similar agricultural products, may be included in this group.

One big advantage of the static-bed system is its simplicity. It consists of a fan and its drive, an oil burner and bins, trays, or any other container with perforated bottom through which the heated air may be passed. Against this advantage, however, several disadvantages may be mentioned, some of which are inherent in a batch system, such as low heat efficiency, variable moisture content in a batch, and low throughput.

Overall rate of drying can be increased by using smaller size chips accompanied by sufficient supply of heat by blowing larger quantities of hot air through the bed. As the size of chips decreases, however, the amount of air that can be passed through the bed decreases for the same bed depth and the same pressure drop. In other words, just to maintain the same airflow rate through the same bed depth, higher pressure drop across the bed must be allowed for, which means increase in power consumption to drive the fan. It can be seen that there is need for the selection of optimum operating conditions, which include bed depth, chip size, airflow rate as well as air temperature.

Although these crop dryers have been used successfully for wheat, rice, coffee, cocoa
beans, etc., the system may still be too expensive for a high-moisture low-cost product like chips for animal feed. Its potential may lie in a combination with sun-drying.

**Moving-bed dryers** — This system is similar to the static-bed except that the bed is moving either continuously or intermittently from one end to another. This allows continuous feeding of wet material from one end and continuous withdrawal of dried products from the other.

The bed movement is achieved by having, among others: (1) the bed of materials resting on a perforated moving band, as in the horizontal pellet coolers; (2) the bed continuously moved by chain conveyors resting on a stationary perforated or louvered floor; (3) the layer of material moving by gravity along a sloping perforated floor or cascading down a louvered bed; (4) a column of the material moving downward as the dried product is continuously removed from the bottom of the column as in a vertical pellet cooler.

Some of the above techniques may be suitable only for free-flowing materials like grains. Their suitability for a particular type of cassava chips must always be experimentally ascertained before application.

Advantages of the moving-bed over static-bed systems are: (1) uniform moisture content of dried products; (2) better control over temperature and moisture content; (3) higher heat efficiency possible.

Although the heat efficiency may be higher than that of the static-bed dryer, the fuel consumption may still be too expensive for chips production for feed purposes. As with the static-bed dryers, the potential of this system may still lie in its combination with sun-drying. Their economics, however, must be determined for each particular location, where wages, fuel cost, and sunshine are taken into consideration.

**Rotary dryers** — In a rotary drying system, the material is fed from one end of a rotating cylinder with longitudinal lifters, and the dried products withdrawn from the other end. The drying gas may enter the cylinder either from the feed (parallel system) or from the dry product ends (countercurrent system). As the cylinder rotates, the material is lifted and dropped periodically through the passing gas. After each lift, the material is moved forward with the help of gas blowing on it in the case of light materials and parallel flow system, or with the help of a slope in the cylinder.

The volume of gas that can be passed through a rotary dryer per unit weight of materials being dried is much more than in the static or moving-bed dryers, and it is relatively independent of the particle size. With the use of small particles or thin slices, therefore, it is possible to dry at a high rate, which, in turn, results in a sudden drop of the gas temperature. It may, therefore, be possible to use gas of very much higher temperature with the feed in a parallel system, during which the chips' temperature will remain relatively low. As the moisture content decreases substantially, the surface temperature of the material being dried begins to increase, by which time the gas temperature should come down to a tolerable level.

The above principle has been used successfully in the drying of grass, where the temperature is claimed to be up to 1800°F while the product temperature remained at between 140 and 155°F. This system was tried for cassava chips in Malaysia but without success. The gas temperature used was between 500 and 600°C. It is suspected that the high initial temperature produces case hardening on the chip, which results in sudden surface temperature increase and scorching.

One possible solution to the above problem would be the use of mechanically dewatered ground cassava. It is hoped that the smaller particles and the lower initial moisture content will minimize case hardening and scorching. A preliminary test at the University of Malaya (Y. S. Yow, personal communication, 1974) shows that ground cassava can be dewatered to 42% moisture content in a hydraulic press at a pressure of 2500 psi. The cake obtained could easily be crumbled. Another advantage of the partial dewatering method is the reduction of fuel requirement, as the amount of water to be evaporated is reduced from about 60 to 20 kg of water per 100 kg of fresh roots. This advantage, however, must be weighed against the cost of mechanical dewatering and the recovery of solid, mainly starch, from the pressed-out water.
Fluidized-bed dryers — When gas is passed through a fixed bed of particles, the pressure drop increases as the gas flow increases. For small particles, the amount of gas that can be passed is very limited. However, if the particles are sufficiently small the passage of gas at a high flow rate creates turbulent motion in the bed. The bed behaves like fluid, and is known as the fluidized bed. A reasonably wide range of particle sizes is preferred for fluidization.

The use of this technique in drying should give many advantages. The most important are high rate of drying due to high turbulence, easy temperature control throughout the bed, no moving part in the dryer, compact size, and low heat losses.

The partially dried ground cassava could be crumbled into loose particles, which indicates that it may be suitable for fluidized-bed drying.

Pneumatic dryers — If the gas flow is further increased in the fluidized bed, individual particles will eventually be carried upward. If sufficient length of passage is provided, wet particles could be dried in hot gas, as the particles are being suspended and pneumatically transported by the gas.

This technique is used in the drying of cassava starch. The partially dried ground cassava, although of larger particle size than the starch, may be sufficiently fine for pneumatic drying.

Pelletizing

Imported as well as “native” pelletizing units are used in Thailand and Indonesia. No commercial cassava pelletizing plant is as yet operating in Malaysia. The imported units are well-integrated and instrumented plants. These originate in Germany, Switzerland, and the USA.

The native plants are all made in Thailand. They make up 75% of the total pelletizing capacity in Thailand and 20% in Indonesia.

Two types of presses are in operation in the above plants. One press uses a horizontal circular plate die with a large number of holes drilled to form a honeycomb pattern. A set of six rolls are resting on the die, which rotate by friction when the die is rotated around a vertical axis. The other press uses a vertical ring die with a set of two rolls inside the ring. Holes are drilled radially throughout the face of the die. When the ring is rotated, the rolls also rotate with it by friction.

Cassava particles are fed in front of the rolls, which crush and force the material through the holes. The compressed material emerges from the other side of the die, which is cut to length to produce pellets. The pellet diameter ranges from 8 to 10 mm. Samples of pellets from the two types of plants are shown in Fig. 9.

The Pelletizing Process

All the plants operate on the same flow sequence. The chips are first screened to remove fines, which contain most of the sand and soil, and to separate the oversize, which is passed through a hammer mill. The middle-size stream combined with the mill product are transferred to a holding bin or feed hoppers on top of the presses. (In Indonesia, the dried roots go directly to a hammer mill before screening.) The material is distributed and conditioned to the correct moisture content with the use of water spray before it enters the presses.

The pellets from the presses are quite warm and soft. These are sent to coolers where the temperature and moisture content are reduced, after which the pellets become reasonably hard. The coolers are either vertical or horizontal moving beds, through which air is drawn with the use of a fan. The cooled pellets are sent to a screen from which the oversize is sent to a bagging machine or storage. The undersize is returned to the feeding system.

The power-laden air from the exhaust is sent to a large cyclone. The recovered cassava powder is returned to the feeding system. Aspirating systems, i.e., exhaust fans and cyclones, are also used over the screens, mills, presses, and other units to recover cassava powder as well as to reduce dust concentration in the surroundings.

The presses in the native plants use vertical ring dies. Diesel engines are used directly in
driving the presses. The chips are directly fed into the presses. In some instances water is sprayed on the chips on the conveyors before they enter the press, as the presses are without conditioners. As in the imported plants, the pellets are screened and cooled before bagging. The screen undersize and the powder recovered from the cooler exhaust are returned to the feed lines.

Some native plants do not operate either the pellet cooler or the pellet screen or both. No instrumentations are used in the plant. The output of pellets ranges from 1.5 to 2.5 t per hour per press.

The products obtained from the two types of plants are classified as “brand” and “native” pellets, respectively. This is not a fair classification, however, as in addition to the quality of the equipment used, there are many other factors affecting the quality of pellets with respect to strength and meal content.

Factors Affecting Pellet Quality

The factors affecting the quality of pellets may be divided into those inherent in the nature of different components and their percentage in the materials to be pressed, the conditions of the materials before pressing, and those related to the press.

Nature of Different Components

Components affecting the pelletability of materials are protein, starch, fibre, and fat, as well as impurities.

Protein-rich materials plasticize when heated and act as a binder to produce strong pellets. Starches gelatinize when heated in the presence of water and likewise act as binder to produce strong pellets. Fibres are difficult to compress but when they are present in sufficiently fine strands in the pellet they give toughness to the product. Fats do not affect the quality of pellets (with respect to strength) produced, but they act as a lubricant resulting in an easy pressing and, therefore, high capacity and low power consumption.

The presence of fibres and absence of fats suggest that cassava is a relatively difficult material to pelletize. The presence of sand and other gritty impurities affect not only the quality of pellets but also the life of the dies and rolls. Its percentage in the materials
should, therefore, be minimized as much as possible.

**Conditions of Materials Before Pressing**

**Moisture content** — The presence of moisture is necessary for the gelatinization of the starch, and also acts as a lubricant in the pelleting canal. This is important particularly in the absence of fats. There is a limit, however, to the amount of water that can be tolerated during pelleting. The water can be visualized as filling the interstices between the cassava particles. When these particles are compressed in the die canal, the particles come closer together, thereby reducing the volume of interparticle space. If there is too much water in the interstices it can prevent further compression. This is called choking (MacBain 1966). The choke-up point is reached when the moisture content is around 18%.

For the pelleting of cassava, the recommended moisture content lies between 16 and 18%.

**Particle size** — Theoretically, the smaller the particle size the stronger the pellet should be after compression, as the fine particles provide greater surface area for interparticle contact. However, as the particles become too fine the bulk density before compression becomes too low and a higher level of compaction is required. Another difficulty is that air may be so effectively entrapped within the bulk of the fine materials that compression becomes almost impossible. The best result is obtained when fine and medium size particles are mixed. Coarse particles tend to provide breaking surfaces in pellets.

**Temperature** — To gelatinize the starch for binding purposes, heat must be supplied. For high-starch materials, MacBain (1966) suggested that the temperature must reach at least 180°F for proper pelleting. To achieve this, the materials may be pre-heated to a certain temperature before they enter the press. The common practice in feed pelleting is to spray the materials with steam, and at the same time adjust the moisture content to a suitable level below the choke-up point. In the cassava pelleting plants, the increase in temperature is achieved purely by the generation of heat due to friction between the cassava and the canal wall. This results in high wear rate on the die. This wear could be reduced and the life of the die increased, while still reaching a high temperature required by gelatinization, if steam is added instead of water for moisture content adjustment. The pressure of the steam may be selected to give the required temperature and moisture content at the same time.

**Factors Related to the Press**

For each temperature there is a minimum compaction time and a minimum pressure required for the formation of strong briquettes and pellets. For brittle material there is also a maximum pressure that can be applied. Johanson (1965) derived an equation for the calculation of maximum pressure in roll-type briquetting presses in terms of the dimensions of the press and the flow properties of the materials being pressed, i.e., coefficient of internal friction, coefficient of external friction between the materials and the press wall, and the compressibility factor. The derivation is based on the theory of continuous flow of granular materials proposed by Jenike et al. (1960).

The conditions in the pelleting press resemble flow of granular materials more than in the roll-type briquetting press. It should, therefore, be possible to relate the effective pressure in the pelleting press to the same flow properties of the materials.

The total compressive force acting on the material is determined by the friction between the material and the wall of the die canal, and the total surface area of the wall. The effective pressure for compaction is the above force divided by the cross-sectional area of the canal.

For a certain coefficient of friction between the material and the die, the effective compaction pressure can be increased by increasing the pelleting length of the canal (die thickness) and by decreasing the canal cross-sectional area (die opening diameter). If the friction between the material and the wall is much higher than the internal friction, shearing could take place within the material, thereby producing low-quality pellets. The coefficient of external friction can be decreased...
by producing a smooth surface and by providing lubrication in the form of fat or moisture. For a certain effective pressure, there is a minimum compaction time to produce sufficiently strong pellets. This is controlled by the speed of rotation of the die as well as the rate of feeding.

From the above discussion it can be seen that for each material or compound to be pressed there must be a certain range of pelletizing length (die thickness), die opening diameter, speed of rotation, and rate of feeding that will produce satisfactory pellets. It is, therefore, important that the optimum combination of these variables be selected for each material to be pressed, for the production of good-quality pellets at the lowest possible operating cost.

**Performance of the Pelletizing Plant**

The most important components of the press are the dies and the rolls. Apart from the variables (die thickness and opening diameter) previously discussed, the quality of the die material and the method of its manufacture have strong influences on the performance of the press. Knudsen and Riebroich-aroen (1971) analyzed the die and roll materials from one manufacturer and found the materials to be high-carbon (0.2% carbon for die and 0.6% carbon for rolls) steel containing about 1% manganese, about 0.35% chromium, and about 0.35% silicon. One manufacturer produces stainless steel dies, although this seems to be unnecessary for cassava pelletizing.

In addition to strength, wear resistance is the most important characteristic of the materials that are obtained mainly by the proper heat treatment of the dies and rolls. The die is manufactured from forged blanks. After machining, a series of heat treatments is applied to produce hardening on the surface while retaining toughness in the interior.

**Imported Plants**

All imported plants use electric motors to drive the presses and other components of the plants for easy control. Many of these plants are well instrumented for the control of the feed moisture content and other operating conditions.

The engineering of the pelletizing plants has more or less reached optimum design after a long period of development and use in the animal feed industry. In general, these plants can produce satisfactory cassava pellets. However, they will produce good pellets only if the facilities are fully utilized and run at optimum conditions.

In one plant I visited, the die is produced from a blank in an adjacent small workshop. There are no proper facilities for heat treatment. In any case they would be too expensive for a single plant to have, unless it produces more dies than it needs. The low quality of the die could be seen from a worn one that had been reduced in thickness to a third of its original size, one-third from each side of the plane die. The life of the die is claimed to be 500 h at 3 t of pellets/h.

At the point of extreme wear of the die, low-quality pellets and low efficiency are expected. A good quality die is expected to process between 2000 and 3000 t of pellets during its lifetime.

The above-mentioned plant may have saved on the cost of dies but the increase in power consumption due to large recycling of meals and lowering of pellet quality should also have been considered.

It would be easy to incorporate the use of steam in the imported plants as the presses are preceded by mixers for conditioning. The proprietors of these plants seem to be reluctant to use steam, due to additional investment and operating costs. The advantages of the use of steam, i.e., increase in production capacity, reduction in power consumption, increase in die life, and better pellet quality, should be properly evaluated.

**Native Plants**

The performance of the native plants was quite varied. One relatively old plant produced good pellets comparable to those obtained from the imported plants. A second plant, which was quite new, produced very low-quality pellets. The pellets were very soft and contained
about 50% meal, and also had the appearance of high moisture content.

The first plant screened the press product; the meal was then recycled back into the presses. The pellets were sent to a cooler before bagging. The production rate was claimed to be 1.75 t/h per press, and the dies were replaced every 300–400 tons of product, i.e., 170–230 h of service.

The second plant did not use a screen and cooler, although they were available in the plant. The product was bagged when it was still hot. The dies were found to be very worn-out. They were replaced every 600–700 t of product, or 240–280 h of service at 2.5 t/h per press. The chip stream was sprayed with water before it entered the press.

The difference in practice between the above two plants clearly results in very different qualities. The causes of the low quality in the native plants may be identified as follows:

High moisture content — In cooling the pellets, the heat is utilized to evaporate moisture, thereby decreasing the moisture content by about 3%. Without the coolers, therefore, the moisture content of the pellets will be approximately the same as the chips fed to the press, which in the case of the second plant mentioned above, was sprayed with water.

No attempt was made to determine the moisture content of the chips apart from the visual observation. It is suggested that chip batches of known moisture content be set aside for pressing and that measured amounts of water be sprayed to the correct level of moisture content before pressing.

Low quality of dies and rolls — The condition of a discarded die from the first-mentioned plant can be seen in Fig. 10. The openings on the outside rows have been completely closed. The conditions of the dies that were still in use in the second plant showed much worse conditions. Foreign pieces of metal were seen imbedded on the inside surface of the die. Some pieces of metal, such as pins, were claimed to have come from the rolls assembly.

Considering the short life of the die and rolls, it may be more economical to use more expensive and properly heat-treated dies in the native presses.

Incomplete removal of tramp metals — From the above discussions, there is no doubt
that the life of the dies could have been pro-
longed if efficient magnets for the removal of tramp metals had been installed.

*Chip or cassava particle size* — In Thailand the chips are directly fed into the press. In Indonesia, however, where the dried roots are much larger than the Thai chips, prior milling is necessary.

Previous discussions have indicated that smaller particles produce better pellets, although too fine a meal becomes difficult to compress. From pressing tests carried out in Thailand, Mathot (1972) found that the use of small chips and strips as starting materials gave 50% higher pressing capacity. Although large chips or cassava pieces are fed into the press, these are crushed by the rolls before they are forced through the dies. In other words, part of the energy is expended for crushing. Since crushing or grinding can be more efficiently carried out in hammer mills, it may be more advantageous to install a set of screens and a hammer mill in the native plants, similar to their use in the preparation of feed in the imported plants.

**Pellet Qualities**

Although a standard is set with regard to cassava products for export, the percentages of sand, moisture, crude fibre, and starch are not (at least not quantitatively) taken into account in the purchase of chips and pellets within the country. The reason for this could be seen in the relatively low standard set for the commodity. This seems to be particularly so with regard to sand. Unless a premium is paid for low percentages of sand, there does not seem to be any point in advocating washing.

It may be too cumbersome for the pelletizers to conduct quantitative tests on chips before buying. In any case, some improvement is still possible on the material before pressing. Percentage of sand could be reduced by screening and moisture content can be adjusted before pelleting. However, the purchase of pellets from pelletizers needs to be accompanied with a penalty and a premium with regard to qualities. In addition to the minimum standards already set for moisture, sand, fibre, and starch contents, standards should be set for meal percentage as well as for hardness and strength.

As long as the pelletizers are paid the same price regardless of moisture content and other qualities, they will continue to produce low-quality pellets in order to gain in weight and low production cost, e.g., by dismantling coolers and screens from their processing units and the use of worn-out dies. This problem has been discussed at length by Mathot (1972).

**Tests for Chips Quality**

Standard analytical tests are available for the determination of starch, fibres, moisture content, ash, and sand. These tests, however, are too cumbersome for the pelletizers to use in their purchase of chips. Visual examinations seem to be adequate for the determination of chips quality with regard to moisture content, crude fibres, and mould.

**Tests for Pellets Quality**

Tests with regard to starch, fibres, moisture content, and sand are the same as for the chips. Tests for hardness and strength are still to be developed.

Hardness and strength can be defined as the measure of the resistance of the material to breakage by impact when handled, dropped, or submitted to heavy burdens. Two tests normally employed for cokes could be adopted for pellets. One test, known as the “Shatter Test” can be used for the measurement of resistance to shatter by impact as during ship loading. Another test, the “Cochrane Test,” can be used to measure the resistance to abrasion.

In the Shatter Test a representative sample of known particle size is prepared and dropped from a box to a steel plate. The amount of breakage is measured by screening the product. The percentages of material remaining on a set of sieves are recorded as the Shatter Indices.

The Cochrane Test consists of the rotation of a sample in a steel drum with angle lifting plates welded inside the drum. The drum is rotated at a constant speed for a set number of rotations and the abraded sample with-
drawn and screened on a sieve. The abrasion index is given by the amount of material remaining on the sieve. This test is not unlike the wear-resistance test described by Mathot (1972).

It is suggested that the maximum meal percentage and the minimum shatter and abrasion resistance be standardized.

Storage

In Malaysia and Thailand, the dried chips, including the powder collected, are bagged in jute sacks, containing about 70–80 kg each and stored in the sheds. These sheds are almost exclusively made of iron roofs and walls on wooden structures. The chips are never kept in these sheds for more than several days. In Malaysia, they are quickly dispatched to the local pig and poultry farms and feedmills. In Thailand, the chips are sent to the pelletizers. In some instances the bagged chips are kept in a yard near the drying floor with canvas covers before loading into trucks.

The chips, either in jute sacks or in bulk, are kept for a longer period of time in the pelletizing plants. The pelletizers have one or more large wooden structure buildings with galvanized iron roofs and walls. Separate steel structures are used to house the large imported plants. The native plants, however, are normally housed in one end of the storage building.

Most of the pellets produced are bagged and transported by trucks to the harbour area, where they are kept in large godowns before shipment. The pellets produced in the harbour area are stored in bulk. Some big traders use silos to store the pellets from which they can be loaded onto ships at a faster rate than by men and cranes.

The conditions in Indonesia are very different from those of Malaysia and Thailand. Because of the large size of the dried roots, they are generally stored at relatively high moisture content. The dried roots may be kept in the house of the farmer who dried the roots. The bulk of the dried roots, however, goes to the buying agents who quickly send it to the exporter’s or the pelletizer’s godown. These godowns are large steel structures with brick walls. In all the godowns visited by the author heavy insect infestations were observed. In general, no fumigation was used, as it was considered too expensive.

In addition to the relatively high moisture content of the roots at the time of storage, another reason for the heavy insect infestation seems to be the long period of storage. The bulk of the cassava in Java is dried during the months of July and August, the driest months of the year. The dried cassava being processed at other times of the year, therefore, may have been in storage from 1 to 10 mo.

The introduction of chipping into Indonesia and the resultant shortening of the drying period may possibly extend the drying season, rather than concentrating heavily on July and August. This should result in a short period of storage in general and possibly a lower storage capacity requirement.

Another disadvantage of high moisture content at the time of storage is the possible increase in temperature due to mould and bacteria activities. Further drying of the roots is achieved because of the high temperature in the 1st wk of storage. This, however, could only be at the expense of the starch in the product.

Conclusions and Research Recommendations

In the previous chapters the various stages of cassava processing from the harvested roots to the pellets at the point of export were discussed. Attempts were made to locate and analyze weak points in the series of processing steps. Fields of research were selected on the basis of these analyses. The suggested investigations are directed toward basic information, the development of new techniques, or improvement of present practices.

Pre-Drying Processing

The use of root washers of the type employed in the cassava starch production should be sufficient for the removal of adhering soil and outer skin. Peeling does not seem to be
necessary for animal feed purposes. For a maximum silica content of 3% in the final product, washing does not seem to be required, particularly for roots harvested from sandy soil.

The performance of the chipping machines as used in Malaysia and Thailand could be improved with the use of mechanical feeders. The life of the cutting blades in the Malaysian chipper could be extended with the use of proper steel and heat treatment. Washing of the roots should also extend the life of the blades.

**Sun-Drying**

It has been shown that cassava drying is generally controlled by diffusion. Further study of the diffusion characteristics as well as the determination of the equilibrium moisture content of cassava at different temperatures would give useful basic information for all types of drying.

Considering that the overall heat efficiency of sun-drying is only 11–14% compared to an average efficiency of 70% for other processes, such as solar distillation and water heating, new methods of sun-drying to increase the efficiency should be developed. The new techniques should be aimed at minimizing heat losses and at the same time increasing the drying temperature. The use of transparent covers to minimize convection losses could be tried. Materials with much better heat-insulating properties than that of concrete would also be required, particularly if attempts are made to increase the absorptivity of the drying floor.

For the improvement of the present sun-drying method, it is suggested that investigations be conducted to obtain optimum combination of chip size and floor loading for different conditions (level of mechanization and labour wages) in different locations.

**Artificial Heat-Drying**

In addition to diffusional properties and equilibrium moisture content, basic information on the drying characteristics of cassava under different conditions is still lacking. More information is needed on gelatinization, scorching, and case hardening in cassava during drying.

The combination of mechanical dewatering and artificial heat-drying seems to offer attractive possibilities as the cost of fuel could be drastically reduced. The suitability of high-efficiency dryers, such as rotary, fluidized-bed, and pneumatic dryers, for the mechanically dewatered cassava needs investigation.

Low-efficiency, cheap, and simple installations, such as the batch fixed-bed dryers are not likely to be economical in the processing of cassava chips with full moisture content, as the cost of drying is very much determined by the fuel consumption. However, these dryers may offer possibilities for partially dried cassava chips with moisture content between 20 and 30%, for which the amount of evaporation needed is from 3 to 9 kg of water per 100 kg of fresh roots compared to 60 kg of water per 100 kg of fresh roots with full moisture content. It is suggested that the combination of these dryers with sun-drying be evaluated for the present size of operation in Thailand and Malaysia. Variables, such as optimum transitional moisture content between sun- and heat-drying, chip size and shape, bed depth, gas temperature, and flow rate need to be taken into consideration.

For larger operations, the moving-bed dryers may offer better prospects than the fixed-bed dryers through higher heat efficiency. The chip size and shape, however, would be more critical than for the fixed-bed dryers, as the chip flow characteristics should also be considered.

**Pelletizing**

Very little information is available on the pelletizing characteristics of cassava. It is possible that this information is kept from circulation for commercial reasons.

Study is needed on the relationship between the materials flow characteristics and the minimum compressive pressure required for the production of strong pellets. Knowledge on the degree of gelatinization necessary for the formation of strong pellets is also needed.

Although the above relationship would be theoretically sound, a more direct approach would yield very useful data. It is, therefore, suggested that investigations be conducted on the effects of particle size, moisture content,
and pre-heat temperature on the quality of pellets as well as the pressing capacity. Particularly relevant and of immediate use to pellet producers in Thailand and Indonesia would be the investigations on the economics of using a set of screens and hammer mills in the reduction of particle size, and the use of steam in conditioning (with respect to moisture content and temperature) of the feed to the press. The use of smaller size chips for pelletizing also requires further study.

Storage

Storage problems with regard to insect infestations is only faced in Indonesia. It is suspected that rather high moisture content at the time of storage and long periods of storage are the causes. Data on the actual losses due to this problem would be useful as a basis for the evaluation of fumigation.

Quality Control

Although standard analyses are available for the determination of various components and impurities in the chips and pellets, there is a need to develop simple standard tests for the determination of abrasion and shatter resistance of the pellets. Standard tests used for coke may be adopted for this purpose.

It must be pointed out that quality improvement can only be achieved if it is associated with increased prices.

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